THE ECONOMIC AND HEALTH EFFECTS OF THE UNITED STATES' EARLIEST SCHOOL VACCINATION MANDATES

By

Nicholas Chadbourne Holtkamp

Dissertation

Submitted to the Faculty of the

Graduate School of Vanderbilt University

in partial fulfillment of the requirements

for the degree of

DOCTOR OF PHILOSOPHY

in

Economics

August 31, 2021

Nashville, Tennessee

Approved:

William Collins, Ph.D.

Brian Beach, Ph.D.

Christopher Carpenter, Ph.D.

Jennifer Shinall, Ph.D.

This work is dedicated to my parents and brother.

ACKNOWLEDGMENTS

I would like to thank my committee members, Brian Beach, Kitt Carpenter, Bill Collins and Jennifer Shinall, for generously lending their support and expertise to the completion of this dissertation. A special thanks to Bill Collins, my advisor, for his limitless patience and encouragement.

I would also like to thank the following individuals for their invaluable support: Ariell Zimran, Sarah Quincy, Andrew Goodman-Bacon, Andrew Dustan, Marianne Wanamaker, Belton Fleisher, Keith Meyers, Christopher Sichko, Nick Marquiss, Ebehi Iyoha, Trang Hoang, Kristine Kotout, Jun Zhao, Matthew Chambers and Teyanna Munyan. This project was supported by funding from the Vanderbilt University Council of Economics Graduate Students.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

Introduction

Despite being one of the richest countries in the world by the turn of the 20th century, the United States continued to pay the large health and economic costs of smallpox. A 1932 article in the *New England Journal of Medicine* lamented that, "the United States as a whole suffers more today from smallpox than any country in the world, bar India, China and possibly Russia" (Woodword 1932). This was especially striking in light of the deadly nature of smallpox, which would kill over 300 million people worldwide in the 20th century alone before its eventual eradication in 1978 (Henderson 2011).

Americans' inability to contain smallpox in the late 19th and early 20th centuries was a result of the high value placed on personal liberty by American institutions (Troesken, 2015 p.7). Federalism, an independent judiciary, and vigorous anti-vaccination sentiment wove an inconsistent patchwork of state vaccination laws across the country. As a result, some states enacted vaccination mandates while others did not, causing smallpox to smolder and spread across the country. This stood in stark contrast to other developed countries that had largely eliminated smallpox with national vaccination mandates earlier in the 19th century.

To assess the consequences of the United States' decentralized approach to vaccination, this dissertation analyzes the effect of state-level compulsory vaccination laws on both health and economic outcomes. In particular, I study laws passed by states in the late 19th and early 20th centuries that required children to be vaccinated against smallpox to attend school. Education and public health officials had recognized in the 19th century the importance of disease prevention for children in terms of both their health and long-term productivity (Meckel 2013, p. 13). As a result, these officials focused their efforts on ensuring that children were vaccinated against smallpox, a disease that took an inordinate toll on children.

This dissertation shows that these school vaccination mandates improved both health and economic outcomes. By increasing the vaccination rate, mandates reduced the prevalence of smallpox. Moreover, the reduced spread of smallpox provided economic benefits. Children in states with a school vaccination mandate were more likely to attend school in the short-run, and held higher paying jobs in the long-run.

Furthermore, this dissertation explores the effects of anti-vaccination sentiment. During this time period when germ theory and the efficacy of vaccination were not widely accepted, anti-vaccination sentiment was widespread. In particular, German immigrants to the United States were known for their especially strong resistance toward vaccination. Using this population as a proxy for anti-vaccination sentiment, I show that German immigrants, who resisted vaccination mandates, did not experience the full benefits of mandates.

Finally, I provide suggestive evidence of a novel spillover of vaccination mandates. Vaccination mandates not only may increase vaccination uptake for the vaccine targeted by the mandate, but also may increase uptake in other future vaccines. Within the historical context of this dissertation, once individuals experienced the success of smallpox vaccination, their faith in vaccines may have extended to future vaccines that targeted other diseases. I provide evidence of this phenomenon by showing that smallpox vaccination mandates may have driven increased uptake in the diphtheria vaccine. After the invention and initial roll-out of the diphtheria vaccine in the latter half of the 1920s, states that already had school vaccination mandates for smallpox experienced a larger drop in diphtheria rates than states without mandates. This suggests states with more experience with the smallpox vaccine were then more likely to utilize the diphtheria vaccine after its invention.

Before describing this dissertation's methodology and results in more detail, in Chapter 2 I provide background information on smallpox, smallpox vaccination, and smallpox vaccination laws. While today smallpox is most likely to appear in history books or fictional spy thrillers, historically it was human kind's most deadly infectious disease. Since there was no known treatment for smallpox once contracted, prevention was of the utmost importance. The invention of a smallpox vaccine by Edward Jenner in 1796 was a breakthrough in smallpox prevention. But even with this new technology, there was substantial heterogeneity in populations' willingness to be vaccinated and in policy makers' willingness to mandate vaccination.

One difficulty in evaluating the efficacy of mandated smallpox vaccination has been a dearth of data on historical mandates. I overcome this difficulty by collecting a novel dataset of historical smallpox vaccination mandates from state session law books. Chapter 3 describes the collection of these laws and documents their content. Additionally, I outline the other health and economic data sources used in this dissertation.

In Chapter 4, I outline the literature on the relationship between infectious diseases, health and human capital in the late 19th and early 20th centuries in the United States as well as in contemporary contexts. Chapter 5 then provides a theoretical framework for exploring the effects of school vaccination mandates. First, it describes how mandates may affect health and human capital development. Second, it explores how anti-vaccination sentiment may temper the benefits of vaccination mandates. Lastly, it illustrates how a spillover of smallpox vaccination mandates may have been increased uptake of diphtheria immunizations.

Chapter 6 describes this dissertation's first set of results: school vaccination mandates substantially reduced the prevalence of smallpox. I find that not only did states with mandates consistently experience less smallpox than states without mandates, but this difference was magnified during smallpox epidemics. I employ a permutation test to show it was unlikely this relationship was due to chance. Moreover, as a placebo test I demonstrate this relationship did not exist between school vaccination mandates and influenza, a disease with characteristics similar to smallpox that did not have a vaccine available at the time. This suggests that the reduction in smallpox due to mandates was not biased by omitted variables such as disease environment, public health capability, or ability to respond to epidemics.

In Chapter 7, I show that mandates provided economic benefits in addition to health benefits. Leveraging the staggered roll-out of mandates within a difference-in-differences framework, I demonstrate that in the long-run, adults exposed to mandates as children enjoyed higher status occupations and higher skilled occupations. These benefits translated to an average increase in occupational income scores of approximately three percent, or an increase in average annual income of approximately $700 in 2020 dollars.

I confirm the causal nature of this relationship with an event study that examines the effect of vaccination mandates on labor market outcomes based on the age of an individual when a mandate was passed (Bailey et al. 2020).[1] Fitting a linear spline to my event study coefficients reveals that the benefits of mandates did not appear for those who were adults upon mandate passage. Instead, not only did the benefits only begin to appear for those who were of schooling age, the magnitude of these benefits increased the longer these individuals were exposed to a vaccination mandate. Furthermore, this increase in benefits leveled off for those who upon passage of a mandate, were too young to attend school or had not yet been born. This pattern is to be expected if a vaccination mandate was to have an effect since these individuals would have been exposed to an active mandate for the same number of schooling years as an individual who was just starting school when a mandate was passed.

In Chapter 8, I attribute these benefits to school vaccination incentivizing increased investment in human capital. Difference-in-differences results support this assertion as they reveal that mandates increased school enrollment of teenagers by approximately three percent. Concurrently, these individuals were also less likely to participate in the labor force by a similar magnitude, suggesting that vaccination mandates induced individuals to delay entering the labor market in favor of increased schooling.

Chapter 9 exploits anti-vaccination sentiment to show that those who resisted compelled vaccination benefited less from compulsory vaccination laws. In the late 19th and

[1] I follow the approach of Bailey et al. (2020) who similarly leverage event studies with linear splines to show that early-life exposure to the Food Stamps program increased later-life human capital.

early 20th centuries, German immigrants were known for resisting compulsory vaccination (Colgrove 2006, p.21; Hopkins 2002, p. 282). In some states, they effectively lobbied to prevent the passage of mandates. In other states with mandates, they still resisted vaccination by refusing vaccination and evading vaccination laws. I show that children of German immigrants benefited less from school vaccination mandates in terms of both school enrollment and long-run occupational standing. These results show that anti-vaccination beliefs may mute the benefits of vaccination policies.

Lastly, in Chapter 10 I provide evidence that school vaccination mandates for smallpox were associated with increased uptake for the diphtheria vaccine after it was invented in 1923. States that had school vaccination mandates for smallpox experienced a larger drop in diphtheria rates after the vaccine's invention, suggesting that a spillover of increased vaccine uptake for smallpox may be increased uptake for other future vaccines.

From a historical perspective, this dissertation documents the costs paid by residents of states that did not pass mandates in the late 19th and early 20th centuries. Troesken (2015 p. 8) attributes the United States' inconsistent constellation of vaccination policies to the decentralized nature of American institutions. Federalism delegated much of the responsibility for vaccination policy to state and local authorities. This enabled anti-vaccination groups in certain states to successfully lobby against mandated vaccination. Moreover, these groups were also able to use the judiciary to challenge the legality of mandates. Consequently, some states enacted school vaccination mandates, while others did not. In states without school vaccination mandates, individuals possessed the ability to decide whether or not to vaccinate their children without vaccination being a prerequisite for school enrollment. But these same individuals also paid the cost of a higher risk of smallpox contraction, and loss of the education and labor market benefits of compulsory school vaccination.

From a contemporary perspective, this dissertation speaks to the benefits of school vaccination mandates, specifically, and vaccination, more broadly. The methodology and results of this dissertation contribute to a growing literature that uses identificiation strategies to document the effects of vaccination programs. While traditionally this literature has focused on health outcomes, such as vaccination or disease rates, more recently it has explored economic effects. In a similar vein, this dissertation highlights the health *and* economic effects of school vaccination mandates. Additionally, it introduces event studies to the literature to improve the identification of long-term effects of vaccination programs. Moreover, it shows that anti-vaccination sentiment may interfere with the efficacy of such programs.

Finally, this dissertation was written during the COVID-19 pandemic. While my work began before the pandemic, it unfortunately became more topical as the pandemic progressed. It is tempting to directly compare the United States' battles against smallpox to the current struggles with COVID-19. However, there are a number of important differences between the two. Most obviously, a century separates the two experiences, and so medical technology and broader historical context differs. Additionally, the diseases themselves differ on key dimensions. Smallpox was a more serious threat for children, while COVID-19 is a more serious threat for the elderly. That being said, there are also striking similarities between the two. Vaccination has been the most effective tool in the fight against both diseases. Furthermore, within United States there still exists substantial vaccine hesitancy and heterogeneity in states' policy responses.

In light of these shared characteristics, the United States' experience with smallpox reminds us that current conflicts over how to balance personal liberty with combating infectious diseases are not new. We know that vaccination technology is not enough now, just as it was not enough a century ago. People also need to be willing to vaccinate.

But the lesson from smallpox is a hopeful one. Policy makers successfully developed policy prescriptions, in this case school vaccination mandates, that helped to contain smallpox. While in some places, and for some populations, it took longer than others, smallpox was still successfully eliminated from the United States by the middle of the 20th century. This dissertation shows that even if the process of combating disease through vaccination is not straightforward, there is still hope that communities can successfully come together to improve their health and economic lives.

CHAPTER 2

Background

2.1 Smallpox

Smallpox is an infectious disease caused by the *variola* virus. Typically, it spreads via prolonged person-to-person contact. After contraction, smallpox incubates for anywhere from 10 to 14 days during which the symptoms first manifest as an onset of high fever, malaise, headache, severe fatigue, severe back pain and less commonly, gastrointestinal symptoms (Belongia and Nailway 2003). Several days after the initial onset of symptoms, the most contagious period of the infection begins when body-wide red lesions appear and develop into virus-filled pustules. Transmission begins to occur once this rash appears. Lesions containing *variola*-filled fluid develop into pustules in the oral, pharyngeal and nasal mucosa. Once these erupt, they spread the virus through aerosolized virus-filled saliva droplets when the infected host coughs, sneezes or talks during prolonged close contact with another person.

During the typical 21 day course of the disease, body-wide pustules begin to scab over and eventually fall off. A smallpox host remains infectious until the last scab has fallen off. Less common means of *variola* transmission occur through direct contact with contaminated fomites such as linens and clothing. Death from the severe forms of smallpox occurs due to viremia, systemic shock and toximemia as the virus blocks the molecules produced by the immune system meant to interfere with viral replication.

Smallpox mortality rates ranged from 20 percent to 1 percent depending on whether the virus was *variola major* or *variola minor*, more and less severe forms of smallpox (Troesken 2005, p. 70; Brabin 2020; Hedrich 1936). Historically, the more deadly *variola major* was the sole form of smallpox in the United States. Only at the start of the 20th century did *variola minor* first appear, soon becoming the most common strain. *variola* *major* was still endemic in the United States, but outbreaks were more commonly caused by *variola minor*.

There is some disagreement as to the exact mortality rate of *variola minor*. Troesken states the mortality rate of *variola minor* was 1 percent or less, Brabin states that it was 2 to 6 percent, and Hedrich estimates that it was 0.9 percent (Troesken 2005; Brabin 2020; Hedrich 1936). But each of these mortality rates agrees that while *variola minior* was less deadly than *variola major*, it was still a serious public health threat.

Surviving smallpox contraction conferred protection from future infection. Additionally, smallpox survivors frequently suffered negative side effects. These included scarring, blindness, pneumonia, sepsis, arthritis, keratitis, and encephalitis (Johns Hopkins Center for Health Security 2014; Mazumder 2007). The most notable of these was blindness, of which smallpox was historically a leading cause. For instance, in 18th century Europe smallpox was responsible for over one third of the cases of blindness (Williams 2010, p. 23). In addition to impaired vision, survivors also suffered from impaired hearing and speaking (Mazumder 2007). Furthermore, childhood smallpox contraction has been found to have led to lower heights in adulthood, suggesting that contraction reduced childhood nutrition. British survivors of childhood smallpox in the 18th and 19th centuries were found to have reduced physical height by at least one inch (Voth and Leunig 1996).[1]

One characteristic of smallpox that made it especially dangerous was that there was no effective treatment (Troesken 2005, p. 71). Various treatments were attempted. For instance, one such treatment was erythotherapy, the treatment of smallpox by objects that were colored red. Patients were fed red foods and drinks, and surrounded by red furnishings. This approach was used in the United States as late as the 1930s. Ultimately though, the most effective treatment was to isolate smallpox victims from others to prevent further spread. Infected individuals were frequently quarantined in either their homes

[1] In addition to these long-term effects, early-life exposure to infectious diseases has been shown to lead to higher later-life morbidity and mortality due to chronic inflammation, which raises the risk of cardiovascular and respiratory problems (Finch and Crimmins 2006).

or isolation hospitals until they either succumbed to or survived the infection. The lack of effective ameliorative medicine or therapies highlighted the importance of innoculation against smallpox to avoid initial contraction.

2.2 Smallpox Vaccination

Prior to the invention of the smallpox vaccine in 1796, populations around the world protected themselves against smallpox by performing variolation. Variolation was the practice of deliberately infecting oneself with a mild form of smallpox. Practitioners would take material from an individual infected with smallpox, and either blow it into an uninfected individual's nose, or scratch it under their skin. This caused patients to suffer a mild form of smallpox. Those who survived the procedure obtained protection from future smallpox infection. This practice was not without danger, though. Even this mild form of smallpox had mortality rates as high as 1 to 2 percent.

In 1796, British physician Edward Jenner invented a smallpox vaccine, the first vaccine in human history. Building upon the knowledge that milk maids who contracted cowpox from cows were not infected by smallpox during epidemics, he discovered that scratching cowpox under the skin of an individual afforded them protection against smallpox. Practitioners would open a wound on the surface of a patient's skin. Into this wound, they would either scratch the lymph of a diseased cow, or material from another individual who had successfully undergone the procedure.

This procedure was a safer approach than variolation. It provided protection that lasted for decades with the most common side effects being fever and fatigue (Troesken 2015, p. 85). Due to a lack of regulation for the production and administration of biologics, the vaccination procedure was less safe than it is today. But, the probability of death was still very low. For instance, in Germany during the late 19th century, only 35 out of 2.275 million vaccinated individuals died from the vaccine (Troesken 2015, p. 77).

Due to the logistical difficulties of transporting diseased cows, at first vaccination material was primarily transmitted arm-to-arm between humans. This distribution of vaccine material proved especially difficult over long distances, such as the Atlantic Ocean. For instance, to transport vaccine material to the Americas, King Carlos IV of Spain organized a seaward expedition that included twenty orphans. At the voyage's outset, only one of the orphans received the vaccine. When this orphan developed a pustule one week after the vaccination procedure, a second orphan was then vaccinated using this pustular material. This process was repeated between the orphans so that the vaccination material could be shared with populations encountered during the expedition. Once receiving the vaccine material, these populations could then continue the inoculation chain on their own (Henderson 2009).

The logistics of vaccine production and distribution improved over the 19th century. By the latter half of the 19th century in the United States, vaccine farms were producing vaccine material by raising cows infected with cowpox. These farms would harvest and preserve the cowpox material, mostly commonly on the end of quills. Such quills would then be sent to vaccinators. Doctors used these quills by first scarifying a patient's skin with incisions, and then into this wound rubbing the preserved lymph of a diseased cow (Troesken 2005, p. 72; Chapin 1900, p. 594).

In the long-run vaccination was so successful in fighting smallpox that by 1978 the disease had been eliminated from the world. But non-uniform acceptance of vaccination, and heterogeneous policy prescriptions, meant that the battle against smallpox took longer in some areas than others, even in countries where vaccination had been available for a long period of time, such as the United States.

2.3 Smallpox Vaccination Legislation

The middle of the 19th century in the United States embodied a confluence of events that prompted policy makers to better confront the threat of smallpox. First, the technology of vaccination advanced to make production easier and distribution more widely available.

Second, the ability of policy makers to coordinate and enforce public health policies improved as government bureaucracies gradually became more effective. Third, rising population levels and density fostered the spread of smallpox, triggering public pressure to address the threat (Duffy 1978).

Consequently, certain state legislatures began to institute vaccination mandates that required children to be vaccinated against smallpox to attend school. Children were the main focus of vaccination efforts for a number of reasons. First, they were the primary victims of smallpox (Hopkins 2002, p. 8). Second, beginning in the middle of the 19th century, schools became increasingly crowded. Worried that these conditions would cultivate infectious diseases, educators and public health officials at the time emphasized the importance of protecting children against disease spread (Duffy 1978). Furthermore, they recognized that the poor health of children impeded the quality of their schooling, which risked negatively impacting their future productivity (Meckel 2013, p. 13). Third, not only were children who contracted the disease directly affected, but disease outbreaks also interrupted schooling more broadly. At the time smallpox was the infectious disease Americans feared most (Willrich 2011, p. 20). As the secretary of the Kentucky Board of Health put it in 1897, ”One case of smallpox in a tramp will create far more alarm in any community in Kentucky than a hundred cases of typhoid fever and a dozen deaths in the leading families” (Willrich 2011, p. 21). This fear drove parents and students to avoid risk of contraction in school settings. For instance, in response to the appearance of smallpox in their communities, parents would stop sending their children to school (Morris 1895; ”Smallpox in Cincinnati” 1882), and quarantine efforts would trigger school closures (Morris 1895; Meckel 2013, p. 43; ”To Prevent Smallpox Contagion” 1892; ”Smallpox Closes Broadalbin Schools” 1924).

To enforce these mandates, children were required to present proof of vaccination to attend school. Vaccination and certificates of vaccination were available from a number of sources. Family physicians vaccinated children under their care. If a child did not have access to a family physician, vaccination was also available in schools and health departments (Chapin 1900, p. 589). Parents who could not afford to have their child vaccinated were provided vaccination for free. States also frequently provided vaccination for free regardless of ability to pay (Chapin 1900, p. 583).

Enforcement of mandates was usually left to local boards of health, boards of education, and pupils' teachers (Chapin 1900, p. 584). Children without vaccination certificates were excluded from school until they could provide proof they were vaccinated. In most states, mandates applied only to children in public schools. Children attending private schools or being homeschooled were usually not subject to the same requirements. This distinction was especially notable in states with compulsory schooling laws. In these states, parents who refused to vaccinate their children could be fined and/or jailed under truancy laws if they did not instead homeschool their children or send their children to private schools without vaccination mandates.

Substantial anti-vaccination sentiment in the 19th and early 20th centuries in the United States complicated enforcement. Enforcement was additionally complicated by the fact that there was substantial anti-vaccination sentiment in the United States in the late 19th and early 20th centuries. Anti-vaccination beliefs stemmed from a number of sources. One was from individuals who did not accept allopathic medicine over alternatives such as homeopathic medicine (Wilrich 2011, p. 257). Another group rejected vaccination due to religious reasons, such as Christian Scientists. Some viewed the decision to vaccinate their children as a personal decision, not a decision to be made by the state (Kaufman 1967). And others still were wary of the potential negative health effects of the vaccine (Troesken 2005, p. 73).

German immigrants were notable for their prevalent anti-vaccination sentiment. Colgrove (2006, p.21) describes German immigrants in New York in the late 19th century as being known to resist state interference in private matters, especially the decision to vaccinate one's child. A health official in Buffalo, New York, in the midst of a smallpox epidemic in the 1880s recalled that, ”I have experienced a great deal of opposition among German people to vaccination. This seems strange, for it is very seldom you will ever find a person, born in Germany, who has not been vaccinated, as there it is compulsory. The moment they land on our free soil, they imbibe the spirit of freedom, especially as regards vaccination” (Hopkins 2002, p. 282). This sentiment was not limited to the Northeastern region of the United States. For example, in Wisconsin, German immigrants led popular resistance to school vaccination mandates, culminating in violent riots targeting vaccination officials during a smallpox epidemic in 1894 (Duffy 1978).

Those with anti-vaccination beliefs resisted mandated school vaccination in a number of ways. At the individual level, families would avoid mandates by using fake vaccination certificates, or even by forging fake vaccination scars (Wilrich 2011, p. 228 and p. 230). At the community level, anti-vaccination groups took advantage of the United States' institutional emphasis on individual liberty to organize their resistance through the political and legal systems. This was enabled by the United States' federal system, which gave power to states to pass their own vaccination laws. Consequently, anti-vaccination groups focused their efforts on specific states to either prevent the passage of vaccination mandates, repeal existing mandates, or even pass laws banning the passage of future vaccination mandates (Troesken 2005, p. 102).

These efforts also extended to the legal system. The United States' strong independent judiciary allowed anti-vaccination groups to mount numerous legal campaigns against vaccination mandates. Usually, anti-vaccination groups lost their cases as courts consistently upheld the right to mandate vaccination. The most influential of these cases were the Supreme Court cases *Jacobson v. Massachusetts* in 1905 and *Zucht v. King* in 1922 (”Jacobson v. Massachusetts” 1905; ”Zucht v. King” 1922). In each case, the Court broadly sided with the government's responsibility to protect public health over the Constitution's protection of personal liberty. In *Jacobson v. Massachusetts*, a man named Henning Jacobson refused to follow a vaccination mandate issued by the city of Cambridge, Massachusetts, during a smallpox epidemic in the early 20th century. Rather than pay the fine for his refusal, he challenged the constitutionality of the statute from which Cambridge derived its authority. The Supreme Court sided with the State of Massachusetts, upholding its power to grant the Cambridge Board of Health authority to mandate vaccination during an epidemic (Mariner et al. 2005). Almost two decades later, *Zucht v. King* expanded this ruling by reinforcing the legality of school vaccination mandates even in times other than during an epidemic.

But anti-vaccinationists still scored some legal victories. For instance, even though courts consistently upheld the right of public health departments to compel vaccination during smallpox epidemics, in some states through legal challenges anti-vaccinationists successfully prevented mandatory vaccination during periods other than epidemics unless it was expressly supported by legislation (Troesken 2005, p. 89 and p.102). This precluded the use of mandates in states where, even if public health officials desired compelled vaccination, anti-vaccination sentiment prevented legislatures from passing mandates.

Due to resistance against vaccination and its compulsion, some states passed school vaccination mandates while others did not. In practice, even within states enforcement was heterogenous, as it depended on local willingness to punish those who refused to vaccinate (Troesken 2005, p. 88). The serious threat of smallpox called for the passage of mandates. But the willingness to pass a mandate and enforce its provisions varied based on populations' attitudes toward vaccination and its compulsion. This led to an inconsistent constellation of school vaccination mandates across the country. In the next chapter, I discuss the temporal and geographic heterogeneity of the passage of these mandates before estimating their effect on health and human capital development.

CHAPTER 3

Data

3.1 A New Dataset of Mandatory Smallpox Vaccination Laws

The data used in this paper originate from a variety of historical sources. I gather data on compulsory school vaccination laws from *Heinonline* (Heinonline 2020). *Heinonline* is a digital repository of contemporary and historical legal documents. Included within these databases are scans of historical state session law books. These books contain a record of the laws passed by each state each year that a session law book was released. For most states, these books were published on a biennial basis.

To collect a comprehensive record of vaccination mandates, I search through scans of these session law books for all 48 states within the continental United States reaching back to the early 19th century. I use two methods to ensure that I obtain a comprehensive legislative record. The first is that most session law books contain an index of laws passed. I use these indexes to document all laws passed related to smallpox and vaccination. Second, *Heinonline's* digital database allows users to search the text of session law books for certain words. Utilizing this capability, I search these session law books for all mentions of *smallpox*, *vaccination* and related words, such as *variola* and *innoculation*. This allows me to compile a comprehensive panel dataset of smallpox vaccination mandates that documents each mandate's date of passage and state of passage.

Figure 1 provides an example of such a school vaccination mandate. Collected from Rhode Island's 1882 session law book, the statute states that all children attending public schools in Rhode Island must have a certificate proving they have been vaccinated. Any child without such a certificate will not be allowed to attend public schools in the state.

I confirm the accuracy of my collection of vaccination mandates against three other datasets of mandates. First, Force and Leake (1921) provide a description of smallpox legislation in twenty states in 1920. Out of these states, eleven had active school vaccination mandates. I confirm that Force and Leake's record matches the record that I collect from *Heinonline*.

My collection provides two additional advantages over Force and Leake's. One, this dissertation's dataset of mandates is more comprehensive than Force and Leake's since it covers all 48 states within the continental United States. Two, it also covers all years that mandates were passed, rather than only those active in 1920. This panel structure of my dataset allows me to leverage the roll-out of mandates to improve the identification strategy of my empirical approach to estimate the effects of mandates, which I describe in more detail in later chapters.

Second, Duffy (1978) and Hodge and Gostin (2001) provide descriptive histories of smallpox legislation in eleven states. These include both the state that passed vaccination legislation and the date of passage. I also confirm the accuracy of my panel dataset of mandates against their records. The fact that my collection coincides with these datasets from Force and Leake, Duffy, and Hodge and Gostin reinforces the accuracy of this dissertation's dataset of vaccination mandates.

When collecting vaccination mandates, I differentiate between three types. The first are state laws that required all children in a given state to be vaccinated against smallpox to attend school. As previously mentioned, these laws usually only applied to children attending public schools. Furthermore, these laws only required smallpox vaccinations, not other vaccinations. The one exception is West Virginia, whose 1937 law included a requirement for compulsory school diphtheria vaccination. No other states in my period of study bundled diphtheria vaccination with smallpox vaccination mandates after the invention of the diphtheria vaccine in 1923.

The second type of laws enabled local boards of health and boards of education to require children within their jurisdiction to be vaccinated as a requirement to attend school. This type of law was seen as a compromise between pro- and anti-vaccination groups that allowed public health officials within a state to mandate school vaccination within their jurisdictions. In practice, these two types of laws functioned similarly since enforcement of mandates required local cooperation. Therefore, I include both of these types of laws together in my dataset.

A key characteristic of these two types of laws is that they were enforceable in times other than an epidemic. This made them effective at preventing epidemics before they were able to start. Moreover, this also allows me to use the years these laws went into effect as an immediate positive shock to vaccination rates.

In addition to these laws, the third type of vaccination laws were ones that allowed states to compel vaccination only during epidemics. I do not include these types of laws in my dataset for three reasons. First, health departments were allowed to compel vaccination during epidemics without explicit legislative authority (Duffy 1978). As a result, it is unclear to what extent these laws strengthened the ability of public health officials to respond to epidemics. Second, beyond scattered historical examples, it is difficult to systematically identify when and where these laws were invoked to mount vaccination campaigns. Finally, the exclusion of these laws threatens to bias my results only if their passage and the occurrence of epidemics was correlated with the passage of the first two types of school vaccination mandates described above. My identification strategy in Chapter 7 suggests that this bias is unlikely as I show an immediate effect of the passage of these first two types of school vaccination mandates.

A list of the years in which the laws I collect took effect for the 48 states in the continental United States appears in Table 1. Maine was the first state to pass a vaccination mandate for smallpox in 1850, and West Virginia was the last to pass one in 1937. Massachusetts is commonly cited as the first state to pass a school vaccination mandate. This is because Massachusetts was the first state to pass a school vaccination mandate that required all children in the state to vaccinate against smallpox. Five years earlier, Maine passed a law that allowed local officials to mandate vaccination even in times when smallpox was not present.

Figure 2 plots the roll-out of these mandates over time. Prior to 1850 no state had a school vaccination mandate. From 1850 to 1900, the number of states that had an active vaccination mandate increased to 16. At the turn of the century, though, states largely stopped passing new school vaccination mandates. One potential explanation is that the reduction in number of new laws passed coincided with a change in the nature of smallpox in the United States. At the start of the 20th century, *variola minor* replaced *variola major* as the dominant form of smallpox. While *variola minor* was still a dangerous disease, it was less deadly than *variola major*. If vaccination mandates were passed in response to a perceived threat from smallpox, the reduction in its average severity may have caused states to slow the passage of new mandates (Troesken 2015, p. 92).

Figure 3 presents a map of the geographic coverage of mandates. In total, 20 of the 48 states in the continental United States passed a school vaccination mandate. Most of the states in the eastern portion of the continent and some of the states in the western portion of the continent passed mandates. But there is an obvious gap in mandate coverage in the central section of the continental United States. Troesken (2015 p. 3 and p. 95) attributes this to populations in these areas being resistant toward compelled vaccination. For instance, in the Midwest state health departments attempted to enact school vaccination mandates without legislative backing. Anti-vaccinationists successfully challenged these mandates in the courts, which ruled that such policies required explicit statutes. In the face of resistance against mandated vaccination, state legislatures were unable to enact such legislation, frustrating the efforts of public health officials.

Taken together, Figures 2 and 3 show that heterogeneity in willingness to adopt mandates resulted in a patchwork of mandates across the United States. This inconsistent web of vaccination policies made it difficult to contain smallpox. However, the temporal and geographic heterogeneity is also essential for my empirical approach in Chapters 6 through 10. By leveraging the staggered roll-out of mandates within a difference-in-differences framework, I am able to estimate the causal effect of mandates on health and economic outcomes.

3.2 Health and Economic Data

In addition to providing a novel dataset of vaccination mandates, I also utilize health and economic data from a number of sources. For health data, I collect historical smallpox data from the *Public Health Reports*. First published at the end of the 19th century, *Public Health Reports* is a weekly peer-reviewed publication that contains papers related to public health. Additionally, it publishes weekly infectious disease data reported by physicians and local officials across the country. As part of these data, there are specific tables that record biannual smallpox tallies at the state level. I collect these state totals for the years 1900-1909 and sum them to annual totals.

I augment these data with smallpox tallies covering the years 1910 to 1940 obtained from *Project Tycho*. *Project Tycho* is a digital repository of historical infectious disease data for the United States (Panhuis et al. 2018).[1] Since during this period there were times when only smallpox cases were reported, and not deaths, I only study disease morbidity when examining the relationship between mandates and smallpox. I sum these data to be annual at the state-level to match the data collected from the smallpox specific tables in the *Public Health Reports*.

Additionally, I collect state-level annual influenza mortality data from the 1924 *Mortality Statistics* ("Mortality Statistics" 1924) for the years 1915 to 1924. Separate from the *Public Health Reports*, the *Mortality Statistics* books were produced by the United States Bureau of the Census and collect disease mortality data from death certificates. I specifically collect influenza mortality data from the 1924 edition to use as a placebo test to examine whether the negative relationship between smallpox rates and school vaccination mandates similarly appears for influenza rates.

[1] *Project Tycho* collected these data from the weekly mortality and morbidity reports from early issues of the *Public Health Reports*

To explore the effect of compulsory school vaccination laws on economic outcomes, I primarily use the 1 percent samples of the individual-level 1870-1940 censuses obtained from IPUMS (Ruggles et al. 2020). IPUMS is an online repository of United States Census data. Since I use the 1 percent census samples, I utilize the sample weights produced by IPUMS in all of my specifications in Chapters 7 through 9.

As a measure of adult earnings, I would ideally use data on individuals' wage and salary incomes. However, the census only began to collect earnings data in 1940. Therefore instead I use occupational income scores which is a constructed variable that assigns each occupation the median total income of all individuals with that occupation in 1950. This variable is made available by IPUMS for all of the censuses in my sample.

Others have employed IPUMS' occupational income scores as a proxy for occupational standing and incomes using 19th and 20th century censuses (Abramitzky et al. 2014; Olivetti and Paserman 2015; Bleakley 2010a). Saavedra and Twinam (2020) analyze the accuracy of these occupational income scores as an estimate for earnings. They demonstrate that there is the potential for bias when using occupational income scores due to within-occupation earnings differences across individuals, for instance due to gender, race or location. To address this issue, I limit my sample to U.S. born white male adults, the population for which occupational income scores are most accurate (Saavedra and Twinam 2020). As a robustness check, I also disaggregate occupational data into skilled and unskilled workers as an additional proxy for occupational standing. I do this by categorizing individuals with professional, managerial, clerical, sales, operative or craft occupations as skilled, and individuals with service and labor occupations as unskilled.

I also analyze the effect of vaccination mandates on the labor market participation of adults. The IPUMS variable for labor market participation from 1870-1930 differs from modern definitions (Ruggles et al. 2020). Instead, it records whether an individual reported an occupation to the census. Using this variable as defined by IPUMS, I take it as a proxy of whether an individual was participating in the workforce. Since the definition of labor market participation changes beginning with the 1940 census, I limit my use of this variable to the 1870-1930 censuses.

To examine the effect of compulsory school vaccination laws on school enrollment, I use the school attendance variable from the 1 percent samples of the 1850-1910 IPUMS samples (Ruggles et al. 2020). For the census years 1850-1900, it is a dummy variable equal to one if an individual has attended school within the past 12 months. For the 1910 census, it is a dummy variable equal to one if an individual has attended school within the past 7.5 months. Since this time period covers the school year prior to when the census question was asked, I also include this 1910 variable in my sample. In practice, these measures of school attendance may more closely represent school enrollment than regular school attendance. Therefore, throughout the rest of the paper I refer to this variable as the probability of school enrollment.

To determine who had a German immigrant parent, I use the IPUMS variable that records the birthplace of an individual's parents (Ruggles et al. 2020). An individual is defined as having a German immigrant parent if at least one of their parents was an immigrant from Germany. I specifically focus on second generation German immigrants because using census data I can pinpoint the state in which they were born within the United States. I use the same variable to define who has a parent that immigrated from central or eastern Europe, which I use as a control group for children of German immigrants. These countries included Austria, Bulgaria, Czechoslovakia, Hungary, Poland, Romania and Yugoslavia.

For control variables, I collect data from a number of other sources. For compulsory schooling laws passed prior to 1880, I use data from Landes and Solmon (1972). For compulsory schooling laws passed after 1880, I utilize data from Clay et al. (2012) since they provide the most recent data on post-1880 laws. For the percent of the population that lives in urban areas, I employ data from Haines (2010). Since this is decennial data, where necessary I linearly interpolate to obtain annual estimates. For annual data on the political affiliation of state governors, I use a dataset compiled by Kaplan (2018). To code the political affiliation of governors, I generate a dummy variable equal to one if a governor is classified as Republican, and equal to zero otherwise.

Lastly, to examine the relationship between vaccination mandates for smallpox and diphtheria rates, I collect diphtheria data from *Project Tycho* for the years 1910-1940. I sum these data to be annual at the state-level. Additionally, I collect city-level diphtheria vaccination rates for pre-school children from Costa and Kahn (2003). These data were collected through a survey of diphtheria vaccination rates in 120 cities in 1929 and presented to the 1931 White House Conference on Child Health and Protection.

CHAPTER 4

Literature Review

This dissertation contributes to a number of literatures in both historical and contemporary contexts. First, others have theorized that vaccination contributed to improved health and human capital development in the late 19th and early 20th centuries in the United States. But this is the first work to provide empirical evidence in support of these theories. Costa (2015) suggests that vaccination contributed to the United States' health transition in the late 19th and early 20th centuries, but describes it as an understudied intervention. Mazumder (2007) posits that compulsory smallpox vaccination laws may have improved educational attainment. However, since his earliest data for vaccine mandates are an incomplete cross-section from 1915, after which most mandates were passed, he is unable to use them to definitively explore their effects. Similarly, Force and Leake (1921) and Hampton (1943) find that compulsory vaccination laws are correlated with reduced smallpox prevalence. But their analyses also use cross-sections of legislation.

Second, by showing that school vaccination mandates benefited both health and human capital development, this dissertation illustrates that the United States paid a large cost for failing to adopt mandates earlier and more widely. Other work has already proposed these costs exist. For instance, Troesken (2015 p. 7) theorizes that these costs are inherent in the United States' institutional (in)ability to fight infectious diseases. Although an emphasis on personal liberty facilitated economic prosperity, it made it difficult to fight a disease such as smallpox. But while Troesken proposes these costs exist, this is the first work to provide empirical evidence that these costs were substantial.

Third, this paper complements the literature on the persistent influence of childhood health by showing that school vaccination had long-run economic effects (Almond et al. 2018; Currie and Almond 2011; Almond and Currie 2011; Currie and Vogl 2013). Other papers have found that improvements to childhood health led to long-run human capital and labor market benefits in the United States in the early 20th century. For instance, children in the early 20th century who benefited from hookworm eradication (Bleakley 2007), malaria eradication (Bleakley 2010a), and water purification (Beach et al. 2016) enjoyed increased education levels and incomes as adults. Conversely, other work has shown that early life exposure to infectious diseases, such as influenza (Almond 2006; Brown and Thomas 2018; Beach et al. 2018) and yellow fever (Saavedra 2017), in the late 19th and early 20th centuries led to long-term negative economic effects. This paper complements their work by showing that improvements to childhood health in the 19th century also had beneficial economic effects. Ex ante it is not clear that this would be the case as public health institutions were less developed in the 19th century than in the 20th century. Evidence in this dissertation suggests that even in the 19th century disease alleviation policies had lasting beneficial effects.

Fourth, this paper speaks to a growing literature that analyzes the economic effects of childhood vaccination in more contemporary contexts. Estimating the causal impact of vaccination is made difficult by the fact that those who choose to vaccinate their children may differ from those who do not. One method used in prior work to overcome this challenge is propensity score matching. For instance, Oskorouchi et al. (2020) use propensity score matching to find that adults in China who had been vaccinated for a range of infectious diseases as children had higher cognitive test scores and educational attainment than those who had not been vaccinated.

Another method employed to establish identification is to utilize the roll-out of childhood vaccination programs as natural experiments. One such example is Driessen et al. (2015) who leverage the implementation of a measles vaccination program for children in Bangladesh in the 1980s. They find this program increased school enrollment for boys by approximately seven percent. Nandi et al. (2020) instead exploit the roll-out of India's Universal Immunization Program in the 1980s, finding that adults who were immunized as children enjoyed an increase in educational attainment of approximately .2 schooling years.[1] Most similar to this paper, Luca (2016) utilizes the roll-out of school vaccination mandates in the United States in the latter half of the 20th century to find that mandates reduced disease rates. Moreover, she finds they improved long-run educational attainment and labor market outcomes of those exposed to mandates as children.

My approach builds on these works by providing a number of original contributions. First, as far as I am aware this is the first research project to find that childhood vaccination achieved each of: a reduction in disease rates, an increase in education in the short-run, and an improvement in labor market outcomes in the long-run. The fact that I find each of these results for a single policy intervention strengthens the claim that vaccination had a causal effect on short-run and long-run economic outcomes. Additionally, this paper is also the first to use event studies to support the assertion that the relationship between childhood vaccination and long-term economic effects is causal. Finally, I provide novel evidence that anti-vaccination beliefs tempered these effects. Not only is this a falsification test that further bolsters the causal interpretation of my results, it also provides evidence that vaccination beliefs may influence the efficacy of vaccination policies.

Fifth, this dissertation also contributes to work that has found school vaccination mandates to increase vaccination uptake and lower disease rates in contemporary settings (Abrevaya and Mulligan 2011; Lawler 2017; Carpenter and Lawler 2019; Churchill 2020). Proponents of the compulsory vaccination of school children have argued that the benefits of mandates include not just these health benefits, but also economic gains. For instance, in a review of the benefits of school vaccination mandates, Jackson (1969) states that, ”it is often argued that if a child suffers permanent disability from a preventable disease, his disability represents an economic loss...in potential earning power.” This paper provides new evidence in support of this assertion that school vaccination mandates offer both health *and* economic benefits.

[1]The Universal Immunization Program included infant vaccination for measles, BCG, OPV, and DPT.

Lastly, this work introduces a new type of spillover to the literature on vaccination spillovers. Other researchers have already found vaccination policies to generate spillovers on vaccination and disease rates for diseases not policy-targeted. Carpenter and Lawler (2019) examine the effect of mandates requiring school children to obtain a tetanus, diphtheria and pertussis (Tdap) booster shot before attending middle school. Forty-eight states within the United States passed such a law, with almost all being passed between 2005 and 2015. They find that these mandates raised Tdap vaccination rates and lowered pertussis rates. Moreover, they show that these mandates also increased vaccination rates for meningococcal disease and HPV, neither of which were specifically targeted by the mandates. The findings in this dissertation build upon of Carpenter and Lawler's in that I find evidence there may be spillovers from vaccine mandates on future vaccines that have yet to be invented or implemented at the time of mandate passage. Specifically, mandates for smallpox vaccination were positively associated with diphtheria uptake. If such spillovers exist, then current analyses of the effects of vaccine mandates underestimate their benefits. This is especially relevant now as the world struggles to raise uptake of newly developed COVID-19 vaccines.

CHAPTER 5

Theoretical Framework

5.1 The Health Effects of Vaccine Mandates

On their face, the theoretical health effects of vaccination mandates seem straightforward. Vaccines effectively prevent disease contraction. Therefore, if a population is compelled to vaccinate, then vaccine uptake should increase. This in turn should lower disease rates.

In practice, though, the ex-ante health effects of vaccination mandates are not as clear. First, for vaccine mandates to raise vaccine rates, there must be margin for improvement. In other words, there must be individuals who the mandate prompts to vaccinate, who otherwise would not, for mandates to increase uptake and lower disease rates. Second, there must be effective enforcement. By its nature, enforcement of compelled vaccination can be challenging due to difficulties in verifying who is vaccinated. Moreover, mandatory vaccination may be viewed as intruding on an individual's ability to control their personal health. As a result, there is the risk of resistance against mandates.

Within the context of the United States in the late 19th and early 20th centuries, there was ample room for improvement in smallpox vaccination rates, suggesting mandates had the opportunity to raise uptake (Duffy 1978). More concerning for policy makers was the ability to enforce mandates. As previously mentioned, enforcement was largely left to local officials. These efforts were complicated by strong anti-vaccination sentiment. Consequently, ex ante is it not clear that vaccination mandates were an effective policy tool for containing smallpox. This leaves the efficacy of school vaccination mandates an open question that this dissertation answers with empirical analysis.

5.2 The Economic Effects of Vaccine Mandates

There are a number of mechanisms by which mandates and their potential health benefits may have then translated to economic effects. First, smallpox primarily affected children and had both short- and long-run effects. Assuming one survives smallpox contraction, there is still the risk of deleterious side effects that may persist into adulthood. By removing the risk of these adverse effects, compulsory vaccination may have improved the short- and long-term health of children. Such improvements to child health have been shown to both foster human capital development and increase future worker productivity in other settings (Almond et al. 2018; Case et al. 2005).

Second, vaccination for a broad range of diseases has been found to have positive effects on cognitive development. Bloom et al. (2012) find that children in the Philippines in the 1990s who had been vaccinated for measles, polio, TB, and DPT performed better on cognitive tests than children who had not been vaccinated. Oskorouchi 2020 et al. (2020) find that adults in China who had been vaccinated for a range of infectious diseases as children had higher cognitive test scores and educational attainment as adults.

One explanation for this relationship between childhood vaccination and long-term cognitive improvement is that in addition to providing direct disease protection, vaccination also trains the immune system through epigenetic reprogramming to gain resistance to other pathogens (Benn et al. 2013). In particular, live vaccines have been found to increase resistance to vaccine-unrelated infections, such as pneumonia and sepsis. Moreover, they have been found to reduce mortality more than would be expected due to a reduction in vaccine-targeted disease alone (Aaby et al. 2020). These non-specific benefits have even been found in response to smallpox vaccination, specifically (Sørup et al. 2011). Consequently, childhood smallpox vaccination may not only have protected against smallpox, but also protected against other infections, which in the long-run may have translated to improved cognitive ability.

Third, disease avoidance interventions other than vaccination were more costly. For instance, the appearance of smallpox in communities caused parents to not send their children to school (Morris 1895; ”Smallpox in Cincinnati” 1882), and schools to close (Morris 1895; Meckel 2013, p. 43; ”To Prevent Smallpox Contagion” 1892; ”Smallpox Closes Broadalbin Schools" 1924). Moreover, the fact that smallpox outbreaks became more common during colder months, which coincided with the school year, made smallpox more likely to interrupt schooling. Others have found that these types of school interruptions have had long term effects on human capital accumulation. For example, Meyers and Thomasson (2020) find that temporary school closures induced by the polio epidemic of 1916 in the United States led to reduced lifetime educational attainment of impacted children. Compulsory school vaccination benefited school children by reducing the need for these more costly interventions due to lowering the probability of smallpox outbreaks.

Fourth, mandatory school vaccinations may have incentivized parents to send their children to school even if smallpox was not present in their community. As previously mentioned, smallpox was the most feared infectious disease during this time period (Willrich 2011, p. 21). If parents knew that all school children were required to be vaccinated against smallpox, it may have made them trust the schooling environment to be safer, and as a result be more likely to send their own child to school.

Taken together, these potential mechanisms broadly suggest two channels by which school vaccination affected long-run worker productivity. The first is that healthier workers may on average be more productive. The second is that school vaccination may have made investment in children's human capital more attractive: (1) the reduced chance of mortality and morbidity made investment in childhood education less risky; (2) the improved health and cognitive abilities of children increased the return to investment in their education; and (3) a safer school environment made schooling less costly and more reliable. These three potential effects collectively suggest that compulsory vaccination may have induced increased investment in children's schooling, which may then manifest as improved labor market outcomes later in life.

However, there are potential offsetting effects. Bleakley (2010b) points out that the ex-ante effect of disease alleviation on schooling may be ambiguous. On the one hand, it may increase the marginal benefit of schooling, as outlined above. On the other hand, a healthier child may achieve a higher wage in the labor market, raising the opportunity cost of staying in school. Furthermore, in the case of smallpox, there are additional reasons to believe that school vaccination mandates may have deincentivized schooling. For instance, the vaccine itself risked triggering negative side effects such as fever or fatigue. And those who resisted vaccination may have removed their children from schools with mandates, interrupting schooling (Troesken 2015, p. 77). Consequently, similar to the health effects of vaccine mandates, the economic effects of vaccine mandates is an open question that this dissertation answers with empirical analysis.

5.3 Anti-Vaccination Sentiment and Mandate Efficacy

Anti-vaccination sentiment in the United States played an important role in weaving an inconsistent patchwork of vaccine policies across the continent. In some states, mandates were able to overcome resistance to be passed. In other states, resistance prevented their passage.

Within states with mandates, anti-vaccination sentiment may still have influenced vaccination policy. The exact nature of this relationship, though, is ambiguous. On one hand, resistance may have made it more difficult to enforce mandates. This in turn may have dulled the efficacy of mandates, even in the presence of beneficial spillovers from others' willingness to vaccinate. On the other hand, there may have been the largest margin for improvement in vaccination uptake for populations with strong anti-vaccination sentiment. If this was the case, and mandates were effectively enforced for these groups, then mandates may have actually been most effective when used with resistant populations.

To explore the relationship between anti-vaccination sentiment and mandate efficacy, I examine the effect of mandates on the children of German immigrants. German immigrants were known for being especially resistant toward vaccination and its compulsion. Not only did they resist vaccination at the individual level, as a community they also organized against mandates. Most notably this culminated in violent riots opposed to vaccination efforts. Therefore, I utilize them as a proxy for anti-vaccination sentiment to examine whether the effect of mandates differed for them as compared to other populations that were more accepting of vaccination and its compulsion.

5.4 Diphtheria Spillovers from Smallpox Vaccination Mandates

The primary goal of smallpox vaccination mandates was of course to increase smallpox vaccination uptake. However, there may also have been unintended additional benefits. One such benefit may have been that these mandates also increased diphtheria vaccination rates once the diphtheria vaccine was available, even though diphtheria vaccination was not compelled.[1]

Diphtheria was a highly infectious and deadly disease that attacked an individual's respiratory system. Similar to smallpox, it spread through airborne particles and by direct contact, and most severely impacted children. Fatality rates reached as high as 20 percent for children of ages five or younger.

There are two primary channels by which spillovers from smallpox vaccination mandates may have raised diphtheria immunization uptake. One is that for the vast majority of individuals, prior to the invention of the diphtheria vaccine in 1923, the smallpox vaccine was their first experience with vaccination. This novelty may have contributed to vaccine hesitancy. But once mandates incentivized individuals to experience the success of smallpox vaccination, they may have been more likely to trust other vaccines. This trust then may have extended to the diphtheria vaccine after its invention and subsequent distribution in the late 1920s.

Not only would more experience with the smallpox vaccine increase trust in vaccines more generally, but they would also acclimate families to the routine of childhood vaccination. For instance, through the experience of smallpox vaccination, families had the opportunity to familiarize themselves with why, when, where and how to vaccinate their

[1]The one exception is West Virginia's 1937 mandate, which compelled vaccinations for smallpox and diphtheria for school children.

children. This experience would then make it easier to vaccinate their children for other vaccines, such as diphtheria. This may have been especially true for the diphtheria and smallpox vaccines because they were both recommended to young children and may safely be taken at the same time (Leake 1927; Collins and Councell 1943).

CHAPTER 6

Smallpox Vaccination Laws and Health

6.1 Empirical Framework

In this chapter, I provide evidence that school vaccination mandates reduced the prevalence of smallpox. First, I show that vaccination rates for smallpox sharply increased for children of schooling age, suggesting that mandates spurred smallpox vaccination. Second, I leverage national smallpox epidemics that occurred between 1900-1940 to illustrate that, during these epidemics, states with school vaccination mandates experienced a much smaller increase in smallpox than states without mandates. Using a permutation test, I demonstrate that these differences between states with and without school vaccination mandates were unlikely to have been due to chance. Finally, I show that these differences do not appear when comparing the difference in influenza mortality for states with and without mandates over a sample of years that includes the 1918 Spanish Flu Pandemic. This suggests that the relationship between school vaccination mandates and reduced smallpox was most likely not due to potential omitted variables such as differences in disease environment, general public health, or ability to respond to epidemics.

Admittedly, none of the above methods provide definitive causal evidence of the effects of mandates. Data limitations preclude methods that would offer stronger causal evidence. This is because while the roll-out of vaccination mandates occurred primarily in the 19th century, infectious disease data only became widely available in the 20th century. However, taken as a whole, these methods still consistently and strongly suggest that mandates successfully combated the spread of smallpox.[1]

6.2 Smallpox Vaccination Laws and Smallpox

The first piece of evidence I provide to explore the relationship between school vaccination mandates and smallpox are smallpox immunization rates disaggregated by age. These appear in Figure 4, which is reproduced from Collins and Councell (1944). The data were compiled from a survey of white families in 28 large cities in the United States in 1935.

The figure provides evidence that school vaccination mandates did in fact substantially increase smallpox vaccination rates. First, smallpox vaccination rates sharply increase specifically for children of ages between five and eight. Since these are the ages that children began to attend school, this suggests that vaccination rates rose to meet the requirements of mandates. Second, this rise in vaccination rates is substantial. Approximately 15 percent of four year olds had been vaccinated against smallpox, whereas approximately 85 percent of eight year olds had been vaccinated, representing an increase of approximately 70 percent.

It is possible that this rise in smallpox immunization rates was not due to mandates. For instance, parents may have vaccinated their children against smallpox at these ages if they were worried about the dangers of sending their child to crowded schools. However, if this were the case, one would expect that diphtheria vaccination rates would also have risen to the levels of smallpox vaccination rates. The fact that they did not, and school vaccination mandates did not also compel diphtheria vaccination, points to mandates having a

[1] Ideally, smallpox data for the entire sample over which school vaccination laws were passed would be available. This would allow me to leverage the staggered roll-out of mandates within a difference-in-differences framework to estimate their effect on smallpox rates. However, smallpox data only became widely available during the 20th century. This also happens to correspond with the time period that states slowed their passage of new mandates, leaving only a small number of states available to leverage for identifying variation. Consequently, the sharpest historical evidence regarding the efficacy of mandates comes from leveraging smallpox epidemics to show that mandates reduced smallpox. I still estimate the effect of mandates on smallpox rates within a difference-in-differences framework for the handful of states that passed mandates in the 20th century. A description of this procedure and the result appears in Section 13.1 in the Appendix. This evidence also indicates that mandates significantly reduced smallpox rates.

substantial positive effect on smallpox immunization rates.[2]

The second piece of evidence that I employ to illuminate the relationship between mandates and smallpox appears in Figure 5, which plots time series of smallpox case rates for states with and without vaccination mandates. The figure reveals two important points. First, states with vaccination mandates consistently had lower smallpox rates than states without vaccination mandates. While it is theoretically possible that this was due to other factors correlated with vaccination mandates, it is suggestive that vaccination mandates were effective in fighting smallpox. Second, there were three epidemic periods over the sample: 1900 to 1909, 1918 to 1921 and 1928 to 1931. I leverage these as exogenous shocks to smallpox rates. If mandates did reduce the prevalence of smallpox, then one would expect smallpox to increase more in states without mandates than in states with mandates specifically during epidemics. Figure 5 shows that this was the case. During smallpox epidemics, states without mandates experienced much larger increases in smallpox during epidemics. This suggests that mandated school vaccination raised vaccination rates to a level that provided substantial protection from the spread of smallpox.[3]

One shortcoming of the data used in Figure 5 is that smallpox cases from the *Public Health Reports* were underreported during this time period. Willrich (2011, p. 11) estimates that the actual smallpox case count is five times higher than that reported. For this to bias my interpretation of Figure 5, though, this measurement error would need to be correlated with mandates. If states with mandates were more likely to report smallpox cases, then the difference in case rates between the two groups of states in Figure 5 would be biased downward. If, on the other hand, states with mandates were less likely to report smallpox cases, then the difference in case rates would be biased upward. Moreover, this systematic measurement error would also need to be magnified specifically during small-

[2]One method to more closely identify the relationship between mandates and smallpox vaccination rates would be to compare immunization rates in places that did and did not have mandates. Unfortunately, microdata for vaccination rates during this time period are not available.

[3]If I drop the states that passed mandates during this time period, the same patterns emerge. These states were New Jersey in 1900, New Mexico in 1901, South Carolina in 1905, Tennessee in 1925 and West Virginia in 1937.

pox epidemics.

It is possible that states without mandates were more likely to report smallpox cases. They may have been more focused on accurate disease reporting than instituting and supporting mandates. However, it seems more likely that the bias moved in the other direction where states with mandates were also more likely to report smallpox cases due to their stronger focus on public health infrastructure. If so, then Figure 5 underestimates the actual benefits of mandates.

6.3 Permutation Test

To show that it is unlikely that the difference in smallpox case rates between the two groups of states in Figure 5 was due to chance, I conduct a permutation test. As shown in Figure 6, the bolded line plots a time series of the actual difference in smallpox rates between states with and without vaccination mandates. As can be seen from the figure, this difference is negative over the entire time period, with the magnitude increasing in times when there were national smallpox epidemics. Each of the dotted lines instead plots this difference in smallpox rates if vaccination mandates were randomly assigned to states. I plot 50 of these permutations. The figure shows that for almost the entire time period none of the permutations reached the negative levels of the actual difference in smallpox rates.[4] Therefore, it is highly unlikely that the actual difference in smallpox rates between states with and without vaccination mandates was due to chance, again suggesting that mandates did effectively reduce smallpox prevalence.

6.4 Placebo Test

The patterns that emerge in Figures 5 and 6 suggest that school vaccination mandates reduced smallpox. There are, however, a number of possible omitted variables. For instance, the consistently lower level of smallpox in states with school vaccination mandates may

[4]The one exception is during the epidemic at the start of the time period, though there are only a small number of permutations that do reach levels more negative than the actual difference in smallpox rates.

have been due to an environment that was less hospitable to infectious diseases in general; states with school vaccination mandates may have had more effective public health institutions; or, states with school vaccination mandates may have been more capable of responding to all epidemics, not just smallpox epidemics. If any of these were true, they may generate a spurious negative relationship between school vaccination mandates and smallpox rates.

I rule out these possibilities by examining the difference in influenza mortality between states with and without vaccination mandates over the years 1915 to 1924. Importantly, this includes an epidemic, the 1918 Flu Pandemic. If omitted variables are biasing the relationship between school vaccination and smallpox, then one would expect to see the same pattern that appeared in Figure 4 to appear in a similar figure that instead plots influenza rates. I choose to use influenza since it is an infectious disease that spreads, like smallpox, through respiratory droplets with periodic large scale epidemics. Moreover, during this time period there was no vaccine available for influenza.

Figure 7 shows that the relationship between school mandates and smallpox found in Figure 3 does not also appear for influenza. Instead, if anything, states with school vaccination mandates had higher rates of influenza. Furthermore, during the 1918 Flu Pandemic, influenza rates in states with a school vaccination mandate increased more than in states without a mandate. This rules out a host of potential confounders. For instance, if states with school vaccination mandates had environments naturally less hospitable to infectious disease, then one would not expect influenza rates to have been higher in these states. Or, if states with school vaccination mandates were better able to respond to epidemics generally, one would not expect influenza rates to have increased more in these states during the 1918 Flu Pandemic.

Lastly, it is not possible to entirely rule out preferences toward vaccination as a potential confounder. In a world without school vaccination mandates, it is possible that these two groups of states would still exhibit differences in smallpox if populations in states with mandates were less reluctant to vaccinate. However, the history of school vaccination mandates suggests that mandates did increase vaccination beyond latent preferences. There are numerous accounts of school vaccination mandates raising vaccination rates (Chapin 1900, p. 587). Moreover, anti-vaccinationists' efforts to fight mandates also suggest that the mandates had substantial bite. Finally, in the next chapter I document that in terms of economic benefits, school vaccination mandates had an immediate effect. Even if vaccination attitudes did contribute toward reducing smallpox rates in states with mandates, it is unlikely that this was to the exclusion of the effect of school vaccination mandates.

CHAPTER 7

Smallpox Vaccination Laws and Long-run Labor Market Outcomes

7.1 Empirical Framework

This chapter leverages the staggered roll-out of state school vaccination mandates within a difference-in-differences framework to show that childhood exposure to mandates improved adult labor market outcomes. I identify whether an adult was exposed to a school vaccination mandate as a child by using information on the state in which they were born and their age when the census was taken. This allows me to determine the age and state of residence of individuals when a mandate was passed.[1] The key identifying assumption of my empirical strategy is that in absence of school vaccination mandates, the labor market outcomes of adults born in states with mandates and those of adults born in states without mandates would exhibit parallel trends.

To verify that this identifying assumption is valid I employ an event study. My event study estimates the effect of mandates on adult labor market outcomes based on the age and state of residence of an individual when a mandate was passed. If the identifying assumption holds, then one would expect that the labor market outcomes of individuals who were adults when a mandate was passed should trend similarly for those in states with and without mandates. This is because the mandates required vaccination of school children, not adults.

If mandates did have an effect, differential trends for individuals in states with and without mandates should only begin to appear for individuals who were of schooling age when a mandate was passed. If mandates had a positive effect, for instance, then one would expect adult labor market outcomes to trend higher for those who were of schooling age in a state that passed a mandate. Moreover, this effect should increase as age decreases for

[1] Since there is the possibility that migration may complicate determining an individual's state of residence at ages other than birth and when the census was taken, for specifications in this chapter I limit the sample to those who were born in the same state in which they were located as an adult.

two reasons. First, the younger an individual was when a mandate was passed, the longer they would be exposed to a mandate. Second, those who were older when a mandate was passed were less likely to be in school, and so less likely to be mandated to vaccinate.[2] This increase, though, should level off for those who were too young to be in school, or not yet born, upon mandate passage. This is because these individuals would be exposed to the same number of schooling years of mandated vaccination as an individual who was starting school when a mandate went into effect.

7.2 Event Study

To conduct an event study that leverages the staggered roll-out of mandates, I first pool 1 percent samples from IPUMS for the census years 1870 through 1940 (Ruggles et al. 2020). Limiting my sample to native-born white men of ages 22 to 55, I utilize the following specification:

$$ln(occscore)_{iasc} = \sum_{k=0}^{10} \phi_k \alpha_{iasc}^{k} + X_{iasc}\beta + \eta_{ac} + \zeta_{sc} + \varepsilon_{iasc} \tag{7.1}$$

Where $ln(occscore)_{iasc}$ is the natural log of the occupational income score of individual i of age a in state s for the census year c; X_{iasc} is a vector of controls, including a dummy variable for whether individual i was of schooling age when a compulsory schooling law was active, and a dummy variable for whether individual i lived in a rural area at the time of the census; η_{ac} are age by census year fixed effects; ζ_{sc} are birth state fixed effects by census year fixed effects; and ε_{iasc} is an idiosyncratic error term. Finally, α_{iasc}^{k} is an indicator variable for the passage of a school vaccination mandate when individual i is in one of $k \in [0,10]$ five-year bins each containing the ages of individuals when a mandate was passed. For instance, the first bin contains those who were ages 34 to 38 when a school

[2]Figure A3 in the Appendix shows why this is expected. This figure shows the average probability of attending school for white male children in the past year by age using the 1850-1910 censuses. Those of ages 9 through 13 were the most likely to be enrolled in school. Older children were substantially less likely to be enrolled. For instance, on average only a little over 20 percent of 18 year olds had enrolled. Consequently, school vaccination mandates should have had a larger effect on those who were ages 9 through 13 than those who were older when a law was passed.

vaccination mandate was passed, the second bin contains those who were ages 29 to 33 when a school vaccination mandate was passed, and on. The omitted category is the bin for those of ages 19 to 23 when a state vaccination mandate was passed. I choose this to be the omitted category since it is the youngest group that was beyond schooling age upon mandate passage.

Figure 8 plots the estimated coefficients of α^k_{iasc}, ϕ_k, while fitting a linear spline with knots placed for those between ages 19 and 23 and ages 4 to 8. The shape of the coefficient estimates across age bins supports the validity of my identifying assumption. The effect of vaccination mandates did not appear for those who were of adult age when a mandate was passed. Instead, the benefits of mandates only appeared for those who were of schooling age or younger. Moreover, this effect increased as age at passage decreased. Those of ages 9 through 13 experienced a larger benefit from mandates than those who were ages 14 to 18. Similarly, for those between the ages 4 and 8, the effect continued to increase. This increase in effect size, though, leveled off for those who were too young to attend school or not yet born upon mandate passage. This pattern is consistent with the identifying assumption needed to show that a difference-in-differences approach is appropriate.

While the effect of mandates should level off for these younger cohorts, it may still increase, albeit at a lower rate as it does in Figure 8. There are a number of reasons for this. First, vaccine mandates may have taken time to roll-out. Second, there may have been sibling spillovers where the vaccination of older siblings conferred additional benefits to younger siblings. Finally, vaccination of children may have protected pregnant women from smallpox contraction. Smallpox negatively affected the health of pregnant women, causing increased probability of miscarriages and stillbirths (Nishiura 2006). If in utero exposure to smallpox had long-term negative effects, then the additional protection from smallpox afforded by vaccination mandates may have had a positive effect on long-run labor market outcomes as well.

To further analyze the shape of the event study, I plot the coefficients of the three linear spline segments in Figure 9. The first coefficient, which represents the slope of the spline for those who were adults when a mandate was passed, is not significantly different from zero. This confirms that adults did not benefit from the mandates. The second coefficient, representing the slope of the spline for those who were of schooling age when a mandate was passed, is significantly positive. The approximate coefficient of .002 implies that each additional year of exposure to a school vaccination mandate was associated with an increase in occupational income scores of approximately .2 percent, an economically significant effect. The last coefficient, for those who were too young to be in school or not yet born when a mandate was passed, is also not significantly different from zero. Consequently, individuals in these cohorts did not experience significantly more benefits than those who were just beginning school when a mandate was passed.

In Figure 10, I examine the change in slope coefficients, comparing the coefficient of each spline to the preceding spline for older age groups. There is no prior spline for those who were ages 19 to 38 upon mandate passage, so its coefficient remains the same as in Figure 8. However, the slope of the spline for those who were of schooling age when a mandate was passed significantly increased from the slope of the spline for those who were adults. Furthermore, this increase in slope was offset by a significant decrease of a similar magnitude in the slope of the spline for those who were too young to be in school or not yet born when a mandate was passed. As in Figure 8, this suggests that the benefits that appeared for those of schooling age when a mandate was passed leveled off for younger cohorts. Collectively, the linear spline coefficients plotted in Figures 8 and 9 confirm my interpretation of the event study in Figure 7 as showing that school vaccination mandates did have a causal effect on adult occupational income scores.

In the Appendix, I repeat this analysis instead using the probability of being a skilled worker as the outcome variable. The event study presented in Figure A4 that uses the probability of being a skilled worker as the outcome closely resembles the event study in Figure 8 that uses occupational income scores as the outcome. Moreover, the coefficient plots in Figures A5 and A6, which correspond to the event study in Figure A4, similarly show that the slopes of the linear spline coefficients significantly increased for those of schooling age upon mandate passage and then leveled off for younger cohorts. This serves as a robustness check for my results using occupational income scores as it shows that for an additional measure of occupational status the event study still supports the validity of my empirical strategy.

Additionally, it is also possible to obtain an estimate for the average treatment effect of mandates from the event study in Figure 8. I measure the level shift in splines introduced by the spline segment for those of schooling age when a mandate was passed. This results in a treatment effect of approximately .025, which translates to full exposure to a vaccination mandate as a child increasing later-life occupational income scores by on average approximately 2.5 percent. This is in line with the difference-in-differences results discussed in the next chapter. This discussion also includes more detail on how to interpret this average treatment effect's magnitude.

Importantly, these event studies rule out the possibility of smallpox epidemics concurrent with the passage of vaccination mandates threatening the validity of my identification strategy. This is a potential worry because it is plausible that the passage of some mandates coincided with smallpox epidemics (Troesken 2015, p. 92). If this were the case, for epidemics to bias my results, they would have needed to affect children in a non-random manner. Specifically, they would have needed to be more likely to affect children of lower socioeconomic status. If they did, this selective culling could have led to those of higher socioeconomic status being more likely to survive to adulthood in states with mandates, leading to higher occupational income scores and probability of being a skilled worker for adults in those states.

These event studies show, though, that this was not the case. If this were the case, this culling effect would have only appeared for the cohorts immediately impacted. In terms of my event study, this would translate to a positive effect that would only appear for those who were alive during an epidemic, and not for those who were not yet born. The fact that I find those who were not yet born upon passage of a mandate also benefited from mandates rules out smallpox epidemics as an alternative explanation for my results.

7.3 Difference-in-differences Results

Having shown evidence consistent with the identifying assumption for my empirical strategy, I next present difference-in-differences results with a number of robustness checks. To do so, I again pool together the 1870 to 1940 censuses to leverage the staggered roll-out of mandates within a difference-in-differences framework. Limiting the sample to native-born white men of ages 22 to 55, I utilize the following specification:

$$y_{iasc} = \alpha VaccinationMandate_{iasc} + X_{iasc}\beta + \eta_{ac} + \zeta_{sc} + \varepsilon_{iasc} \qquad (7.2)$$

This specification is the same as the specification in Equation 7.1 with two exceptions. First, y_{isac} is one of three labor market outcomes: the natural log of an individual's occupational income score, the probability of being a skilled worker, or the probability of being in the labor force. The second exception is that instead of including event study coefficients, I include $VaccinationMandate_{iasc}$ as a measure of exposure to a compulsory school vaccination law for individual i of age a in state s for census year c. To assign exposure I use the age of each individual to determine how old they were when a compulsory school vaccination law was passed in the state in which they were born. If they were older than 18 at the time a law was passed, I assign them a value of 0. If they were younger than six or not yet born, I assign them a value of 1. If they were between six and eighteen years old, I assign them a value based on how many years of school still remained, assuming they were in school until 18 years old. For instance, someone who was 18 years old when a compulsory school vaccination law was passed in their state is assigned 1/14; or someone who was six years old when a compulsory school vaccination law was passed in their state is assigned 13/14. The coefficient α is the estimated effect of full childhood exposure to a vaccination mandate on adult labor market outcomes. If vaccination mandates improved labor market outcomes, then one would expect α to be significantly positive.

Summary statistics appear in Table 2. 73 percent of individuals worked in a skilled occupation. The other 27 percent worked occupations that involved unskilled service or manual labor. The vast majority of individuals were categorized as being in the labor force by reporting an occupation. This suggests that there was a smaller margin for change in labor market participation than for the other two outcomes.

The results presented in Table 3 show that school vaccination mandates did improve later-life labor market outcomes. With controls included in column 2, full exposure to a vaccination mandate led to a statistically and economically significant increase in adult occupational scores by approximately three percent. In concert, full exposure to a mandate increased the probability of being in a skilled occupation by approximately four percentage points, which corresponds to approximately five percent of the average probability of being in a skilled occupation. The effect of mandates on the probability of being in the labor force was neither statistically or economically significant, suggesting that improvement in labor market outcomes developed on the intensive rather than the extensive margin. Taken together these results suggest that school vaccination mandates induced occupational upgrading as exposed individuals moved from low-skilled manual labor occupations to more highly skilled blue and white collar occupations.

These magnitudes are in line with other work that has estimated the benefits of disease alleviation during this time period in the United States. For instance, Beach et al. (2016) find that typhoid elimination translated to an approximately 2 percent increase in incomes. Bleakley (2007; 2010a; 2010b) finds larger effects from the elimination of hookworm and malaria. For instance, he finds that the elimination of hookworm resulted in an increase in adult income scores of approximately 17 percent (Bleakley 2010b). This difference may potentially be due to the fact that school vaccination mandates did not entirely eliminate smallpox, unlike hookworm eradication. Moreover, diseases like hookworm were chronic conditions with low case-fatality rates. As a result, they potentially generated a larger drag on human capital accumulation and worker productivity than a disease like smallpox whose symptoms were more obvious, pressing and temporary.

Lastly, I consider these results to be lower bound estimates. Vaccination confers protection on not just vaccinated individuals, but also on unvaccinated individuals by reducing their potential exposure to infectious disease. In the context of this dissertation, individuals in states without a vaccination law may have benefited from the increased vaccination rates of states with a vaccination law, which would attenuate the estimated effects of mandates.

7.4 Robustness Checks

I conduct a number of separate robustness checks for these results. First, state enforcement of vaccination mandates strengthened after 1870 (Hopkins 2002, p. 284). Therefore, I drop from my sample all states that passed school vaccination mandates prior to 1870. Second, most of the states that passed vaccination mandates were located east of the Mississippi River. During the 19th century, areas to the west of the Mississippi River underwent a rapid expansion in population. To ensure these macroeconomic changes do not spuriously generate my results, I limit the geographic scope of states in my sample to those east of the Mississippi River. Third, even though all specifications include a control for exposure to compulsory schooling laws, there is still the worry that this may not entirely account for the proclivity of states with compulsory schooling laws to invest in education. To more comprehensively account for this potential bias, I additionally include compulsory schooling law fixed effects. I construct these fixed effects by organizing each state that passed a compulsory schooling law into a bin based on the decade of schooling law passage. I then interact these fixed effects with census year by age fixed effects. This flexibly controls for the evolution of states that passed compulsory schooling laws at different times. Finally, for the specification using the log of occupational incomes scores as an outcome, I also exclude farmers. Occupational income scores are an especially noisy proxy for the incomes of farmers because farmers may have had large within-occupation variation in income. Therefore, it important to ensure my results are robust to excluding farmers from my sample.

Estimates for the coefficient on $VaccinationMandate$ appear in Table 4 for each of these robustness checks and for each of the three labor market outcomes. Moreover, Figures 11, 12 and 13 also plot these coefficients for the outcomes using the log of occupational income scores, probability of being a skilled worker, and probability of being in the labor force, respectively. The interpretation of the coefficients remains stable for all of these robustness checks. This suggests that my baseline results are not spuriously driven by the passage of early mandates, states west of the Mississippi River, compulsory schooling laws, or the inclusion of farmers.

Finally, in Section 13.2 in the Appendix, I also explore whether the passage of school vaccination mandates was significantly associated with three potential confounders for which historical data are available: passage of a compulsory schooling law, having a Republican governor, or changes in the percentage of the population that was urban. It is possible that each of these may bias my results. In the case of compulsory schooling laws, others have found evidence that they increased educational attainment (Clay et al. 2012). If the passage of compulsory schooling laws was additionally positively correlated with the passage of school vaccination mandates, they may bias my results in the upward direction. In the case of having a Republican governor, it is possible that certain political parties were more favorable toward investment in public goods, such as public education and public health. If this was the case, this also risks biasing my results, though the direction of the bias would depend on the specific relationship between the Republican party and these public investments, which is challenging to track over the long-time period covered here. Lastly, omission of a measure of urbanization threatens to upwardly bias my results if mandates and other investments in public goods were enacted in response to increasingly crowded cities.

Due to these concerns, I estimate in Section 13.2 in the Appendix whether any of these potential confounders significantly predicted the passage of school vaccination mandates. Difference-in-differences results show that none of these was a significant predictor, which reduces the concern that these variables bias the results described above.

CHAPTER 8

Smallpox Vaccination Laws and Short-run Schooling and Labor Market Outcomes

8.1 Empirical Framework

Having established that exposure to school vaccination mandates improved long-run labor market outcomes, I next examine possible mechanisms. Specifically, I explore whether mandates had an immediate effect on teens' schooling and labor market decisions. To do so, I employ a difference-in-differences research design to estimate these potential effects. This empirical approach leverages the staggered roll-out of mandates between the years 1850 to 1910. I focus specifically on this time period because it is when most of the vaccination mandates were passed and consistent census data containing schooling and labor market measures for teens are available.

Data limitations unfortunately preclude the use of an event study to examine whether this difference-in-differences design exhibits parallel pretrends. A combination of census data constraints and the timing of mandate passage makes it difficult to employ a balanced panel with enough pre-periods and post-periods to create a useful event study. Therefore, instead these results may be characterized as suggestive of the mechanism by which mandates improved long-run labor market outcomes, rather than definitively identifying a causal effect.

8.2 Difference-in-differences with Robustness Checks

To examine the short-run effects of school vaccination mandates, I estimate their relationship with school enrollment and labor market participation of 16 to 18 year olds using the 1 percent IPUMS samples of the census for the years 1850 to 1910. I focus on 16 to 18 year olds for two reasons. First, this is the age group for which schooling was most on the margin as younger children were already enrolled in school at high rates. Second, by focusing on this age group, I am also able to examine changes in labor market participation as labor market participation data are available for males of ages 16 and above beginning with the 1850 census.

I make two additional sample restrictions. One, I restrict the sample to native-born white males so that the sample corresponds to the one used in the previous chapter. Furthermore, the sample is also restricted to those who live in the same state in which they were born. This allows me to limit the potential confounding effect of migration by removing from the sample individuals who grew up in a state different from the one in which they were born.

Summary statistics for this sample appear in Table 5. Most notably, teens were more likely to be active in the labor force than attending school. Whereas 67 percent of individuals were in the labor force, only 40 percent had enrolled in school the prior year. This highlights the margin for change for teens both in terms of decreasing their labor market participation and increasing their schooling.

To estimate the effect of vaccination laws, I leverage their roll-out with the following difference-in-differences specification:

$$y_{iasc} = \alpha VaccinationMandate_{iasc} + X_{iasc}\beta + \gamma_s + \eta_{ac} + \varepsilon_{iasc} \tag{8.1}$$

Where y_{iasc} is a dummy variable for either school enrollment or labor market participation for individual i of age a in state s for the census year c; $VaccinationMandate_{iasc}$ is a dummy variable equal to one if there is an active school vaccination law in state s in census year c; X_{iasc} is a vector of controls, including a dummy variable for whether a compulsory vaccination law was active in state s in census year y, a dummy variable for whether state s in census year y had a Republican governor, the urban percent of the population of state s in census year y, and a dummy variable for whether individual i lived in a rural area at the time of the census; γ_s are state fixed effects; η_{ac} are age by census year fixed effects; and ε_{iasc} is an idiosyncratic error term. If vaccination mandates had a positive effect on school enrollment, then when using school enrollment as the outcome, $\alpha > 0$. If mandates instead had a negative effect on teens' labor market participation, when using labor market participation as the outcome, $\alpha < 0$.

The estimated coefficients for α are presented in Table 6 and plotted in Figure 14 with 95 percent confidence intervals. The table and figure additionally include the same sample restrictions used in Chapter 7 that serve as robustness checks. The results show that school vaccination mandates increased school enrollment. While the coefficients are statistically significant at the 85 percent level, with each robustness check they tell a consistent story that mandates increased school enrollment by approximately 3 percentage points, an economically significant magnitude, especially for this population with an average enrollment rate of 40 percent. This interpretation is bolstered by the fact that this increase in school enrollment was matched with a commensurate decrease in labor market participation that is significant at conventional levels.

These results suggest that the health benefits provided by vaccination mandates induced investment in human capital by incentivizing substitution out of the labor market and into schooling. While mandates may have made teens healthier and more productive workers, this effect was overwhelmed by their educational benefits. Furthermore, these results also suggest that the increase in adult occupational standing due to exposure to vaccination mandates as a child was at least partially driven by increased investment in human capital.

CHAPTER 9

The Tempering Effect of Anti-Vaccination Sentiment

9.1 Empirical Framework

If school vaccination mandates did increase adult labor market outcomes through increased investment in human capital, then as described in Section 5.3, one may expect this relationship to vary based on willingness to comply with mandates. In this chapter, I show that the benefits of vaccination mandates were reduced for children of German immigrants, who as described tended to strongly oppose compulsory vaccination. Many resented state intrusion upon what they deemed to be a private decision. In particular, German immigrants often saw the United States as a country in which they had the personal liberty to choose to vaccinate their children, unlike in their home country with its especially strict vaccination laws (Hopkins 2002, p. 282).

To examine the differential effect of vaccination mandates for children of German immigrants, I use as a control group children with at least one immigrant parent from other eastern and central European countries in an effort to make the control group as similar as possible to the treatment group, with the exception of vaccination beliefs. While historical work on anti-vaccination sentiment in the United States focuses on the anti-vaccination beliefs of German immigrants, records of the vaccination sentiment of other central and eastern European groups are more scarce. This could be because German immigrants did hold stronger anti-vaccination beliefs than these other immigrant groups. But there is also the possibility this is due to the fact that there was a large number of German immigrants in the United States, and so their beliefs gained more notoriety than other immigrant groups with smaller populations.

Therefore, I provide an additional piece of evidence that German immigrants held stronger anti-vaccination beliefs than central and eastern European immigrants. As already mentioned, a primary cause of German immigrants' anti-vaccination sentiment was the strict vaccination regime in Germany. Germany was known internationally as instituting a highly effective compulsory vaccine regime that had largely eliminated smallpox (Kotar and Gesser 2003, p. 260). If other eastern and central European countries had less strict vaccination regimes, immigrants from these countries may have had less reason to harbor anti-vaccination sentiment upon arriving in the United States.

Under the assumption that the intensity of a vaccination program is negatively related to a country's smallpox rates, I use national smallpox rates as a proxy for the strictness of a country's vaccination program. According to national-level smallpox data, Germany had remarkably lower smallpox rates than other central and eastern European countries (Abbott 1902). For instance, between 1880 and 1899 Germany had a mean smallpox death rate of 1.8 per million inhabitants. Austria, however, had a mean smallpox death rate over two hundred times higher at 380 per million inhabitants. Hungary had an even higher smallpox death rate of 516 per million inhabitants. This marked difference in smallpox death rates suggests that eastern and central European immigrants were not subjected to strict enforcement, as in Germany, and perhaps did not develop strong anti-vaccination sentiment even before coming to the U.S.

have harbored the same anti-vaccination sentiment of Germans due to their home countries not enforcing as strict of a vaccination regime.

9.2 Long-run Results

Taking as given that German immigrants had stronger anti-vaccination beliefs than other central and eastern European immigrants, I first examine whether the effect of vaccination mandate exposure on adult labor market outcomes varied for children of German immigrants. I reestimate Equation 7.2 with two additions to the specification. First, I restrict the sample to sons of eastern and central European immigrants. Second, I interact a dummy variable for whether an individual was the son of a German immigrant with the *Vaccina-*

tionMandate treatment variable. If the children of German immigrants did experience less benefit from vaccination mandates than the children of eastern or central European immigrants, then one would expect the triple differences coefficient on the interaction term in the follow specification, ϕ, to be significantly negative:

$$y_{iasc} = \alpha VaccinationMandate_{iasc} + \omega German_{iasc} + \phi VaccinationMandate_{iasc} * German_{iasc} + X_{iasc}\beta + \eta_{ac} + \zeta_{sc} + \varepsilon_{iasc} \quad (9.1)$$

Results in Table 7 show that the sons of German immigrants did benefit significantly less from vaccination mandates than the sons of other eastern and central European immigrants. In terms of occupational income scores, sons of German immigrants experienced an approximately 2 percent increase due to mandates, as opposed to the 6.7 percent increase for sons of central and eastern European immigrants. In terms of the probability of being a skilled worker, sons of German immigrants also benefited significantly less.

9.3 Short-run Results

Next, I also examine whether the sons of German immigrants benefited less in terms of schooling. I reestimate Equation 7.3 and again limit the sample to sons of eastern and central European immigrants while interacting a dummy variable for whether an individual was the son of a German immigrant with the treatment variable, *VaccinationMandate*. The results in Table 8 show that the sons of German immigrants were significantly less likely to increase their school enrollment in response to a vaccination mandate. Moreover, they were also significantly less likely to decrease their labor market participation.

These results taken together with the ones in Table 7 tell a consistent story. Even in states with school vaccination mandates, German immigrants resisted mandated vaccination of their children. This could have taken a variety of forms. An act such as faking a vaccination certificate would have deprived their child of the protective effect of vaccination. Removing their child from school to avoid mandates would not only deprive their child of vaccination, but also interrupt their child's schooling. Moreover, a more broad-reaching act, such as exerting political pressure to not allow a mandate to be enforced where they lived, would have had an even larger influence if their community was not provided the benefits of widespread vaccination uptake. Due to a combination of acts similar to these, the sons of German immigrants did not enjoy the benefits of vaccination to the same degree as sons of other central and eastern European immigrants. Consequently, as children they were not as likely to substitute out of the labor force into school. And as adults, they did not enjoy the same increase in occupational status.

Lastly, these long-run and short-run results both serve as falsification tests for the results presented in Chapters 7 and 8. As mentioned in Section 5.3, the direction of the effect of mandates on populations with strong anti-vaccination sentiment is theoretically ambiguous. But in the case of German immigrants in the United States, there are reasons to believe that the effect should be negative. Namely, the historical record emphasizes challenges in enforcing mandates on this population. Consequently, the fact that German immigrants benefited significantly less from mandates in both the long-run and short-run provides additional evidence that the results found in Chapters 7 and 8 are indeed causal.

CHAPTER 10

Diphtheria Spillovers of Smallpox Vaccination Laws

10.1 Empirical Framework

I employ two approaches to explore the relationship between smallpox vaccination mandates and diphtheria. The first is that I estimate the association between the two using a cross-section of preschool diphtheria immunization rates for 120 cities in 1929. If there were positive spillovers on diphtheria rates from smallpox vaccination mandates, then one would expect preschool children in states with mandates to on average have higher diphtheria immunization rates than those in states without mandates.

Figure 15 presents a map of the availability of these diphtheria immunization data. The shaded states represent states with school vaccination mandates in 1929, and the dots represent cities with available diphtheria immunization data. These data are available for states with and without mandates, providing the necessary variation for a cross-sectional regression to estimate an associate between mandates and diphtheria immunization rates.

Second, if the compulsion of smallpox vaccination did raise diphtheria vaccination uptake, then these spillovers should also manifest as lowered diphtheria rates. I examine time series of diphtheria case rates for states with and without mandates over the years 1910 to 1940. While a diphtheria anti-toxin that effectively treated diphtheria was invented in the late 19th century, a diphtheria vaccine first became available in 1923. If there were positive spillovers from mandates on diphtheria vaccination uptake, then one would expect that states with mandates would experience a larger drop in diphtheria rates after the invention of the diphtheria vaccine.

10.2 Results

To estimate the relationship between smallpox vaccination mandates and diphtheria immunization rates, I employ the following specification:

$$y_{sc} = \alpha VaccinationMandate_s + X_{sc}\beta + \varepsilon_{sc} \qquad (10.1)$$

Where y_{sc} is the diphtheria immunization rate for city c in state s; $VaccinationMandate_s$ is a dummy variable equal to one if there is an active smallpox mandate in state s, and equal to zero otherwise; X_{sc} is a vector of control variables, including population, health expenditures, and whether the state governor belongs to the Republican party; and ε_{sc} is an idiosyncratic error term. If having a state school vaccination mandate for smallpox was associated with higher diphtheria immunization rates, then α should be significantly greater than zero.

Summary statistics for the sample are presented in Table 9. There was an active smallpox mandate in approximately half of the states in which one of the 120 cities was located. Moreover, the mean diphtheria immunization rate in these cities was only 16 percent. This relatively low rate may be due to the fact that in 1929 the diphtheria vaccine was in its early stages of distribution.

Results for the specification presented in Equation 10.1 appear in Table 10. After including control variables in Column 2, cities in states with smallpox vaccination mandates on average had diphtheria immunization rates approximately 5 percentage points higher than cities in states without mandates. Not only is this coefficient statistically significant, it is also economically significant. A 5 percentage point increase in diphtheria immunization rates represents a thirty percent increase in the mean diphtheria immunization rate.

Additionally, Figures 16 and 17 suggest that elevated diphtheria immunization rates translated to lower diphtheria rates. Figure 16 plots the average diphtheria case rates for states with and without mandates over the years 1910 to 1940. The vertical line in the figure marks the invention of the diphtheria vaccine in 1923. While there was a spike in diphtheria in 1929, over the long-run there was a consistent drop in diphtheria rates after its vaccine's invention.

Moreover, states with mandates experienced a larger drop than states without. Figure 17 makes this especially clear. The figure plots the difference in diphtheria case rates between states without and without mandates. Before the invention of the diphtheria vaccine, states with mandates consistently had higher diphtheria rates. After 1923, though, diphtheria rates in states with mandates dropped faster than for states without mandates. By the 1930s, states with mandates actually had lower diphtheria rates than states without mandates.

While neither of these empirical approaches provide definitive causal evidence, they do offer suggestive evidence that school vaccination mandates for smallpox led to higher uptake for the diphtheria vaccine. This in turn led to lower diphtheria rates. Consequently, to capture the full scope of mandates' benefits, cost-benefit analyses of compulsory vaccination policies should consider spillovers to future vaccines.

CHAPTER 11

Conclusion

This dissertation shows that school vaccination mandates played an important role in promoting the health and economic well-being of Americans in the late 19th and early 20th centuries. Prior work has struggled to uncover the full scope of the effects of these laws due to data limitations. I overcome this difficulty by contributing a novel dataset of school vaccination mandates and combining it with data from a variety of other sources. Utilizing this dataset, I find that compulsory vaccination for school children substantially reduced the prevalence of smallpox.

To better quantify these health benefits, I assume that the difference in smallpox case rates between states with and without mandates over the time period 1900 to 1940 was due to mandates raising smallpox vaccine uptake for school children. Since Willrich (2011, p. 11) estimates the *Public Health Reports* undercounted actual case counts by a factor of five, I then multiply this amount of prevented smallpox cases by five. To translate these prevented cases to prevented deaths, I assume that the case fatality rate of smallpox in the 20th century was .9 percent based on estimates by Hedrick (1936). This is mostly likely an underestimate as *variola major* was still endemic in the 20th century. Moreover, Brabin finds the case-fatality rate of smallpox at the start of the 20th century to be between 2 to 6 percent. But based on this conservative case fatality rate of .9 percent, I estimate school vaccination mandates to have prevented a minimum of approximately 17,000 deaths.

To crudely assign a monetary value to these prevented deaths, I use the value of statistical life for 1940 from Costa and Kahn (2004). Their lower bound estimate for the value of a statistical life in 1940 is $713,000 in 1990 dollars, or $1,419,890 dollars in 2020 dollars. Therefore, I multiply this value by the approximately 17,000 deaths avoided to reach a value of approximately $24 billion in 2020 dollars saved by school vaccination mandates over the time period 1900-1940.

This should be considered a lower-bound estimate for the benefits of mandates in terms of lives saved since it only includes lives saved for the time period when smallpox data are available, in the 20th century. It does not include lives saved during the 19th century, a time period when mandates were in effect but smallpox data are not widely available. Moreover, it does not include lives saved due to potential spillovers to the diphtheria vaccine.

In addition to beneficial health effects, I also show that school vaccination mandates produced economic benefits. Mandates improved the long-run labor market outcomes of adults who were exposed to school vaccination as children. These adults on average enjoyed a three percent increase in occupational income scores, which translates to an increase in annual income of approximately $700 in 2020 dollars.[1]

I propose a number of mechanisms by which school vaccination mandates may have improved long-run adult labor market outcomes, and provide evidence that one such mechanism was through fostering human capital development. Mandates increased the school enrollment of teenagers by approximately three percent. Simultaneously, it decreased their labor market participation by a similar magnitude. This suggests that school vaccination induced teenagers to substitute out of work and into schooling, which in turn led to higher adult incomes.

Furthermore, this dissertation shows that anti-vaccination beliefs reduced the benefits of vaccination mandates. As a proxy for anti-vaccination beliefs, I use German immigrants, who were known for their resistance toward compulsory vaccination. Results demonstrate that the children of German immigrants benefited significantly less from vaccination mandates both in terms of adult labor market outcomes and teenage school enrollment. Not only does this provide evidence that anti-vaccination beliefs may mute the benefits of mandates, it also serves as a falsification test that reinforces the causal interpretation of my

[1] I calculate this by first translating the coefficient on *Vaccination mandate* in the first column of Table 3 from logs to levels. This results in an increase in occupational income scores of approximately .654, or an increase in annual income of $65.40 in 1950 dollars. Transforming this into 2020 dollars results in an increase in annual income of approximately $700 in 2020 dollars.

findings.

Finally, I provide evidence of spillovers from mandated smallpox vaccination. States that historically compelled children to vaccinate against smallpox to attend school enjoyed higher diphtheria vaccination rates and a sharper drop in diphtheria case rates after the invention of the diphtheria vaccine. This suggests that cost-benefit calculations for vaccination mandates may underestimate the benefits if spillovers to future vaccines are not included.

These results provide a number of contributions. First, this dissertation illuminates the health and economic benefits of school vaccination mandates in the late 19th and early 20th centuries in the United States. By showing the benefits of these laws, this paper demonstrates there were large costs for states that did not pass school vaccination mandates (Troesken 2015, p. 5). Without mandates people were allowed to make individual decisions about whether or not to vaccinate their children and to forego the positive externalities from widespread uptake. But the cost of allowing this individual approach was substantial. Individuals in states without mandates suffered from higher disease rates and did not enjoy the labor market and human capital benefits of school vaccination.

Second, this paper provides new evidence that vaccination, broadly, and school vaccination mandates, specifically, provide economic benefits in addition to health benefits. I show that childhood vaccination may reduce disease rates, increase education in the short-run, and improve labor market outcomes in the long-run. The utilization of event studies bolsters the claim that these effects are causal. Furthermore, I find novel evidence these effects may be tempered by anti-vaccination sentiment.

Third, this paper contributes to the literature that has found contemporary school vaccination mandates to increase vaccination rates and reduce disease rates (Abrevaya and Mulligan 2011; Lawler 2017; Carpenter and Lawler 2019; Churchill 2020). Proponents of the compulsory vaccination of school children argue that the benefits of mandates include not just improved health, but also increased earning power later in life (Jackson 1969). By leveraging the roll-out of historical mandates in combination with historical census data, I am able to confirm there are substantial benefits for later life earnings and human capital development in certain settings. Moreover, I also find evidence that these benefits may extend to future vaccines for other diseases.

Finally, these results speak to the COVID-19 pandemic with which the world continues to struggle. Just as Americans a century ago struggled to balance personal liberty with combating smallpox, Americans now similarly struggle with how to raise COVID-19 vaccination rates without violating a person's ability to make health decisions for themselves and their children.

Based on this dissertation's findings, the American experience with school vaccination mandates for smallpox suggests that when policy makers weigh whether to mandate COVID-19 vaccination for school children, they should not limit their considerations to potential health effects. They should also consider short- and long-run economic effects. Moreover, policy makers should include the potential influence of anti-vaccination sentiment within their considerations. The experience of vaccination resistance in the late 19th and early 20th centuries in the United State suggests that anti-vaccinationists may impact vaccination legislation as well as blunt the potential benefits of mandates.

More generally, this dissertation illuminates that the United States has always sewn a patchwork of policies to respond to infectious diseases. This is inherent in its federal system and independent judiciary. While conflicts over how to balance personal liberty with public health still exist, the battles from the past have helped in the fight against infectious diseases today. The United States paid a cost for not adopting smallpox vaccination mandates earlier and more widely. But, through trial and error, the United States also came to better understand the benefits of vaccination broadly, and school vaccination mandates specifically. This led to the embedment of vaccination and its compulsion into American political and legal systems. While currently there are rightfully many discussion about vaccine hesitancy in the United States, Americans' trust in vaccination and their ability to combat infectious diseases has still made substantial progress from the late 19th and early 20th centuries.

CHAPTER 12

Tables and Figures

Table 1: Timing of Vaccination Mandate Passage

State	Year
Maine	1850
Massachusetts	1855
New York	1860
New Hampshire	1861
Maryland	1865
Virginia	1872
Ohio	1872
Georgia	1881
Kentucky	1881
Rhode Island	1881
Connecticut	1882
Delaware	1883
Washington	1889
California	1889
Pennsylvania	1895
New Jersey	1900
New Mexico	1901
South Carolina	1905
Tennessee	1925
West Virginia	1937

This table reports the year a school vaccination law was passed in a given state. These laws were collected by the author from session law books accessed through Heinonline. Washington's law was repealed in 1920. Oregon passed a school vaccination mandate in 1914, but it was not enforced, so it is not included here.

Table 2: Summary Statistics

	Mean	Min	Max	Count
ln(occscore)	3.05	1.09	4.38	638421
Pr(skilled)	.73	0	1	491438
Pr(in labor force)	.96	0	1	490376
Vaccination mandate	.39	0	1	638421
Compulsory schooling law	.58	0	1	638421
Age	35.25	22	55	638421
Rural	.54	0	1	638421

This sample contains the 1 percent samples of census years 1870 to 1940. In addition, this sample is limited to nonmigrant native-born white males between the ages 22 and 55. *ln(occscore)* is the natural log of the occupational score. *Pr(skilled)* is the probability of being a skilled worker. *Pr(in labor force)* is the probability that an individual reports an occupation to the census. *Vaccination mandate* represents an individual's childhood exposure to a school vaccination mandate. See Chapter 3 for a discussion of the creation of this variable. *Compulsory schooling law* represents an individual's childhood exposure to a compulsory schooling law. See Chapter 3 for a discussion of the creation of this variable. *Rural* is a dummy variable equal to one if an individual lives in a rural area, equal to zero otherwise.

Table 3: Vaccination Mandates Improved Adult Labor Market Outcomes

	ln(occscore)		*Pr(skilled)*		*Pr(in labor force)*	
	(1)	(2)	(3)	(4)	(5)	(6)
Vaccination mandate	0.0275***	0.0292***	0.0384***	0.0402***	0.00374	0.00224
	(0.00900)	(0.00886)	(0.0140)	(0.0105)	(0.00323)	(0.00324)
Compulsory schooling law		-0.00665		-0.00841		0.00429*
		(0.00488)		(0.00563)		(0.00217)
Rural		-0.435***		-0.248***		0.00354*
		(0.0258)		(0.0161)		(0.00181)
Dependent Variable Mean	3.05	3.05	.73	.73	.96	.96
N	638421	638421	491438	491438	490376	490376

Standard errors appear in parentheses clustered at the state level. This sample includes the 1 percent samples of census years 1870 to 1940, and is limited to nonmigrant native-born white males between the ages 22 and 55. Each specification includes fixed effects for birth state, age, census year, birth state by census year and age by census year. *ln(occscore)* is the natural log of the occupational score. *Pr(skilled)* is the probability of being a skilled worker. *Pr(in labor force)* is the probability that an individual reports an occupation to the census. *Vaccination mandate* represents an individual's childhood exposure to a school vaccination mandate. See Chapter 3 for a discussion of the creation of this variable. *Compulsory schooling law* represents an individual's childhood exposure to a compulsory schooling law. See Chapter 3 for a discussion of the creation of this variable. *Rural* is a dummy variable equal to one if an individual lives in a rural area, equal to zero otherwise. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Robustness Checks for Effect of vaccination Mandates on Adult Labor Market Outcomes

	ln(occscore)	*Pr(skilled)*	*Pr(in labor force)*
	(1)	(2)	(3)
Baseline	0.0292***	0.0402***	0.00224
	(0.00886)	(0.0105)	(0.00324)
Post-1870 mandates only	0.0315**	0.0465***	0.00199
	(0.0126)	(0.0152)	(0.00385)
East of Mississippi River only	0.0195**	0.0272**	0.000556
	(0.00701)	(0.0105)	(0.00344)
Includes CSL FEs	0.0188***	0.0269***	0.00480***
	(0.00659)	(0.00938)	(0.00210)
Farmers excluded	0.0719***		
	(0.0193)		

Each coefficient is the coefficient on *Vaccination mandate* for a separate regression. Coefficients in columns (1), (2) and (3) were estimated using *ln(occscore)*, *Pr(skilled)* and *Pr(in labor force)* as outcomes, respectively. The "baseline" specification is the one presented in Table 3. The sample limited to "Post-1870 mandates" does not include states that passed a vaccination mandate prior to 1870. The sample limited to "East of Mississippi River only" includes only states located east of the Mississippi River. The sample that "Includes CSL FEs" is the baseline specification with the addition of compulsory schooling law fixed effects. See Chapter 3 for the construction of these fixed effects. Finally, The sample with "farmers excluded" does not include those with their occupation listed as farmer. Standard errors appear in parentheses clustered at the state level. This sample includes the 1 percent samples of census years 1870 to 1940, and is limited to nonmigrant native-born white males between the ages 22 and 55. Each specification includes fixed effects for birth state, age, census year, birth state by census year and age by census year. In addition, each specification includes controls for exposure to compulsory schooling laws as a child and whether an individual lives in a rural area. *ln(occscore)* is the natural log of the occupational score. *Pr(skilled)* is the probability of being a skilled worker. *Pr(in labor force)* is the probability that an individual reports an occupation to the census. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Summary Statistics

	Mean	Min	Max	Count
Pr(enrollment)	.40	0	1	60175
Pr(in labor force)	.67	0	1	60175
Vaccination mandate	.31	0	1	60175
Compulsory schooling law	.43	0	1	60175
Republican governor	.53	0	1	60175
Percent urban	.35	0	.91	60175
Age	16.98	16	18	60175
Rural	.70	0	1	60175

This sample includes the 1 percent samples of census years 1850 to 1910, and is limited to native-born white males between the ages 16 and 18 who lived in the same state in which they were born. *Pr(enrollment)* is the probability a child had attended school in the past 12 months for the 1850-1910 censuses, and the past 7.5 months for the 1910 census, which includes the full school year prior to when the census was taken *Pr(in labor force)* is the probability that an individual reports an occupation to the census. *Vaccination mandate* is a dummy variable equal to one if a school vaccination law is active in a given state in a given year. *Compulsory schooling law* is a dummy variable equal to one if a compulsory schooling law is active in a given state in a given year. *Republican governor* is a dummy variable equal to one if a given state in a given year has a Republican governor. *Percent urban* is the percent of the population that is urban in a a given state in a given year. *Rural* is a dummy variable equal to one if an individual lives in a rural area. The census data were obtained from Ruggles et al. (2020). The gubernatorial data were obtained from Kaplan (2018). The population that was percent urban was obtained from Haines (2010).

Table 6: Vaccination Mandates Improved Teen's School Enrollment and Decreased Labor Market Participation

	Pr(enrolled)	*Pr(in labor force)*
	(1)	(2)
Baseline	0.0307	-0.0321*
	(0.0208)	(0.0168)
Post-1870 mandates only	0.0321	-0.0511***
	(0.0198)	(0.0183)
East of Mississippi River only	0.0370	-0.0246
	(0.0237)	(0.0177)
Includes CSL FEs	0.0304	-0.0319*
	(0.0207)	(0.0168)

Each coefficient is the coefficient on *VaccinationMandate* for a separate regression. Standard errors appear in parentheses clustered at the state level. Coefficients in columns (1) and (2) were estimated using *Pr(enrolled)* and *Pr(in labor force)* as outcomes, respectively. The "baseline" specification includes the 1 percent samples of census years 1850 to 1910, and is limited to native-born white males between the ages 16 and 18 who lived in the same state in which they were born. The sample limited to "Post-1870 mandates" does not include states that passed a vaccination mandate prior to 1870. The sample limited to "East of Mississippi River only" includes only states located east of the Mississippi River. The sample that "Includes CSL FEs" is the baseline specification with the addition of compulsory schooling law fixed effects. *Pr(enrollment)* is the probability a child had attended school in the past 12 months for the 1850-1910 censuses, and the past 7.5 months for the 1910 census, which includes the full school year prior to when the census was taken *Pr(in labor force)* is the probability that an individual reports an occupation to the census. The census data were obtained from Ruggles et al. (2020). The gubernatorial data were obtained from Kaplan (2018). The population that was percent urban was obtained from Haines (2010). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: Children of German Immigrants Benefited Less from Vaccination Mandates in the Long-Run

	ln(occscore)	*Pr(skilled)*	*Pr(in labor force)*
	(1)	(2)	(3)
Vaccination mandate	0.0673**	0.0755**	-0.00111
	(0.0294)	(0.0306)	(0.00571)
German child	0.0207	0.0232**	0.00433
	(0.0133)	(0.0106)	(0.00498)
*Vaccination mandate * German child*	-0.0436**	-0.0314**	0.00266
	(0.0165)	(0.0133)	(0.00526)
Dependent Variable Mean	3.13	.78	.96
N	77809	64209	73362

Standard errors appear in parentheses clustered at the state level. This sample includes the 1 percent samples of census years 1870 to 1940, and is limited to nonmigrant native-born white males between the ages 22 and 55 with parents who were first generation immigrants from central and eastern Europe. Central and eastern European countries are defined the same as by IPUMS, which includes Austria, Bulgaria, Czechloslovakia, Germany, Hungary, Poland, Romania and Yugoslavia. Each specification includes fixed effects for birth state, age, census year, birth state by census year and age by census year. In addition, each specification includes controls for exposure to compulsory schooling laws as a child and whether an individual lives in a rural area. *Vaccination mandate* represents an individual's childhood exposure to a school vaccination mandate. See Chapter 3 for a discussion of the creation of this variable. *German child* is a dummy variable for whether an individual had a parent who was a first generation immigrant from Germany. *ln(occscore)* is the natural log of the occupational score. *Pr(skilled)* is the probability of being a skilled worker. *Pr(in labor force)* is the probability that an individual reports an occupation to the census.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 8: Children of German Immigrants Benefited Less from Vaccination Mandates in the Short-Run

	(1) *Pr(enrollment)*	(2) *Pr(in labor force)*
Vaccination mandate	0.0795*	-0.0747
	(0.0426)	(0.0534)
German child	0.0230	-0.0720**
	(0.0238)	(0.0341)
*Vaccination mandate * German child*	-0.0612**	0.0867**
	(0.0262)	(0.0374)
Dependent Variable Mean	.24	.76
N	5501	5501

Standard errors appear in parentheses clustered at the state level. This sample includes the 1 percent samples of census years 1850 to 1910, and is limited to native-born white males between the ages 16 and 18 who lived in the same state in which they were born, and who had parents who were first generation immigrants from central and eastern Europe. Central and eastern European countries are defined the same as by IPUMS, which includes Austria, Bulgaria, Czechloslovakia, Germany, Hungary, Poland, Romania and Yugoslavia. Each specification includes fixed effects for state, age, census year, and age by census year. In addition, each specification includes controls for compulsory schooling laws, whether an individual lives in a rural area, whether a state has a Republican governor, and the percent of a state's population that is urban. *Vaccination mandate* is a dummy variable equal to one if a school vaccination law is active in a given state in a given year. *German child* is a dummy variable for whether an individual had a parent who was a first generation immigrant from Germany. *Pr(enrollment)* is the probability a child had attended school in the past 12 months for the 1850-1910 censuses, and the past 7.5 months for the 1910 census, which includes the full school year prior to when the census was taken *Pr(in labor force)* is the probability that an individual reports an occupation to the census. The census data were obtained from Ruggles et al. (2020). The gubernatorial data were obtained from Kaplan (2018). The population that was percent urban was obtained from Haines (2010). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 9: Summary Statistics

	Mean	Min	Max	Count
Vaccination mandate	.51	0	1	120
Diphtheria immunization (in 1929, percent)	16.12	1	50	120
Population (in 1930, 1000 persons)	304.37	40	6930	120
Health expenditure (in 1929, dollars)	343066	4100	5434220	120
Republican governor	.57	0	1	120

This table presents summary statistics for 120 cities across the United States in 1929. *Vaccination mandate* is a dummy variable equal to one if a city was located in a state with an active school vaccination mandate in 1929, and equal to 0 otherwise. This variable was collected by the author. *Diphtheria immunization* is a variable equal to the diphtheria immunization rate in a given city. *Population* is the population size of a given city in 1930 in units of 1000 persons. *Health expenditure* is the health expenditure of a given city in 1929 in units of dollars. These three variables were collected from Costa and Kahn (2003). *Republican governor* is a dummy variable equal to one if a state had a Republican governor in 1929, and equal to zero otherwise. This variable was collected from Kaplan (2018).

Table 10: Smallpox Vaccination Mandates Associated with Higher Diphtheria Vaccination Uptake

	(1) *Diphtheria immunization*	(2) *Diphtheria immunization*
Vaccination mandate	6.64***	4.86**
	(1.96)	(1.98)
Population		0.0002
		(0.001)
Health expenditure		0.000003*
		(0.000002)
Republican governor		-4.72**
		(2.08)
Dependent Variable Mean	16.12	16.12
N	120	120

This table presents the results of a cross-sectional regression with a sample composed of 120 cities in 1929. *Vaccination mandate* is a dummy variable equal to one if a city was located in a state with an active school vaccination mandate in 1929, and equal to 0 otherwise. This variable was collected by the author. *Diphtheria immunization* is a variable equal to the diphtheria immunization rate in a given city. *Population* is the population size of a given city in 1930 in units of 1000 persons. *Health expenditure* is the health expenditure of a given city in 1929 in units of dollars. These three variables were collected from Costa and Kahn (2003). *Republican governor* is a dummy variable equal to one if a state had a Republican governor in 1929, and equal to zero otherwise. This variable was collected from Kaplan (2018). Heteroskedasticity-robust standard errors appear in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Figure 1: Rhode Island's 1882 Vaccination Mandate

CHAPTER 872.

AN ACT IN ADDITION TO CHAPTER 58 OF THE GENERAL STATUTES, "GENERAL PROVISIONS RELATING TO PUBLIC SCHOOLS."

Passed April 26, 1881.

It is enacted by the General Assembly as follows:

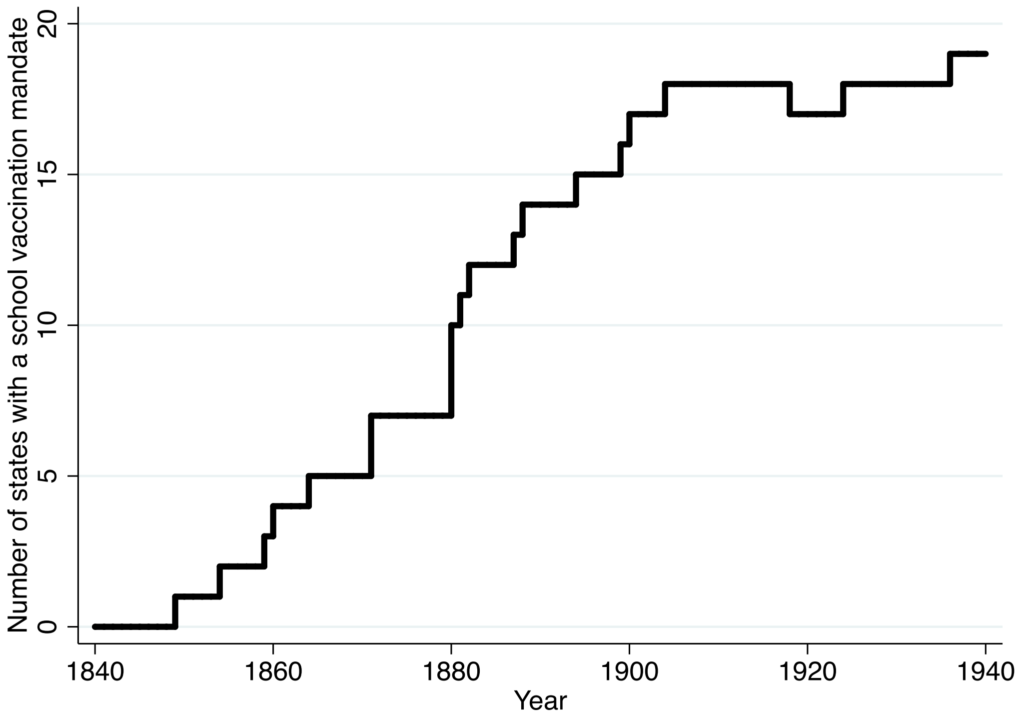
No pupil allowed to attend public school without certificate of vaccination.

SECTION 1. No person shall be permitted to attend any public school in this state as a pupil, unless such person shall furnish to the teacher of such school, a certificate of some practising physician that such person has been properly vaccinated as a protection from small pox, and every teacher in the public schools shall keep a record of the names of such pupils in their respective schools as have presented such certificate.

Record.

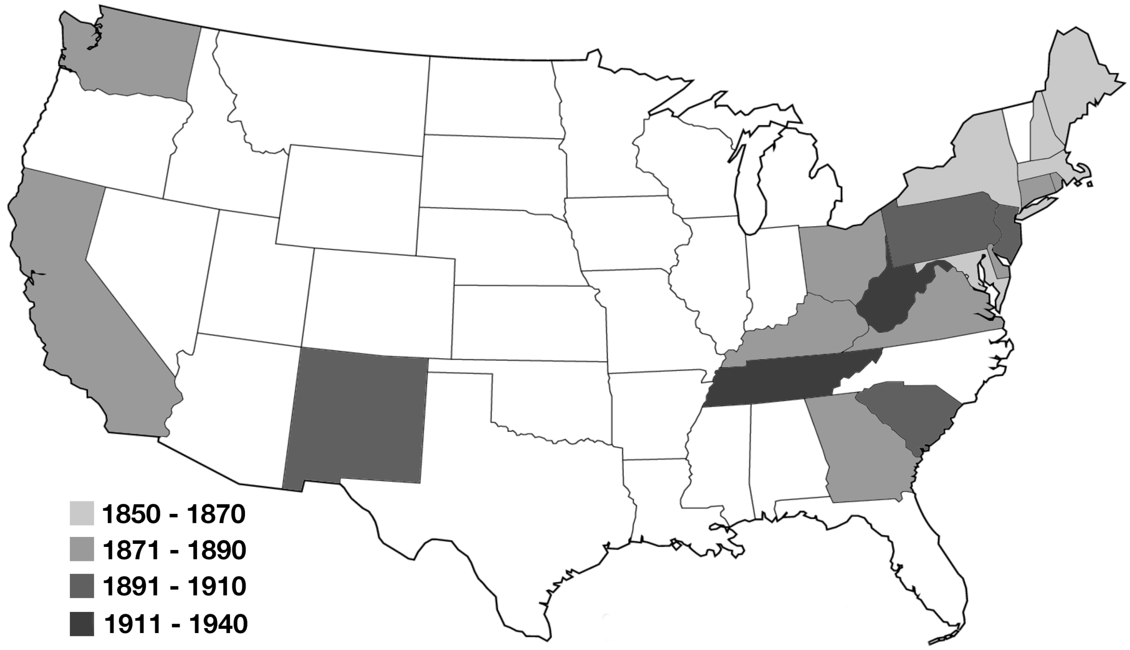
Note: Collected by the author from Heinonline's historical archive of state session laws.

Figure 2: Timing of Passage of Vaccination Mandates



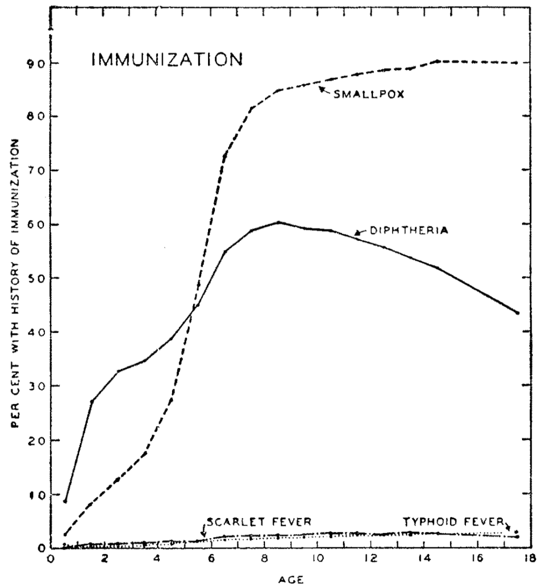
Note: This figures presents the number of states with an active school vaccination mandate in a given year for the years 1840 to 1940. The mandates were collected by the author from state session law books accessed through Heinonline.

Figure 3: Map of the Roll-out of Vaccination Mandates



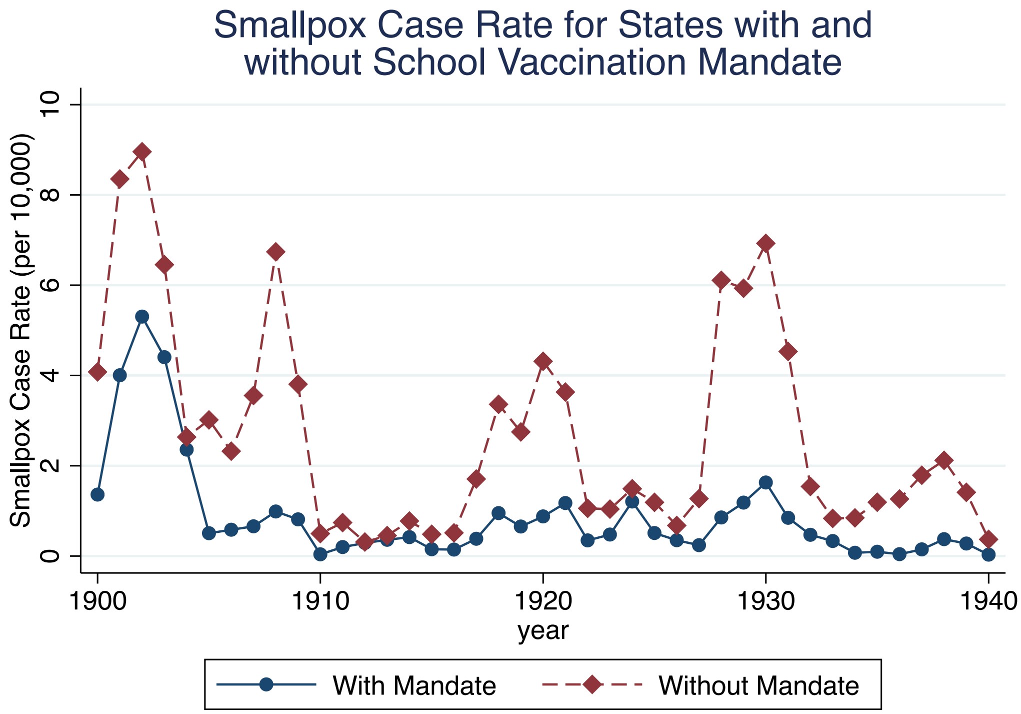
Note: The shading of each state corresponds to the year in which it passed a compulsory school vaccination law. These laws were collected by the author from state session law books accessed through Heinonline.

Figure 4: Smallpox Vaccination Rates by Age in 1935



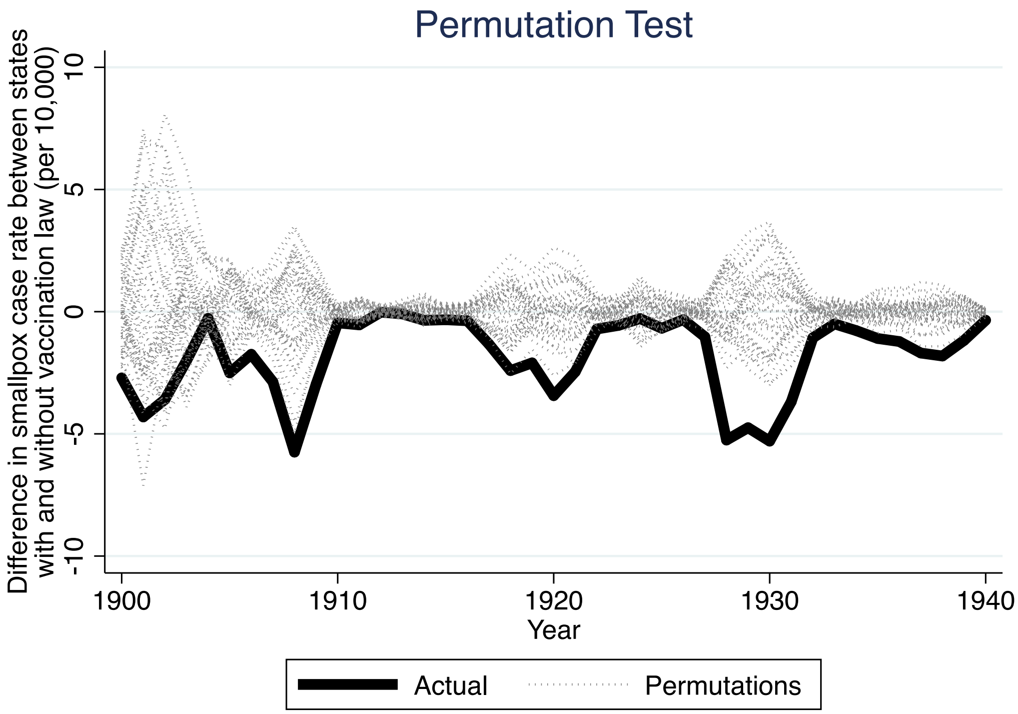
Note: This figure was obtained from Collins and Councell (1944). It shows the immunization rate by age for each of smallpox, diphtheria, scarlet fever and typhoid. Immunization data were collected from a survey of white families in 28 large cities in 1935. Especially notable is the large jump in smallpox vaccination rates at the ages 5 through 8, when children begin to attend school. This suggests that school vaccination mandates spurred smallpox vaccination.

Figure 5: Vaccination Mandates Reduced the Prevalence of Smallpox



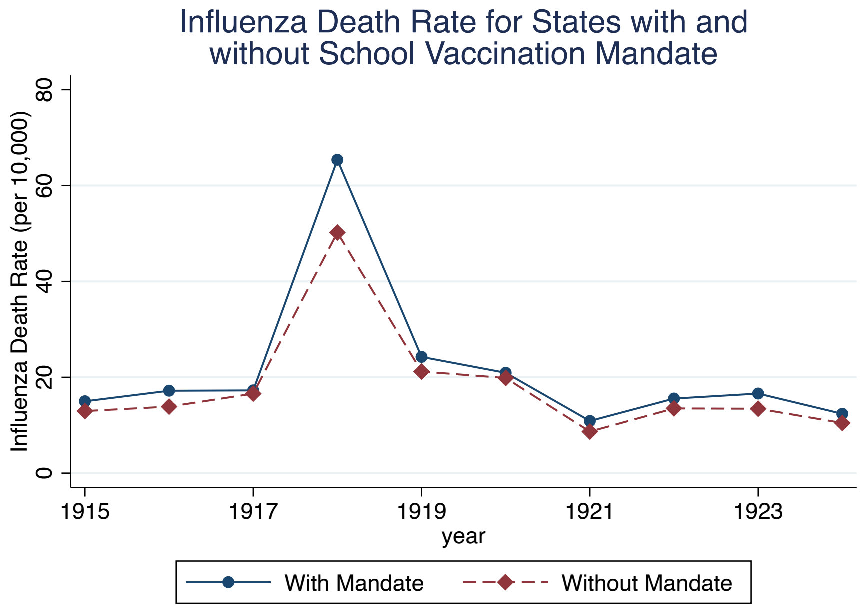
Note: This figure presents smallpox rates for states with and without school vaccination mandates for the continental United States over the years 1900-1940. It illuminates two key facts. First, states with a school vaccination mandate consistently had lower smallpox rates than states without a school vaccination mandate. Second, during epidemic periods, smallpox rates for states without a school vaccination mandate increased more than for states with a mandate. These two facts suggest that school vaccination mandates reduced smallpox rates. Data on which states had a school vaccination mandate were collected by the author from state session law books accessed through Heinonline. Smallpox data were collected by the author from the Public Health Reports and obtained from Project Tycho.

Figure 6: Permutation Test



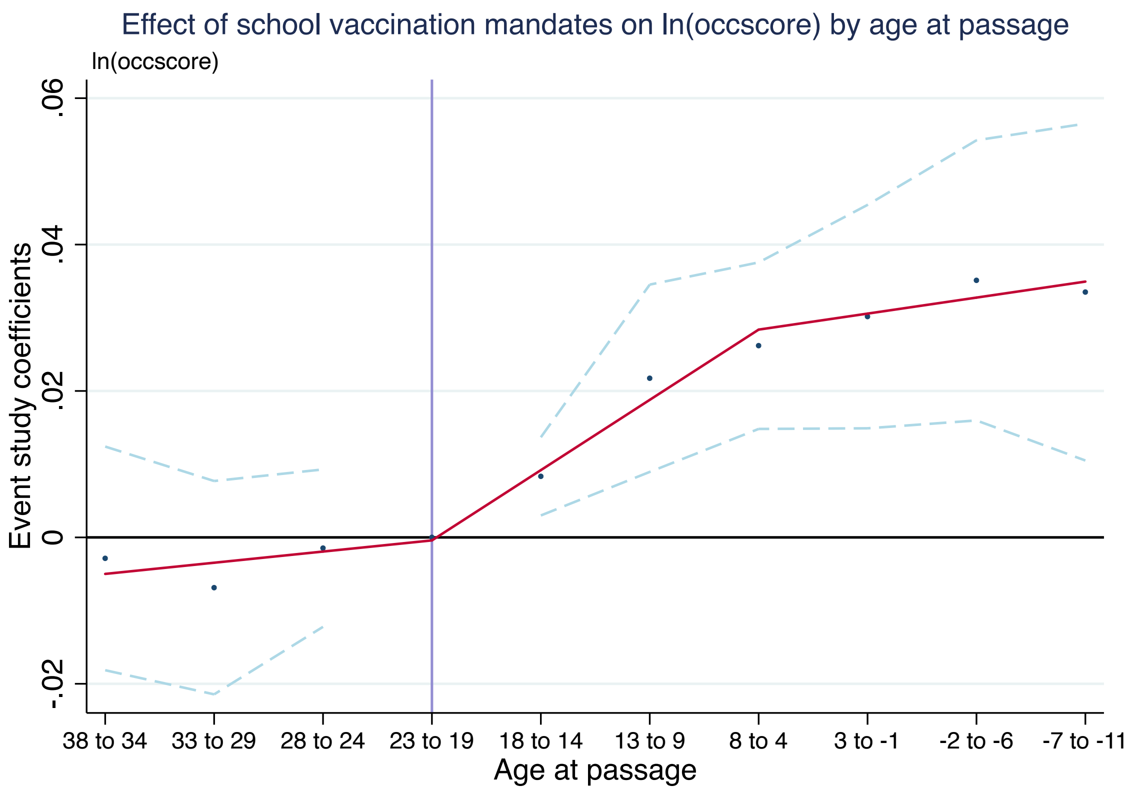
Note: This figure presents a permutation test for the difference in smallpox rates between states with and without school vaccination mandates. The bold line represents the actual difference in smallpox rates between states with and without compulsory vaccination laws. Each thin dotted line represents a generated time series of this difference. These time series were generated by randomly assigning which states did or did not have a compulsory vaccination law and then plotting the time series of the difference between the two groups of states. These permutations were randomly generated fifty times. The figure shows that for almost the entire time period none of the permutations were as negative as the actual difference between the two groups of states. The only exception appears at the start of the time period, though it is a small number of permutations that reach more negative levels. This suggests that the difference in smallpox rates between states with and without compulsory vaccination was not due to chance.

Figure 7: Placebo Test with Influenza Death Rates



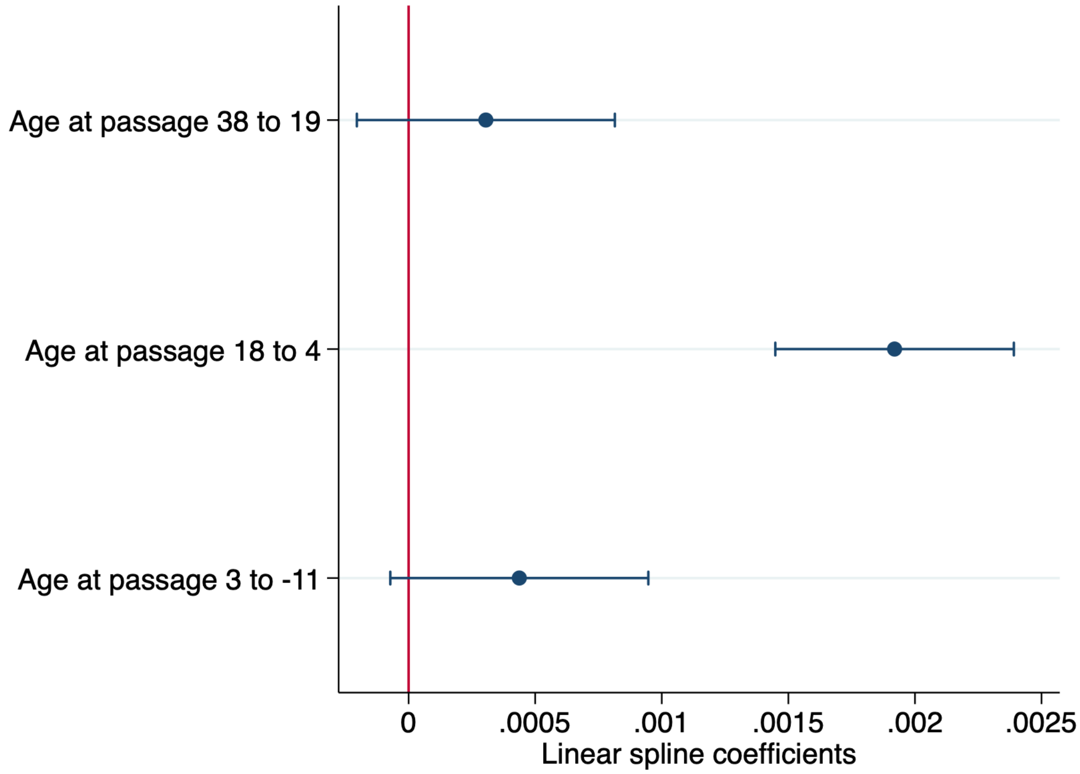
Note: This figure presents average annual influenza death rates for states with and without school vaccination mandates. In contrast to Figure 5, states with a school vaccination mandate experienced consistently higher influenza death rates. Furthermore, this difference was magnified during the 1918 Influenza Pandemic. This suggests that the differences shown in Figure 5 were not confounded by differences in general public health capabilities or the ability to respond to epidemics. Data on which states had a school vaccination mandate were collected by the author from state session law books accessed through Heinonline. Annual influenza death rates by state were collected by the author from the Department of Commerce's 1924 Mortality Statistics.

Figure 8: Positive Effect of Vaccination Mandates on Occupational Standing Only Appeared for Those of Schooling Age and Younger when Law Passed



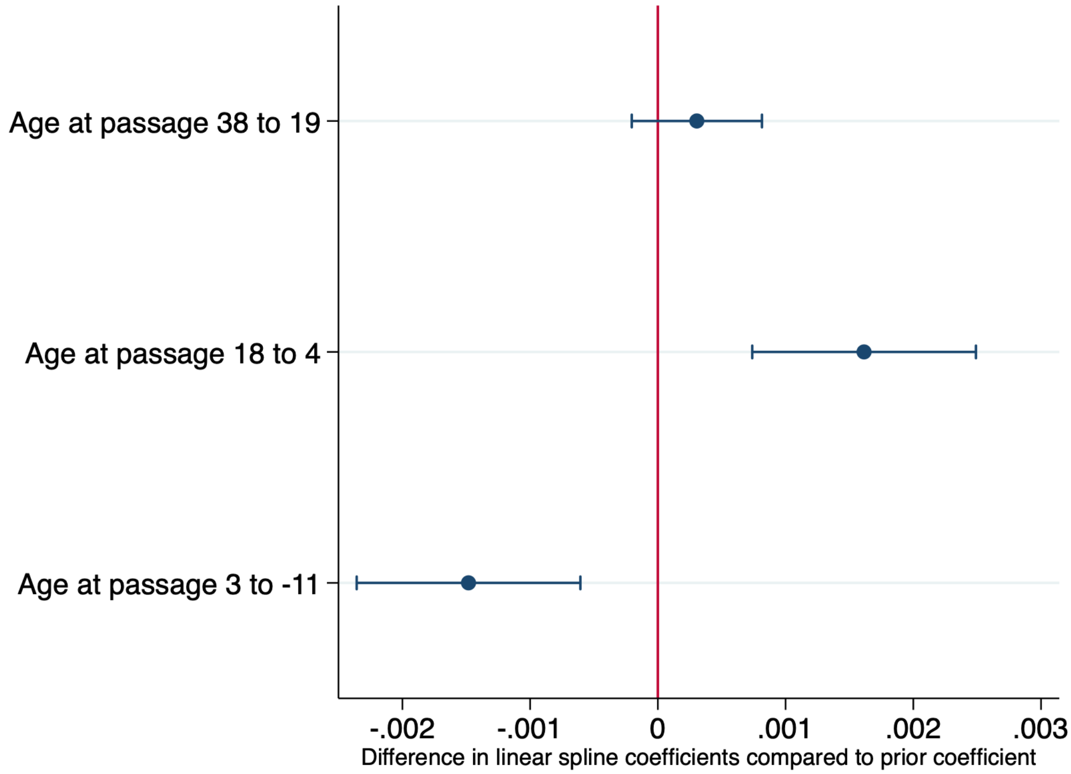
Note: This figure presents event study estimates for the effect of exposure to a school vaccination mandate on the log of adult occscores by age when a mandate was passed. Coefficients are contained within five year bins, each representing the ages of individuals when a mandate was passed. The omitted group contains individuals who were ages 23 to 19 when a mandate was passed. The dashed line represents the 95 percent confidence interval. A linear spline regression is drawn for these coefficients with knots placed at individuals who were ages 23 to 19 when a law was passed, and ages 8 to 4 when a law was passed. The first spline segment shows that those who were adults when a mandate was passed did not experience an effect significantly different from those who were ages 23 to 19. The second spline segment shows that those who were of schooling age when a law was passed experienced a positive effect that increased as age at passage decreased. Finally, the third spline segment shows that this effect leveled out for those who were too young for school or not yet born when a law was passed. The spline coefficients themselves and a test for the change in slopes of the linear spline segments are presented in Figures 9 and 10, respectively. This sample contains the 1 percent samples of census years 1870 to 1940 and is limited to native-born nonmigrant white males between the ages 22 and 55. Standard errors are clustered at the state level. *ln(occscore)* is the natural log of the occupational score.

Figure 9: Linear Spline Coefficients for Splines in Figure 8



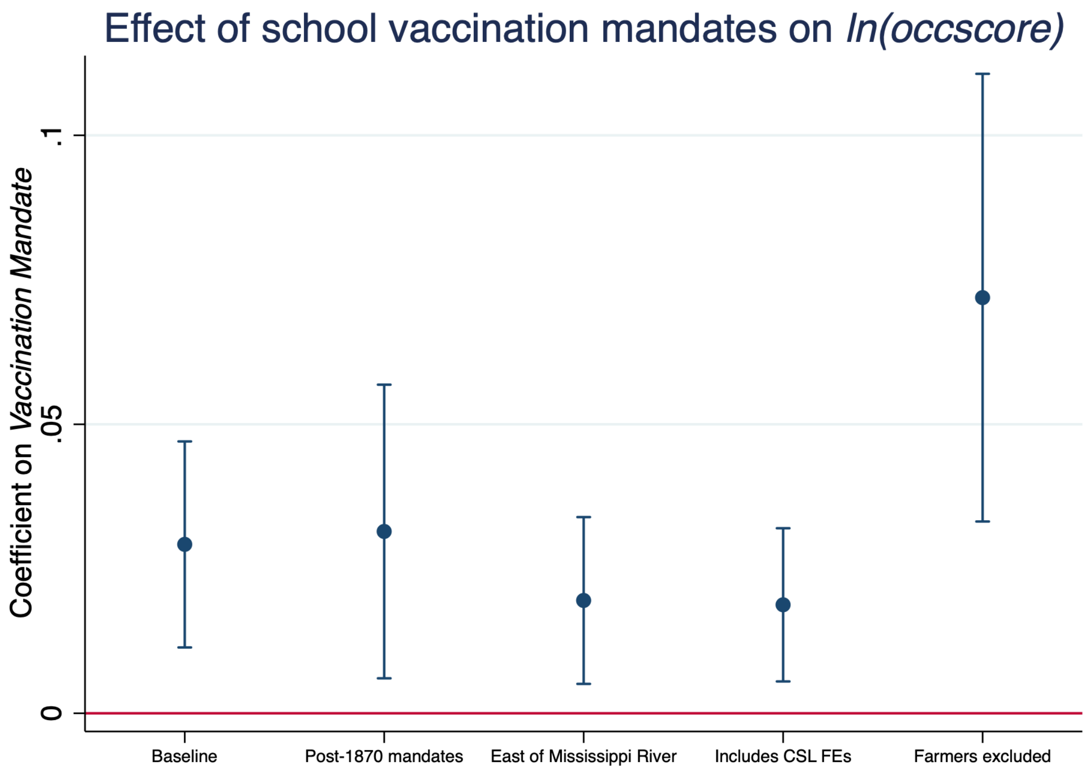
Note: This figure presents the coefficients for the linear spline segments in Figure 8. The confidence intervals represent the 95 percent confidence interval. Neither of the segments for ages 38 to 19 or 3 to -11 are significantly different from zero. Moreover, the segment for ages 18 to 4 is significantly greater than zero. This confirms the interpretation that the coefficients in Figure 8 show that the positive effect of vaccination mandates on *ln(occscore* increased only for those who were of schooling age when a law was passed, and that this effect leveled out but continued for those who were too young for school or not yet born when a mandate was passed. This sample contains the 1 percent samples of census years 1870 to 1940. In addition, this sample is limited to native-born nonmigrant white males between the ages 22 and 55. *ln(occscore)* is the natural log of the occupational score.

Figure 10: Change in Linear Spline Coefficients for Splines in Figure 8



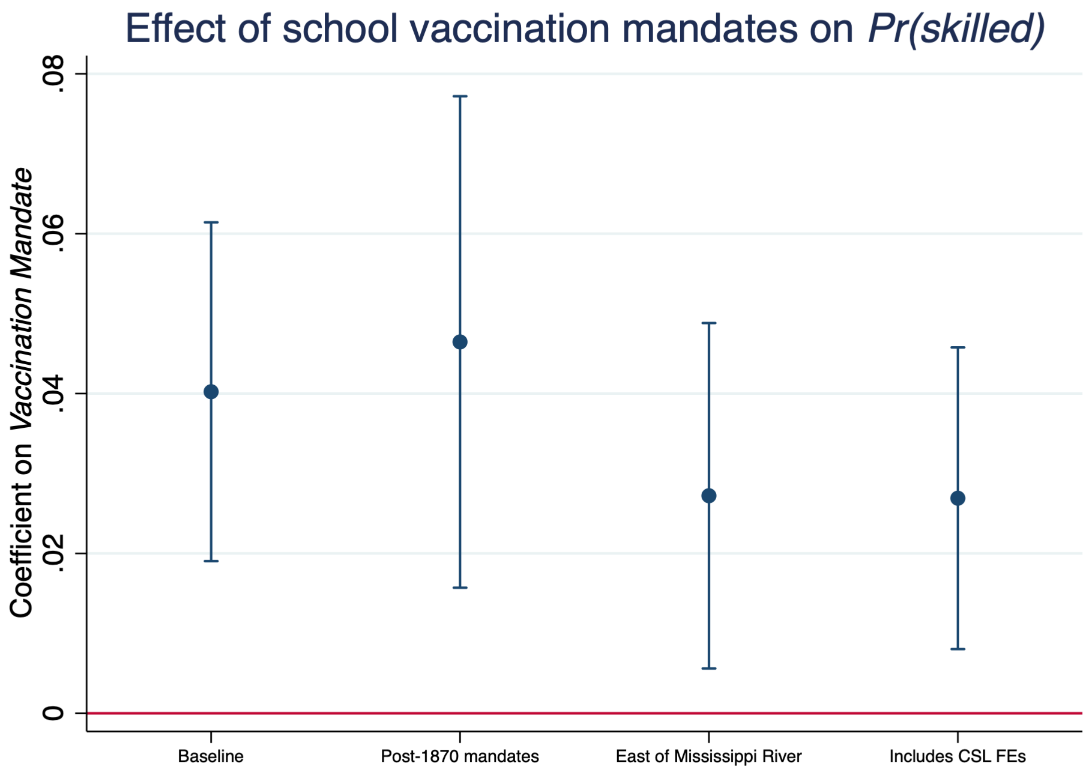
Note: This figure tests whether changes in the slopes of the linear spline segments in Figure 8 were statistically significant. The confidence intervals represent the 95 percent confidence interval. The coefficient for ages 38 to 19 is the same as in Figure 9 because there is no prior slope to test against. The coefficient for ages 18 to 4 is significantly positive, showing that there was a significant increase in the slope of the linear spline compared to the segment for ages 38 to 19. The coefficient for ages 3 to -11 shows that there was then a statistically significant decrease in slope, illustrating that there was a leveling out of the effect for those too young to go to school or not yet born when a mandate was passed. This sample contains the 1 percent samples of census years 1870 to 1940. In addition, this sample is limited to native-born nonmigrant white males between the ages 22 and 55.

Figure 11: Positive Effect of Vaccination Mandates on Occupational Standing Robust to Alternative Samples and Specifications



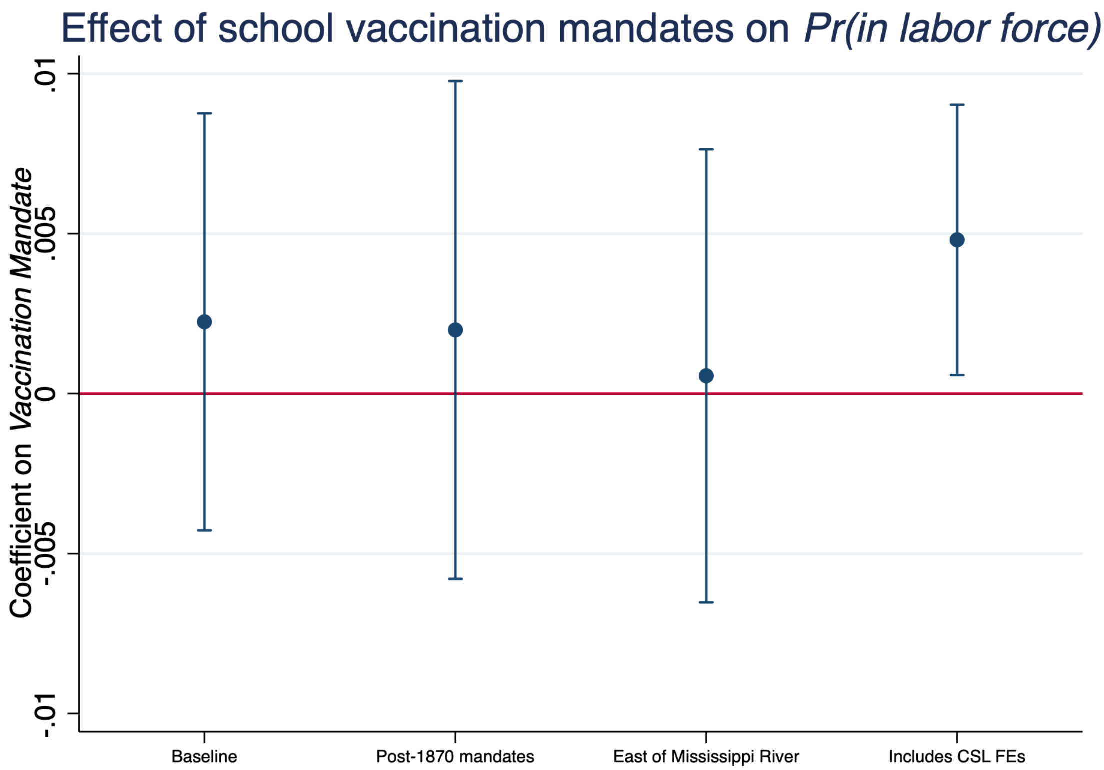
Note: Each coefficient is the difference-in-differences coefficient on *Vaccination mandate* in a separate regression using *ln(occscore)* as the outcome. The ”baseline” specification is the one presented in Table 3. The sample limited to ”Post-1870 mandates” does not include states that passed a vaccination mandate prior to 1870. TThe sample limited to ”East of Mississippi River only” includes only states located east of the Mississippi River. The sample that ”Includes CSL FEs” is the baseline specification with the addition of compulsory schooling law fixed effects. See Chapter 3 for the construction of these fixed effects. Finally, The sample with ”farmers excluded” does not include those with their occupation listed as farmer. The confidence intervals represent the 95 percent confidence interval. Standard errors are clustered at the state-level. This sample includes the 1 percent samples of census years 1870 to 1940, and is limited to native-born white males between the ages 22 and 55 who were born in the same state in which they were located in the census. Each specification includes fixed effects for birth state, age, census year, birth state by census year and age by census year. In addition, each specification includes controls for exposure to compulsory schooling laws as a child and whether an individual lives in a rural area. *ln(occscore)* is the natural log of the occupational score.

Figure 12: Positive Effect of Vaccination Mandates on Probability of Being Skilled Worker Robust to Alternative Samples and Specifications



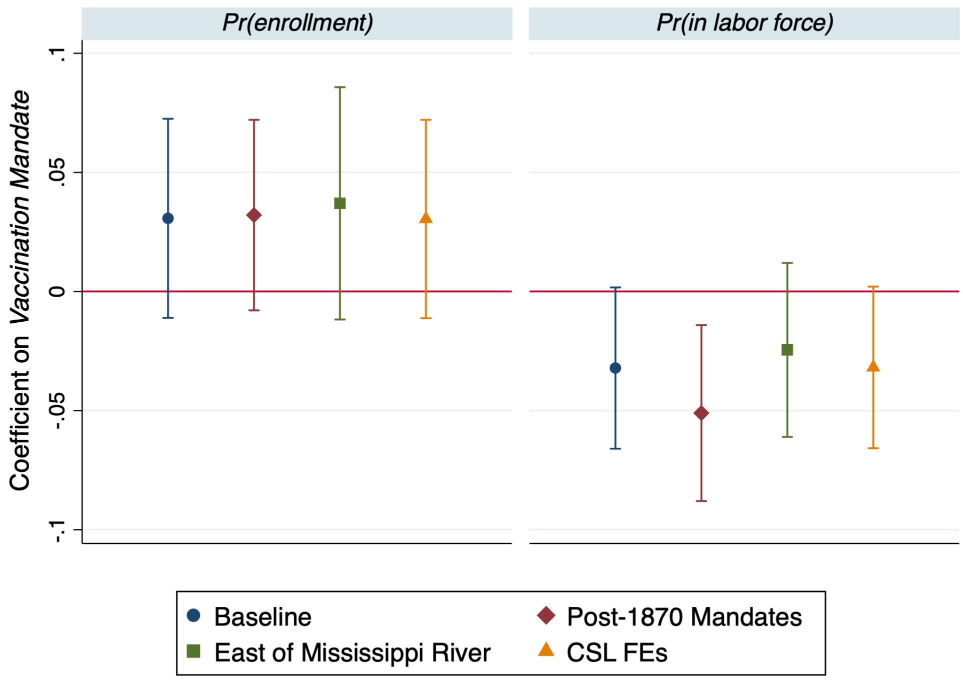
Note: Each coefficient is the difference-in-differences coefficient on *Vaccination mandate* in a separate regression using *Pr(skilled)* as the outcome. The ”baseline” specification is the one presented in Table 3. The sample limited to ”Post-1870 mandates” does not include states that passed a vaccination mandate prior to 1870. The sample limited to ”East of Mississippi River only” includes only states located east of the Mississippi River. The sample that ”Includes CSL FEs” is the baseline specification with the addition of compulsory schooling law fixed effects. See Chapter 3 for the construction of these fixed effects. The confidence intervals represent the 95 percent confidence interval. Standard errors are clustered at the state-level. This sample includes the 1 percent samples of census years 1870 to 1940, and is limited to native-born white males between the ages 22 and 55 who were born in the same state in which they were located in the census. Each specification includes fixed effects for birth state, age, census year, birth state by census year and age by census year. In addition, each specification includes controls for exposure to compulsory schooling laws as a child and whether an individual lives in a rural area. *Pr(skilled)* is the probability of being a skilled worker.

Figure 13: Effect of Vaccination Mandates on Probability of Being in Labor Force Robust to Alternative Samples and Specifications



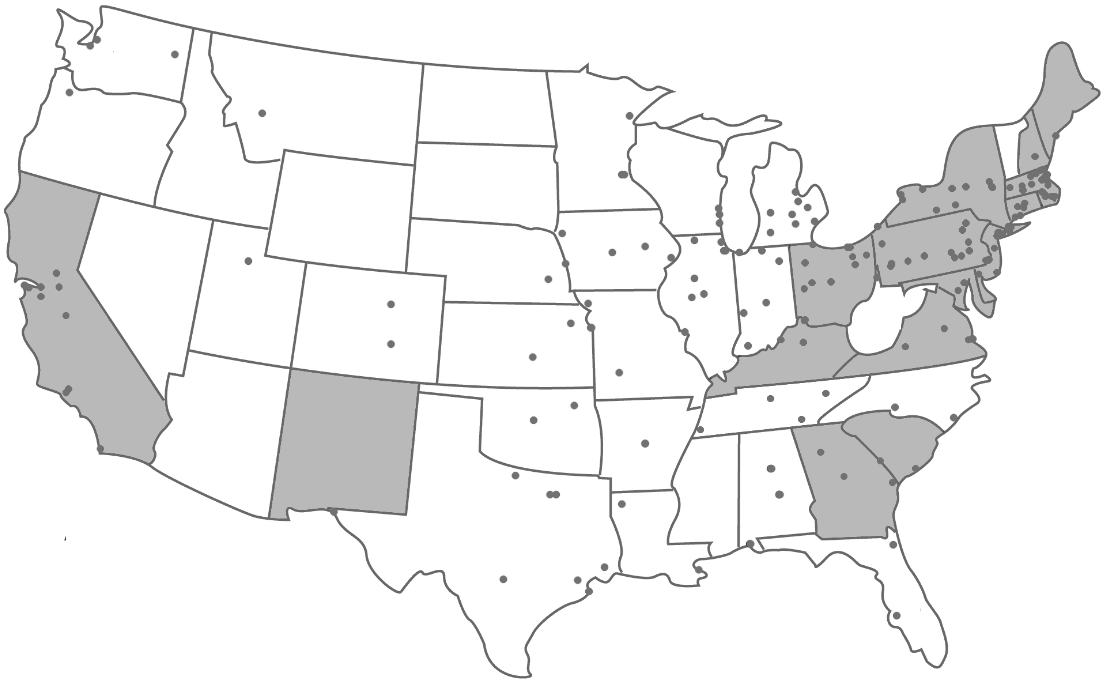
Note: Each coefficient is the difference-in-differences coefficient on *Vaccination mandate* in a separate regression using *Pr(in labor force)* as the outcome. The ”baseline” specification is the one presented in Table 3. The sample limited to ”Post-1870 mandates” does not include states that passed a vaccination mandate prior to 1870. The sample limited to ”East of Mississippi River only” includes only states located east of the Mississippi River. The sample that ”Includes CSL FEs” is the baseline specification with the addition of compulsory schooling law fixed effects. See Chapter 3 for the construction of these fixed effects. The confidence intervals represent the 95 percent confidence interval. Standard errors are clustered at the state-level. This sample includes the 1 percent samples of census years 1870 to 1940, and is limited to native-born white males between the ages 22 and 55 who were born in the same state in which they were located in the census. Each specification includes fixed effects for birth state, age, census year, birth state by census year and age by census year. In addition, each specification includes controls for exposure to compulsory schooling laws as a child and whether an individual lives in a rural area. *Pr(in labor force)* is the probability that an individual reports an occupation to the census.

Figure 14: Vaccination mandates Increased School Enrollment and Decreased Probability of Being in Labor Force



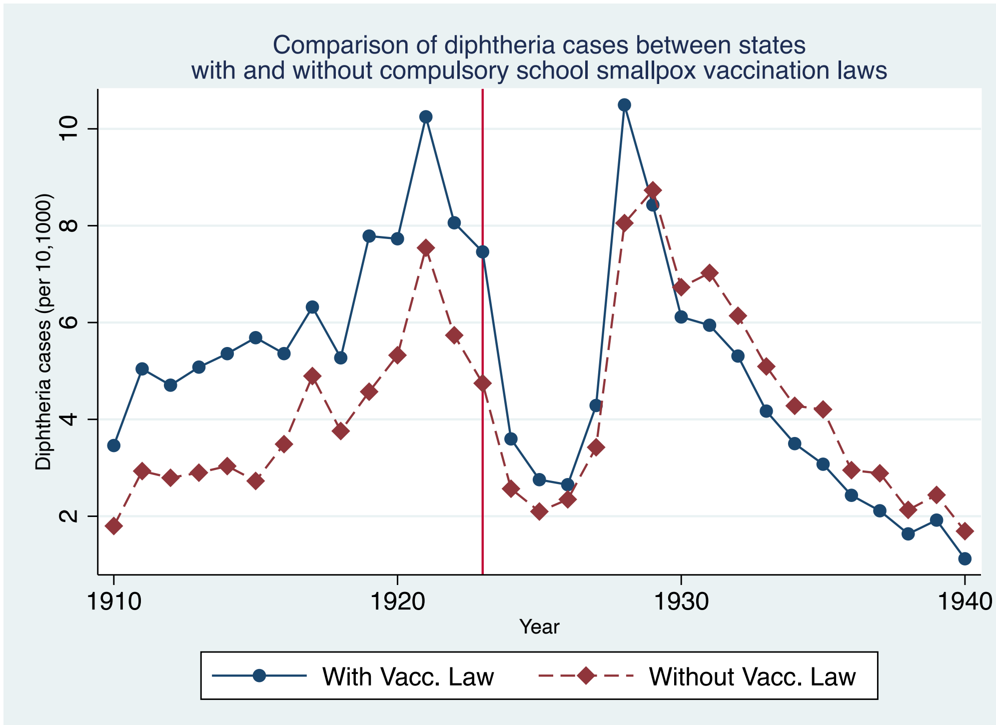
Note: Each coefficient is the difference-in-differences coefficient on *Vaccination mandate* in a separate regression using either *Pr(enrollment)* or *Pr(in labor force)* as the outcome. The plotted confidence intervals are for the 95 percent confident interval. The ”baseline” specification employs a sample of male white children of ages 16 to 18 who lived in the same state in which they were born. Compared to the baseline specification, the sample limited to ”Post-1870 mandates” additionally does not include states that passed a vaccination mandate prior to 1870. The sample limited to ”Non-migrants only” instead only includes individuals who live in the same state in which they were born. The sample limited to ”East of Mississippi River only” instead includes only states located east of the Mississippi River. Finally, compared to the baseline specification, the sample that ”Includes CSL FEs” is instead the baseline specification with the addition of compulsory schooling law fixed effects. See Chapter 3 for the construction of these fixed effects. The confidence intervals represent the 95 percent confidence intervals. Standard errors are clustered at the state-level. This sample includes the 1 percent samples of census years 1850 to 1910. Each specification includes fixed effects for birth state, age, census year, age by census year. In addition, each specification includes controls for exposure to compulsory schooling laws as a child, whether an individual lived in a rural area, whether the governor belonged to the Republican party, and the percent of the state population that was urban. *Pr(enrollment)* is the probability that an individual had attended school within the prior 12 months for the 1850-1900 censuses, and had attended school within the prior 7.5 months for the 1910 census. *Pr(in labor force)* is the probability that an individual reports an occupation to the census.

Figure 15: Map of States with Vaccination Mandates and Cities with Diphtheria Immunization Data



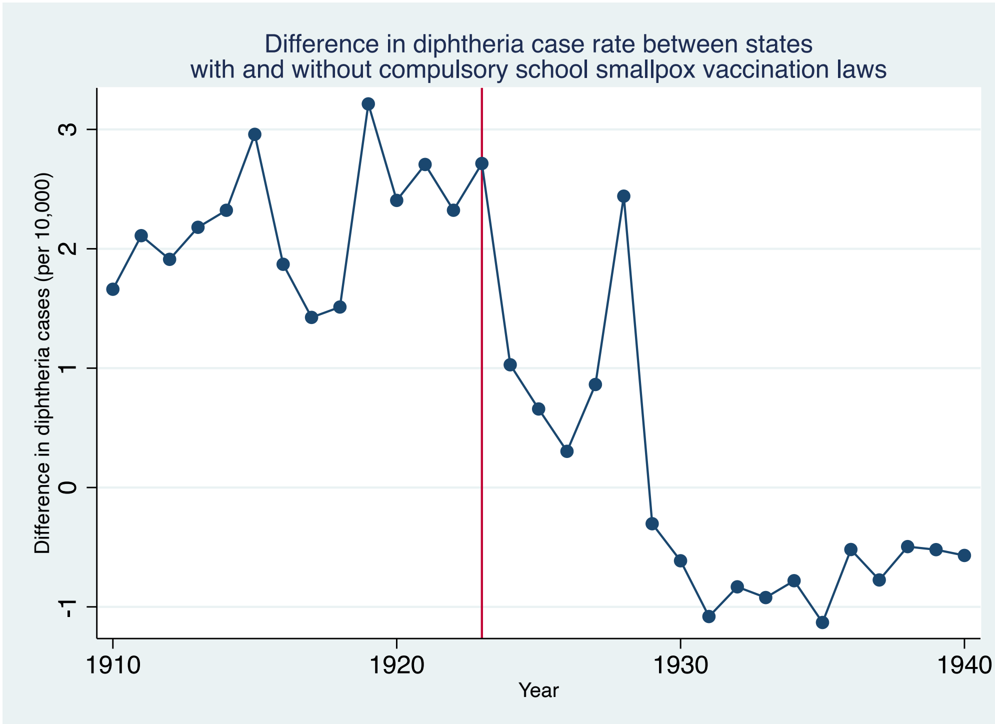
Note: Each shaded state has an active school vaccination mandate in 1929. These laws were collected by the author. Each dot locates a city with available diphtheria immunization data. These data were obtained from Costa and Kahn (2003).

Figure 16: Comparison of Diphtheria Cases Between States with and without Vaccination Mandates



Note: This figure presents diphtheria case rates for states with and without school vaccination mandates for smallpox over the years 1910 to 1940. The vertical line at 1923 represents the year the diphtheria vaccine was invented. The figure shows that after the invention and subsequent roll-out of the diphtheria vaccine in the late 1920s, diphtheria rates dropped more in states with school vaccination mandates. School vaccination mandate data were collected by the author. Diphtheria data were obtained from *Project Tycho*.

Figure 17: Difference in Diphtheria Case Rates Between States with and without Vaccination Mandates



Note: This figure presents the difference in diphtheria case rates between states with and without school vaccination mandates for smallpox over the years 1910 to 1940. The vertical line at 1923 represents the year the diphtheria vaccine was invented. The figure shows that after the invention and subsequent roll-out of the diphtheria vaccine in the late 1920s, diphtheria rates dropped more in states with school vaccination mandates. School vaccination mandate data were collected by the author. Diphtheria data were obtained from *Project Tycho*.

CHAPTER 13

Appendix

13.1 Additional Evidence Vaccination Mandates Reduced Smallpox

To examine whether compulsory school vaccination laws reduced the prevalence of smallpox, I employ a difference-in-differences design using the roll-out of mandates listed in Table 1 over the sample years 1900-1940. The specification is as follows:

$$SmallpoxCaseRate_{sy} = \alpha VaccinationMandate_{sy} + X_{sy}\beta + \gamma_s + \delta_y + \varepsilon_{sy} \tag{13.1}$$

Where $SmallpoxCaseRate_{sy}$ is the number of smallpox cases per 10,000 people in state s and year y; $VaccinationMandate_{sy}$ is a dummy variable equal to one if a compulsory school vaccination law is in effect in state s in year y, and equal to zero otherwise; X_{sy} is a vector of controls including whether a state has an active compulsory schooling law, whether a state has a Republican governor, and urban population; γ_s are state fixed effects; δ_y are year fixed effects; and ε_{sy} is an idiosyncratic error term. If compulsory school vaccination laws did decrease smallpox case rates, then one would expect α to be significantly negative.

In addition to examining the effect of vaccination mandates on smallpox rates, I also examine the effect of mandates on the probability of a state-level smallpox epidemic occurring. I define a state-level epidemic as occurring when smallpox rates in a given year surpass twice the mean smallpox rate for that state over the entire time period.

Table A1 presents summary statistics. The mean smallpox case rate over the time period is approximately 2.42 cases per 10,000 people with the maximum rate spiking above 50 cases per 10,000 people. State-level epidemics occur in approximately 15 percent of the years.

Results presented in Table A2 show that compulsory school vaccination laws significantly lowered the smallpox rate. The coefficient on *VaccinationMandate* in the first column implies that on average vaccination mandates decreased the smallpox rate by 1.712 cases per 10,000 persons, approximately seventy percent of the mean smallpox rate, a considerable effect. After controlling for compulsory schooling laws, Republican governors and percent of the population that is urban, the coefficient on *VaccinationMandate* in column 3 does not substantially change. The coefficients on *VaccinationMandate* in columns 4 through 6 also suggest that vaccination mandates significantly reduced the probability of a state-level epidemic occurring. The coefficient on *VaccinationMandate* in column 6 implies that vaccination mandates almost entirely eliminated the probability of a state-level epidemic occurring.

To examine the dynamics of the effect of vaccination mandates on smallpox case rates I estimate a balanced event study with the following specification:

$$SmallpoxCaseRate_{sy} = \sum_{k=-4}^{4} \phi_k \alpha_{sy}^{k} + X_{sy}\beta + \gamma_s + \delta_y + \varepsilon_{sy} \tag{13.2}$$

Where the variables are the same as in the difference-in-differences specification in Equation 3.1 with the exception of α_{sy}^{k} which is an indicator for the passage of a compulsory school vaccination law four years prior and four years after the passage of a mandate. I exclude the indicator for the year prior to the passage of a mandate.

The event study in Figure A1 shows that there is a a significant decrease in smallpox case rates after the passage of a mandate. Within three years after the passage of a mandate the effect of mandates becomes significantly negative. In the pre-period, none of the estimated coefficients are significantly different than zero. However, there does seem to be a general increase in smallpox rates prior to the passage of a law, implying the possibility that difference-in-difference results may be driven by the natural course of an epidemic rather than the passage of a law itself. I address this challenge to my identification strategy in Chapter 7 where I show that epidemics possibly concurrent with the passage of vaccination mandates did not cause the long-run increase in adult incomes that I attribute to mandates.

Finally, in Figure A2 I also examine time series for smallpox case rates for two states that passed laws after 1900, South Carolina and Tennessee, and two of their neighboring states, North Carolina and Virginia. North Carolina and Virginia offer valuable comparison groups because Virginia had an active school vaccination law during the entire period while North Carolina never had an active school vaccination mandate. Furthermore, comparing four neighboring states is a useful exercise because it controls for similar geographic characteristics.

The figure supports the interpretation of my difference-in-differences results that passage of a mandate reduced smallpox rates. In the time period before South Carolina passed a mandate in 1905, the three states without an active mandate all experienced large spikes in smallpox. In contrast, the one state with a school vaccination mandate, Virginia, experienced a much lower increase in smallpox rates. After South Carolina passed its mandate in 1905, it joined Virginia with lower smallpox rates than Tennessee and North Carolina. For instance, it did not experience the second wave of smallpox from 1906 to 1909 that North Carolina did. Over the following years before Tennessee passed its mandate, South Carolina and Virginia enjoyed lower smallpox rates than the other two mandate-less states. Once Tennessee passed its mandate in 1925, it joined these two states as having less smallpox than the only state now without a mandate, North Carolina. For instance, during the region's last smallpox outbreak in 1928, North Carolina experienced a larger spike in smallpox case rates than the other three states.

Table A1: Summary Statistics

	Mean	Min	Max	Count
Smallpox case rate (per 10,000 persons)	2.42	0	53.42	1756
Pr(State epidemic)	.14	0	1	1756
Vaccination mandate	.37	0	1	1756
Compulsory schooling law	.85	0	1	1756
Republican governor	.42	0	1	1743
Percent urban	.42	.07	.92	1756

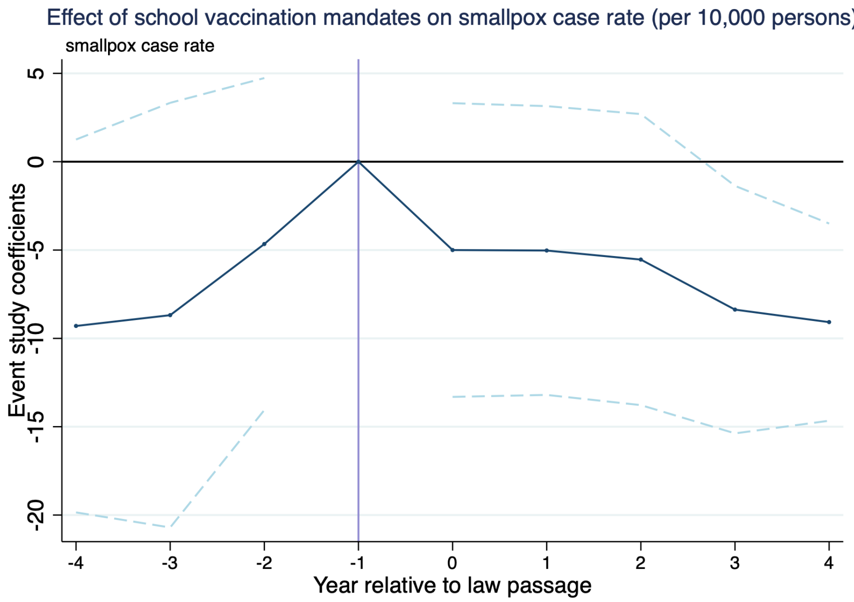
This sample includes the continental United States for the years 1900-1940. *Smallpox case rate* are state by year smallpox case counts per 10,000 persons that were collected by the author from the Public Health Reports and obtained from Project Tycho. *State epidemic* is a dummy variable equal to one when smallpox rates in a given year for a given state surpass the twice the mean smallpox rate for that state for the years 1900-1940. *Vaccination mandate* is a dummy variable equal to one if a given state in a given year has an active compulsory school vaccination law. These laws are collected by the author from historical session laws books. *Compulsory schooling law* is a dummy variable equal to one if a given state in a given year has an active compulsory schooling law. Compulsory schooling laws are obtained from Clay et al. (2012). If a state in a given year does not have smallpox data, I treat it as missing. *Republican governor* is a dummy variable equal to one if a given state in a given year has a Republican governor. These data were collected from Kaplan (2020). *Percent urban* is the percent of the total population that lives in an urban area. These data were collected from Haines (2010). Since these data were compiled from decennial censuses, I linearly interpolate the values for the intervening years.

Table A2: Vaccination Mandates Decreased Prevalence of Smallpox

	Smallpox case rate			*Pr(State epidemic)*		
	(1)	(2)	(3)	(4)	(5)	(6)
Vaccination mandate	-1.712**	-1.765**	-1.890**	-0.123***	-0.117***	-0.136***
	(0.717)	(0.715)	(0.736)	(1.081)	(0.0427)	(0.0457)
Compulsory schooling law		0.221	0.246		-0.0225	-0.0315
		(0.779)	(0.828)		(0.0639)	(0.0677)
Republican governor			-0.0264			0.0130
			(0.367)			(0.0229)
Percent urban			0.288			0.403
			(7.979)			(0.577)
Dependent Variable Mean	2.42	2.42	2.42	.14	.14	.14
N	1756	1756	1743	1756	1756	1743

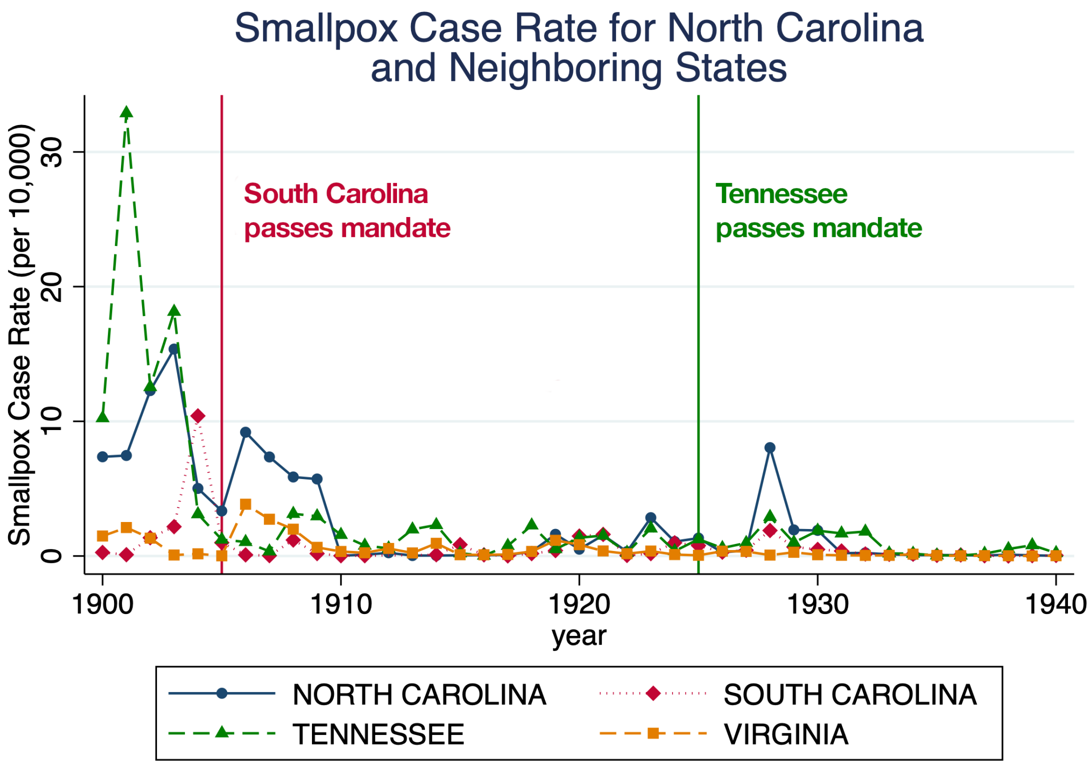
Standard errors clustered at the state level appear in parentheses. This sample includes the continental United States for the years 1900-1940. *Smallpox case rate* are state by year smallpox case counts per 10,000 persons that were collected by the author from the Public Health Reports and obtained from Project Tycho. *State epidemic* is a dummy variable equal to one when smallpox rates in a given year for a given state surpass the twice the mean smallpox rate for that state for the years 1900-1940. *Vaccination mandate* is a dummy variable equal to one if a given state in a given year has an active compulsory school vaccination law. These laws are collected by the author from historical session laws books. *Compulsory schooling law* is a dummy variable equal to one if a given state in a given year has an active compulsory schooling law. Compulsory schooling laws are obtained from Clay et al. (2012). If a state in a given year does not have smallpox data, I treat it as missing. *Republican governor* is a dummy variable equal to one if a given state in a given year has a Republican governor. These data were collected from Kaplan (2020). *Percent urban* is the percent of the total population that lives in an urban area. These data were collected from Haines (2010). Since these data were compiled from decennial censuses, I linearly interpolate the values for the intervening years. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Figure A1: Smallpox Case Rates Decreased After Passage of School Vaccination Mandates



Note: This is a balanced event study for the effect of school vaccination mandates on smallpox case rates. The identifying variation originates from the passage of mandates in only two states, South Carolina and Tennessee. The sample includes the continental United States for the years 1900-1940. Standard errors are clustered at the state level. *Smallpox case rate* are state by year smallpox case counts per 10,000 persons that were collected by the author from the Public Health Reports and obtained from Project Tycho. Data for vaccination mandates were collected by the author from historical session laws books. Controls include those for compulsory schooling laws, whether there is a Republican governor, and percent of the population that is urban. Compulsory schooling laws were obtained from Clay et al. (2012). Gubernatorial data were collected from Kaplan (2020). Urban population data were collected from Haines (2010). Since these data were compiled from decennial censuses, I linearly interpolate the values for the intervening years.

Figure A2: Smallpox Case Rates for North Carolina and Neighboring States



Note: This figure presents time series of smallpox case rates for North Carolina and three neighboring states, South Carolina, Virginia and Tennessee, from 1900-1940. During this time period North Carolina never had an active school vaccination mandate, Virginia always had an active school vaccination mandate, South Carolina had an active mandate after 1905, and Tennessee had an active mandate after 1925. This figure shows that Virginia, which had an active mandate during the entire time period, consistently had the lowest rate of smallpox. After South Carolina passed a school vaccination mandate in 1905, it also had consistently low smallpox rates compared to the two states without an active mandate, North Carolina and Tennessee. For instance, North Carolina experienced a second wave of smallpox from 1906 to 1909, which South Carolina did not experience after its mandate went into effect. Before Tennessee passed its mandate, it consistently experienced high smallpox rates relative to the two states without a mandate, Virginia and South Carolina. But after it passed its mandate in 1925, it did not experience the smallpox epidemic North Carolina did in 1928. Taken together this evidence suggests that the passage of a vaccination mandate reduced smallpox rates. Data on which states had a school vaccination mandate were collected by the author from state session law books accessed through Heinonline. Smallpox data were collected by the author from the Public Health Reports and obtained from Project Tycho.

13.2 Evidence Mandates not Significantly Associated with Potential Confounders

In this section, I show that the passage of vaccination mandates was not significantly associated with the following three potential confounders. First, the passage of vaccination mandates may have been correlated with the passage of compulsory schooling laws if states that were willing to improve childhood health through compelled vaccination were also willing to improve education through compelled schooling. Second, the political affiliation of governors may have been a confounder if one political party was more willing than another to use state powers to improve both health and schooling. Third, increased urbanization may have induced increased investment in education. At the same time, more crowded cities may have generated a more dangerous disease environment, raising the need for a vaccination mandate. In all three cases if these variables were associated with the passage of vaccination mandates then they would threaten to bias my estimates of the effect of mandates on adult labor market outcomes since education is an important determinant of income. Table A.3 presents summary statistics for these variables over the sample years 1850-1940.

I show that these variable were not significantly associated with vaccination mandates by estimating the following specification within a difference-in-differences framework:

$$VaccinationMandate_{sy} = X_{sy}\beta + \gamma_s + \delta_y + \varepsilon_{sy} \tag{13.3}$$

Where $VaccinationMandate_{sy}$ is a dummy variable equal to one if a mandate is active in state s in year y; and, X_{sy} is a vector of potential confounders that includes $CompulsorySchoolingLaw_{sy}$, which is a dummy variable equal to one if a compulsory schooling law is active in state s and year y; $RepublicanGovernor_{sy}$, which is a dummy variable equal to one if state s has a Republican governor in year y; and $PercentUrban$, which is the percentage of the population living in urban areas. Additionally, γ_s are state fixed effects, δ_y are year fixed effects, and ε_{sy} is an idiosyncratic error term.

The results in Table A.4 show that none of these three variables are significantly associated with a vaccination mandate. Since compulsory schooling laws are the most worrisome potential confounder, in column 1 I first estimate their relationship with mandates without controls. As expected I find there is a positive relationship between the two, however it is not significant. Including the covariates representing a governor's political party and the percent of the population that is urban in column 2 reduces the magnitude and significance of the coefficient for compulsory schooling laws even further. Moreover, the coefficients for these two additional covariates are both insignificant as well. Taken together this evidence suggests that compulsory schooling laws, governors' political parties and urbanization are not threats to my identification strategy for estimating the effect of vaccination mandates.

Table A3: Summary Statistics

	Mean	Min	Max	Count
Vaccination mandate	.29	0	1	3763
Compulsory schooling law	.57	0	1	3763
Republican governor	.39	0	1	3763
Percent urban	.33	0	.92	3763

This sample includes the continental United States for the years 1850-1940. *Vaccination mandate* is a dummy variable equal to one if a given state in a given year has an active compulsory school vaccination law. These laws are collected by the author from historical session laws books. *Compulsory schooling law* is a dummy variable equal to one if a given state in a given year has an active compulsory schooling law. Compulsory schooling laws are obtained from Clay et al. (2012) and Rauscher (2014). *Republican governor* is a dummy variable equal to one if a given state in a given year has a Republican governor. These data were collected from Kaplan (2020). *Percent urban* is the percent of the total population that lives in an urban area. These data were collected from Haines (2010). Since these data were compiled from decennial censuses, I linearly interpolate the values for the intervening years.

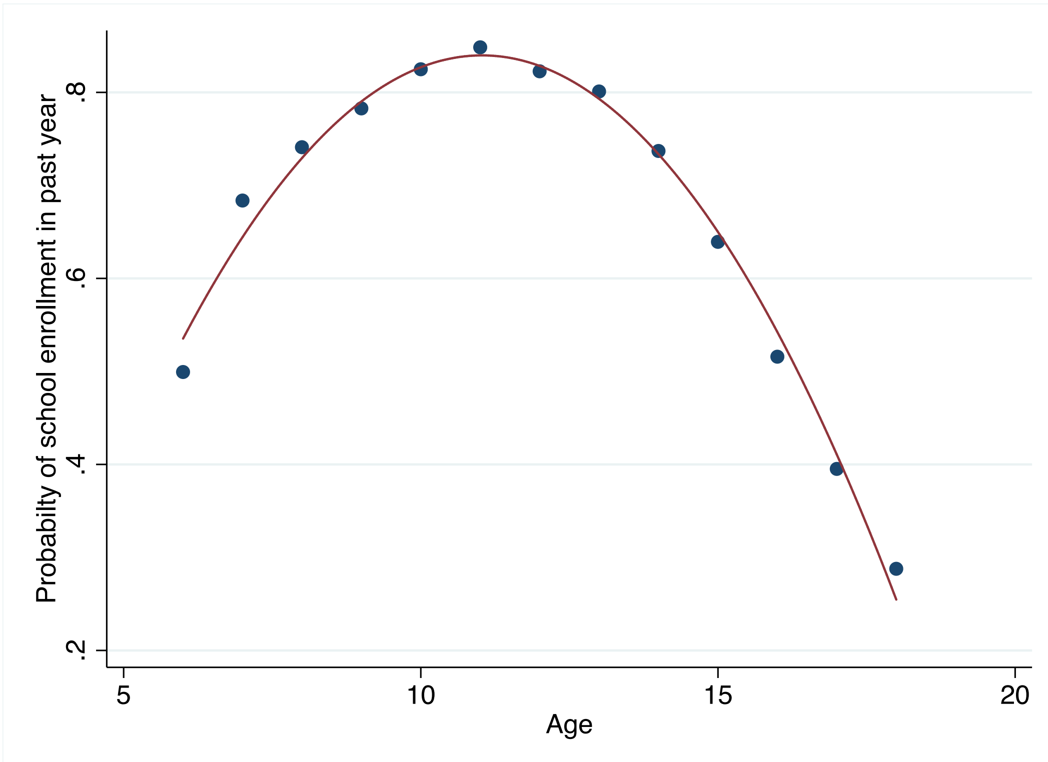
Table A4: Vaccination Mandates not Significantly Associated with Potential Confounders

	Vaccination mandate	
	(1)	(2)
Compulsory schooling law	0.0895	0.0686
	(0.0567)	(0.0579)
Republican governor		0.0476
		(0.0320)
Percent urban		0.281
		(0.492)
Dependent Variable Mean	.29	.29
N	3763	3763

This sample includes the continental United States for the years 1850-1940. Each specification includes state and year fixed effects. *Vaccination mandate* is a dummy variable equal to one if a given state in a given year has an active compulsory school vaccination law. These laws are collected by the author from historical session laws books. *Compulsory schooling law* is a dummy variable equal to one if a given state in a given year has an active compulsory schooling law. Compulsory schooling laws are obtained from Clay et al. (2012) and Rauscher (2014). *Republican governor* is a dummy variable equal to one if a given state in a given year has a Republican governor. These data were collected from Kaplan (2020). *Percent urban* is the percent of the total population that lives in an urban area. These data were collected from Haines (2010). Since these data were compiled from decennial censuses, I linearly interpolate the values for the intervening years. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

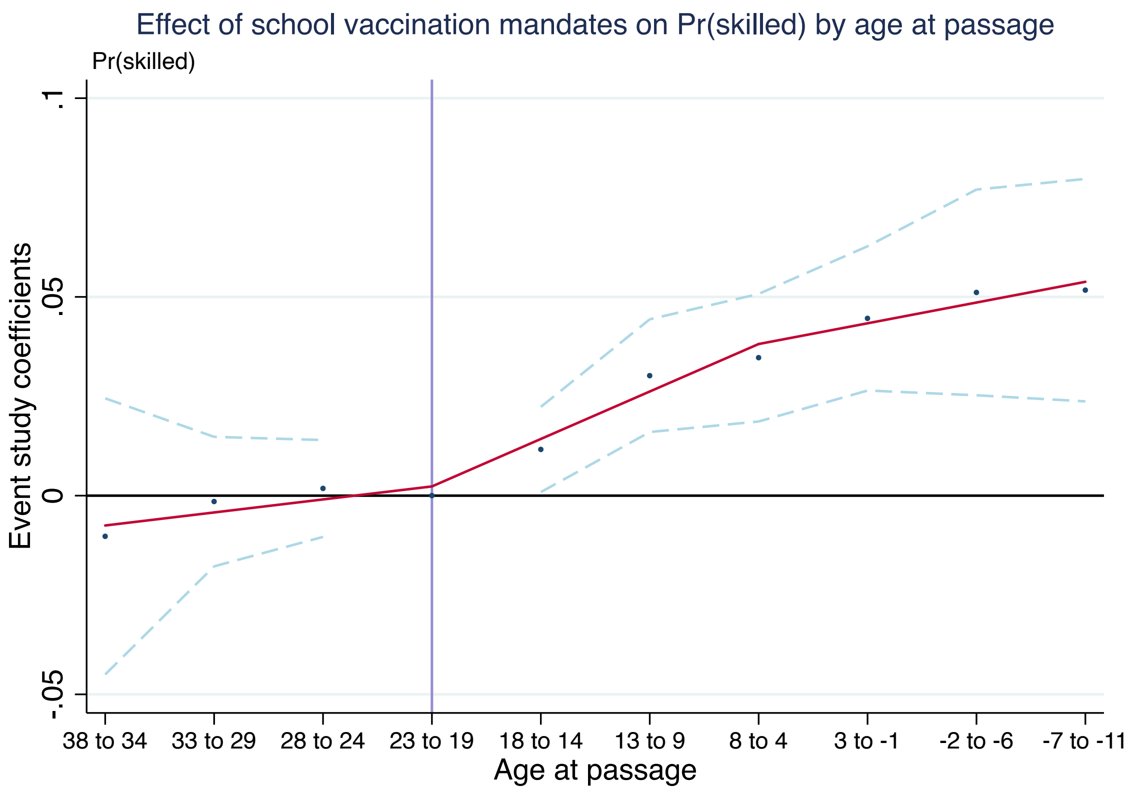
13.3 Other Appendix Figures

Figure A3: School Enrollment by Age



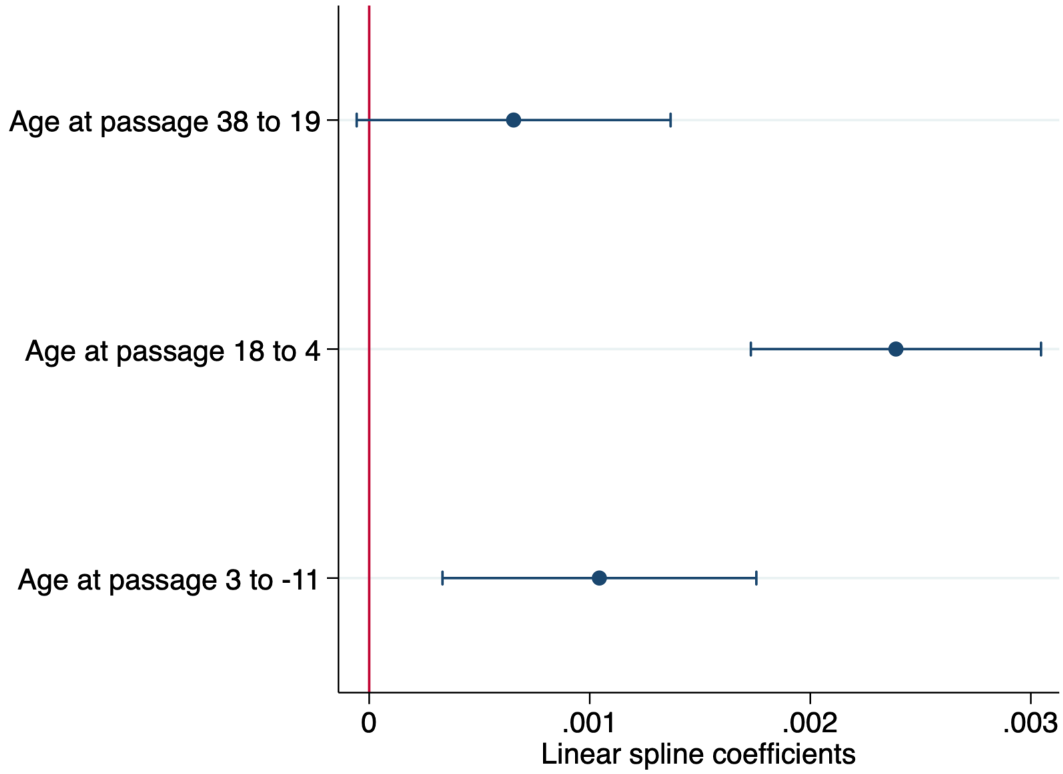
Note: This figure shows average school enrollment by age for native-born white male children using 1 percent samples of the 1850 to 1900 censuses. The figure shows that school enrollment was highest for those of age 11, and that the five year bin of ages with highest enrollment is for those of ages 9 to 13. This suggests that in Figure 8 the effect of vaccination mandates on adult labor market outcomes should increase as age decreases for those of schooling age.

Figure A4: Positive Effect of Vaccination Mandates on Probability of Being Skilled Worker Only Appeared for Those of Schooling Age and Younger when Law Passed



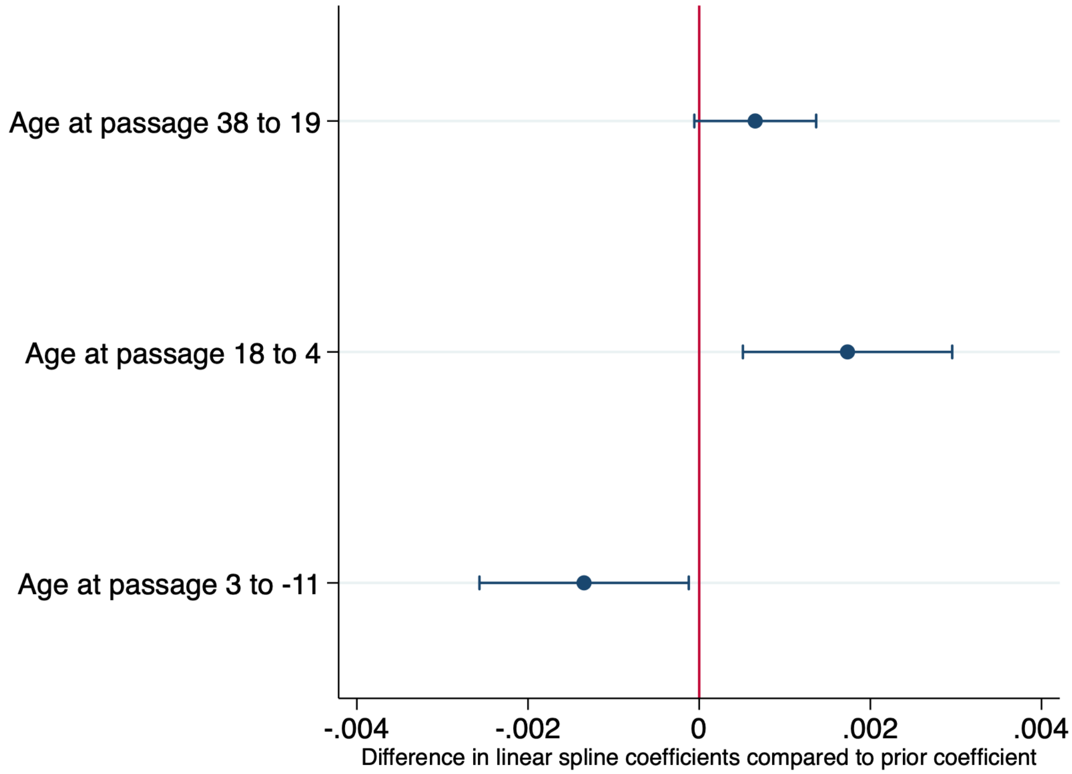
Note: This figure presents event study estimates for the effect of exposure to a school vaccination mandate on the probability of being a skilled worker by age when a mandate was passed. Coefficients are contained within five year bins, each representing the ages of individuals when a mandate was passed. The omitted group contains individuals who were ages 23 to 19 when a mandate was passed. The dashed line represents the 95 percent confidence interval. A linear spline regression is drawn for these coefficients with knots placed at individuals who were ages 23 to 19 when a law was passed, and ages 8 to 4 when a law was passed. The first spline segment shows that those who were adults when a mandate was passed did not experience an effect significantly different from those who were ages 23 to 19. The second spline segment shows that those who were of schooling age when a law was passed experienced a positive effect that increased as age at passage decreased. Finally, the third spline segment shows that this effect leveled out for those who were too young for school or not yet born when a law was passed. The spline coefficients themselves and a test for the change in slopes of the linear spline segments are presented in Figures A5 and A6, respectively. This sample utilizes the 1 percent samples of census years 1870 to 1940, and is limited to native-born nonmigrant white males between the ages 22 and 55. Standard errors are clustered at the state level. *Pr(skilled)* is the probability that an individual was a skilled worker.

Figure A5: Linear Spline Coefficients for Splines in Figure A3



Note: This figure presents the coefficients for the linear spline segments in Figure A3. The confidence intervals represent the 95 percent confidence interval. The segment for ages 38 to 19 is not significantly different from zero. While the segments for ages 18 to 4 and 3 to -11 are significantly greater than zero, the magnitude of the coefficient for the latter group is smaller. This confirms the interpretation that the coefficients in Figure 8 show that the positive effect of vaccination mandates on *Pr(skilled* increased only for those who were of schooling age when a law was passed, and that this effect leveled out but continued for those who were too young for school or not yet born when a mandate was passed. This sample utilizes the 1 percent samples of census years 1870 to 1940. In addition, this sample is limited to native-born nonmigrant white males between the ages 22 and 55. *Pr(occscore)* is the probability that an individual was a skilled worker.

Figure A6: Change in Linear Spline Coefficients for Splines in Figure A4



Note: This figure tests whether changes in the slopes of the linear spline segments in Figure A3 were statistically significant. The confidence intervals represent the 95 percent confidence interval. The coefficient for ages 38 to 19 is the same as in Figure A5 because there is no prior slope to test against. The coefficient for ages 18 to 4 is significantly positive, showing that there was a significant increase in the slope of the linear spline compared to the segment for ages 38 to 19. The coefficient for ages 3 to -11 shows that there was then a statistically significant decrease in slope, illustrating that there was a leveling out of the effect for those too young to go to school or not yet born when a mandate was passed. This sample contains the 1 percent samples of census years 1870 to 1940. In addition, this sample is limited to native-born nonmigrant white males between the ages 22 and 55.

References

Aaby, P., Benn, C. S., Flanagan, K. L., Klein, S. L., Kollmann, T. R., Lynn, D. J., and Shann, F. (2020). The Non-specific and Sex-differential Effects of Vaccines. *Nature Reviews Immunology*, pages 1–7.

Abbott, S. (1902). Progress in Public Hygiene. *The Boston Medical and Surgical Journal*, 146(18):465–467.

Abramitzky, R., Boustan, L. P., and Eriksson, K. (2014). A Nation of Immigrants: Assimilation and Economic Outcomes in the Age of Mass Migration. *Journal of Political Economy*, 122(3):467–506.

Abrevaya, J. and Mulligan, K. (2011). Effectiveness of State-level Vaccination Mandates: Evidence from the Varicella Vaccine. *Journal of Health Economics*, 30(5):966–976.

Almond, D. (2006). Is the 1918 Influenza Pandemic over? Long-term Effects of in utero Influenza Exposure in the Post-1940 US Population. *Journal of Political Economy*, 114(4):672–712.

Almond, D. and Currie, J. (2011). ”Killing Me Softly: The Fetal Origins Hypothesis. *Journal of Economic Perspectives*, 25(3):153–72.

Almond, D., Currie, J., and Duque, V. (2018). Childhood Circumstances and Adult outcomes: Act II. *Journal of Economic Literature*, 56(4):1360–1446.

Bailey, M. J., Hoynes, H. W., Rossin-Slater, M., and Walker, R. (2020). Is the Social Safety Net a Long-term Investment? Large-scale Evidence from the Food Stamps Program. National Bureau of Economic Research (NBER) Working Paper 26942.

Beach, B., Ferrie, J., Saavedra, M., and Troesken, W. (2016). Typhoid Fever, Water Quality, and Human Capital Formation. *The Journal of Economic History*, 76(1):41–75.

Beach, Brian and Ferrie, Joseph P and Saavedra, Martin H (2018). Fetal Shock or Selection? The 1918 Influenza Pandemic and Human Capital Development. National Bureau of Economic Research (NBER) Working Paper 24725.

Belongia, E. A. and Naleway, A. L. (2003). Smallpox Vaccine: The Good, the Bad, and the Ugly. *Clinical Medicine & Research*, 1(2):87–92.

Benn, C. S., Netea, M. G., Selin, L. K., and Aaby, P. (2013). A Small Jab–A Big Effect: Nonspecific Immunomodulation by Vaccines. *Trends in Immunology*, 34(9):431–439.

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

Bleakley, H. (2010a). Malaria Eradication in the Americas: A Retrospective Analysis of Childhood Exposure. *American Economic Journal: Applied Economics*, 2(2):1–45.

Bleakley, H. (2010b). Health, Human Capital, and Development. *Annual Review of Economics*, 2(1):283–310.

Bleakley, H., Costa, D., and Lleras-Muney, A. (2014). Health, Education, and Income in the United States, 1820–2000. In *Human Capital in History: The American Record*, pages 121–159. University of Chicago Press.

Bleakley, H. and Lange, F. (2009). Chronic Disease Burden and the Interaction of Education, Fertility, and Growth. *The Review of Economics and Statistics*, 91(1):52–65.

Bloom, D. E., Canning, D., and Shenoy, E. S. (2011). The Effect of Vaccination on Children's Physical and Cognitive Development in the Philippines. *Applied Economics*, 44(21):2777–2783.

Brabin, B. (2020). An Analysis of the United States and United Kingdom Smallpox Epidemics (1901-5) - The Special Relationship that Tested Public Health Strategies for Disease Control. *Medical History*, 64(1):1–31.

Brown, Ryan, and Thomas, Duncan (2018). On the Long Term Effects of the 1918 US Influenza Pandemic. Unpublished Mansucript.

Carpenter, C. S. and Lawler, E. C. (2019). Direct and Spillover Effects of Middle School Vaccination Requirements. *American Economic Journal: Economic Policy*, 11(1):95–125.

Case, A., Fertig, A., and Paxson, C. (2005). The Lasting Impact of Childhood Health and Circumstance. *Journal of Health Economics*, 24(2):365–389.

Chapin, C. V. (1900). *Municipal Sanitation in the United States*. Snow & Farnham.

Clay, K., Lingwall, J., and Stephens Jr, M. (2012). Do Schooling Laws Matter? Evidence from the Introduction of Compulsory Attendance Laws in the United States. National Bureau of Economic Research (NBER) Working Paper 18477.

Colgrove, J. (2006). *State of Immunity: The Politics of Vaccination in Twentieth-century America*, volume 16. Univ of California Press.

Collins, S. and Councell, C. (1943). Extent of Immunization and Case Histories for Diphtheria, Smallpox, Scarlet Fever, and Typhoid Fever in 200,000 Surveyed Families in 28 Large Cities. *Public Health Reports*, pages 1121–1151.

Costa, D. L. (2015). Health and the Economy in the United States from 1750 to the Present. *Journal of Economic Literature*, 53(3):503–70.

Costa, D. L. and Kahn, M. E. (2004). Changes in the Value of Life, 1940–1980. *Journal of Risk and Uncertainty*, 29(2):159–180.

Crimmins, E. M. and Finch, C. E. (2006). Infection, Inflammation, Height and Longevity. *PNAS*, 103(2):498–503.

Currie, J. and Almond, D. (2011). Human Capital Development Before Age Five. In *Handbook of Labor Economics*, volume 4, pages 1315–1486. Elsevier.

Currie, J. and Vogl, T. (2013). Early-life Health and Adult Circumstance in Developing Countries. *Annual Review of Economics*, 5(1):1–36.

Driessen, J., Razzaque, A., Walker, D., and Canning, D. (2015). The Effect of Childhood Measles Vaccination on School Enrolment in Matlab, Bangladesh. *Applied Economics*, 47(55):6019–6040.

Duffy, J. (1978). School Vaccination: The Precursor to School Medical Inspection. *Journal of the History of Medicine and Allied Sciences*, 33(3):344–355.

Flu Vaccine Now Required for all Massachusetts School Students Enrolled in Child Care, Pre-School, K-12, and Post-Secondary Institutions (2020, August 19). Massachusetts Department of Public Health. URL: https://www.mass.gov/news/flu-vaccine-now-required-for-all-massachusetts-school-students-enrolled-in-child-care-pre. Accessed 2020-11-01.

Force, J. N. and Leake, J. P. (1921). Smallpox in Twenty States, 1915-1920. *Public Health Reports*, pages 1979–1989.

Haines, M. R. (2010). Historical, Demographic, Economic, and Social Data: The United States, 1790–2002. *Ann Arbor, MI: Inter-university Consortium for Political and Social Research*.

Hampton, B. C. (1943). Smallpox in Relation to State Vaccination Laws and Regulations. *Public Health Reports (1896-1970)*, pages 1771–1778.

Hedrich, A. W. (1936). Changes in the Incidence and Fatality of Smallpox in Recent Decades. *Public Health Reports (1896-1970)*, pages 363–392.

Heinonline (2020). URL: heinonline.org. Accessed 2020-11-01.

Henderson, D. A. (2011). The Eradication of Smallpox–an Overview of the Past, Present, and Future. *Vaccine*, 29:D7–D9.

Hodge Jr., J. and Gostin, L. O. (2002). School Vaccination Requirements: Historical, Social, and Legal Perspectives. *Kentucky Law Journal*, 90(4):831–890.

Hopkins, D. R. (2002). *The Greatest Killer: Smallpox in History*, volume 793. University of Chicago Press.

Jackson, C. L. (1969). State Laws on Compulsory Immunization in the United States. *Public Health Reports*, 84(9):787.

Jacobson v. Mass. (1905). 197 U.S. 11.

Johns Hopkins Center for Health Security (2014). Variola virus (smallpox) fact sheet. URL: https://www.centerforhealthsecurity.org/our-work/publications/smallpox-fact-sheet. Accessed 2020-09-09.

Kaplan, J. (2018). United States Governors 1775-2018. Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 2020-07-01. https://doi.org/10.3886/E102000V2.

Kaufman, M. (1967). The American Anti-vaccinationists and their Arguments. *Bulletin of the History of Medicine*, 41(5):463–478.

Kerr, J. W. and Moll, A. A. (1914). *Communicable Diseases: An Analysis of the Laws and Regulations for the Control Thereof in Force in the United States*. Number 62. US Government Printing Office.

Kotar, S. and Gessler, J. (2013). *Smallpox: A History*. McFarland.

Landes, W. M. and Solmon, L. C. (1972). Compulsory Schooling Legislation: An Economic Analysis of Law and Social change in the Nineteenth Century. *The Journal of Economic History*, pages 54–91.

Lawler, E. C. (2017). Effectiveness of Vaccination Recommendations Versus Mandates: Evidence from the Hepatitis A Vaccine. *Journal of Health Economics*, 52:45–62.

Leake, J. P. and Others (1927). *Questions and Answers on Smallpox and Vaccination*. United States Public Health Service.

Luca, D. L. (2016). The Effects of Mandatory Vaccination Laws on Childhood Health and Adult Educational Attainment. *Available at SSRN 1987898*.

Mariner, W. K., Annas, G. J., and Glantz, L. H. (2005). Jacobson v Massachusetts: It's not your Great-great-grandfather's Public Health Law. *American Journal of Public Health*, 95(4):581–590.

Mazumder, B. (2007). How Did Schooling Laws Improve Long-Term Health and Lower Mortality? Federal Reserve Bank of Chicago Working Paper 2006-23.

Meckel, R. A. (2013). *Classrooms and Clinics: Urban Schools and the Protection and Promotion of Child health, 1870-1930*. Rutgers University Press.

Meyers, K. and Thomasson, M. A. (2020). Can Pandemics Affect Educational Attainment? Evidence from the Polio Epidemic of 1916. *Cliometrica*, pages 1–35.

Morality Statistics (1924). Department of Commerce.

Moreau, M. (1895). Infectious Diseases in Public Schools. *The Sanitarian (1873-1904)*, (307):497.

Nandi, A., Kumar, S., Shet, A., Bloom, D. E., and Laxminarayan, R. (2020). Childhood Vaccinations and Adult Schooling Attainment: Long-term Evidence from India's Universal Immunisation Programme. *Social Science & Medicine*, page 112885.

Nishiura, H. (2006). Smallpox during Pregnancy and Maternal Outcomes. *Emerging Infectious Diseases*, 12(7):1119.

Olivetti, C. and Paserman, M. D. (2015). In the Name of the Son (and the Daughter): Intergenerational Mobility in the United States, 1850-1940. *American Economic Review*, 105(8):2695–2724.

Oskorouchi, H. R., Sousa-Poza, A., and Bloom, D. E. (2020). The Long-Term Cognitive and Schooling Effects of Childhood Vaccinations in China. National Bureau of Economic Research (NBER) Working Paper 27217.

Ruggles, S., Flood, S., Goeken, R., Grover, J., Meyer, E., Pacas, J., and Sobek, M. (2020). IPUMS USA: Version 10.0 [dataset].

Saavedra, M. (2017). Early-life Disease Exposure and Occupational Status: The Impact of Yellow Fever during the 19th Century. *Explorations in Economic History*, 64:62–81.

Saavedra, M. and Twinam, T. (2020). A Machine Learning Approach to Improving Occupational Income Scores. *Explorations in Economic History*, 75:101304.

Smallpox Closes Broadalbin Schools (1924, June 14). The New York Times. Page 14.

Smallpox in Cincinnati (1882, April 20). The New York Times. Page 1.

Sørup, S., Villumsen, M., Ravn, H., Benn, C. S., Sørensen, T. I., Aaby, P., Jess, T., and Roth, A. (2011). Smallpox Vaccination and All-cause Infectious Disease Hospitalization: A Danish Register-based Cohort Study. *International Journal of Epidemiology*, 40(4):955–963.

To Prevent Smallpox Contagion (1892, June 11). Chicago Daily Tribune. Page 13.

Troesken, W. (2015). *The Pox of Liberty: How the Constitution Left Americans Rich, Free, and Prone to Infection*. University of Chicago Press.

van Panhuis, W. G., Cross, A., and Burke, D. S. (2018). Project Tycho 2.0: A repository to Improve the Integration and Reuse of Data for Global Population Health. *Journal of the American Medical Informatics Association*, 25(12):1608–1617.

Voth, H. and Leunig, T. (1996). Did Smallpox Reduce Height? Stature and the Standard of Living in London, 1770-1873. *The Economic History Review*, 49(3):541–560.

Williams, G. (2010). *Angel of Death: The Story of Smallpox*. Springer.

Willrich, M. (2011). *Pox: An American History*. Penguin.

Woodward, S. B. (1932). The Story of Smallpox in Massachusetts. *New England Journal of Medicine*, 206(23):1181–1191.

Zajacova, A. and Lawrence, E. M. (2018). The Relationship between Education and Health: Reducing Disparities through a Contextual Approach. *Annual Review of Public Health*, 39:273–289.

Zucht v. King (1922). 260 U.S. 174.