Effects of a Vaccine Mandate on Health and School Outcomes: New Evidence from California

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Dedication

To my mother, Yaping Zhang, for her encouragement and support.

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Abstract of Dissertation

Effects of a Vaccine Mandate on Health and School Outcomes: New Evidence from California

This dissertation evaluates the impact of California's 2016 vaccine mandate, Senate Bill 277 (SB277), which eliminated non-medical exemptions for school-entry immunization requirements. Specifically, it empirically assesses the mandate's effects on health and school outcomes, using a unique dataset of county-level vaccination rates and incidence data on vaccine-preventable diseases (VPDs), as well as a school-level dataset on chronic absenteeism.

The dissertation follows a three-essay format. The first essay examines trends in pertussis and measles cases of California before and after the mandate, along with associations with immunization coverage rates. It also provides detailed documentation on the immunization coverage and VPD prevalence by each California county. The second essay applies a difference-in-differences (DiD) approach and a synthetic control methodology to causally estimate the mandate's impact on vaccination coverage and the prevalence of two VPDs: measles and pertussis. The third essay analyzes school-level chronic absenteeism rates resulting from the mandate's implementation, using a DiD design.

The findings reveal an improvement in immunization coverage, a reduction in disease burden, and a decline in chronic absenteeism associated with the implementation of the 2016 California vaccine mandate. Together, these results suggest that repealing non-medical exemptions for school-entry vaccination is an effective policy tool to mitigate public health risks and reduce chronic school absenteeism.

Table of Contents

Dedication ..... **iv**

Acknowledgments ..... **v**

Abstract of Dissertation ..... **vi**

Table of Contents ..... **vii**

List of Figures ..... **viii**

List of Tables ..... **x**

Essay 1: Pertussis and Measles in California: Trends in Incidence and Vaccination Coverage Before and After the 2016 Vaccine Mandate 1

Essay 2: California's 2016 Vaccine Mandate on Vaccination Coverage and Disease Burden – A Causal Study 36

Essay 3: From Clinics to Classrooms: How California's 2016 Vaccine Mandate Affects Chronic School Absenteeism 92

List of Figures

Figure 1.1 Trends in Total Case and Incidence Rate of Pertussis and Measles in California 19

Figure 1.2 Year-to-Year Change in Total Case and Incidence Rate of Pertussis and Measles in California 20

Figure 1.3 Vaccination Coverage and Prevalence of Pertussis and Measles in California 21

Figure 1.4 County-Level Change in DTP Coverage vs. Pertussis Incidence Before and After Mandate 22

Figure 1.5 County-Level Change in MMR Coverage vs. Measles Incidence Before and After Mandate 23

Figure 1.6 Heatmap: Pertussis Case Rate and DTP Vaccination Rate in California Counties 30

Figure 1.7 Heatmap: Measles Case Rate and MMR Vaccination Rate in California Counties 33

Figure 2.1 MMR and DTP Coverage Rates: California and Other States 76

Figure 2.2. Measles and Pertussis Total Cases: California vs. Other States 77

Figure 2.3 Event Study Results: MMR Coverage and Measles Prevalence 78

Figure 2.4 Event Study Results: DTP Coverage and Pertussis Prevalence 80

Figure 2.5 Synthetic Control Results: Pertussis Prevalence Measures 82

Figure 2.6 Placebo Test: Synthetic Control Gaps in Pertussis Measures 84

Figure 2.7 Total Number of Measles Reported by Each State: 2000-2022 86

Figure 2.8 Total Number of Pertussis Reported by Each State: 2000-2022 87

Figure 2.9 Average MMR Coverage Rates: Before and After 88

Figure 2.10 Average DTP Coverage Rates: Before and After..... 89

Figure 2.11 Total Number of Measles Reported by States: Before and After..... 90

Figure 2.12 Total Number of Pertussis Reported by States: Before and After..... 91

Figure 3.1 Average Chronic Absenteeism Rate in California: 2013-2020 132

Figure 3.2 Event Study Results: Effect of California's 2016 Vaccine Mandate on Chronic Absenteeism Rates 134

Figure 3.3 Total Number of Enrolled Students and Percent Share by Race in California 142

Figure 3.4 Total Number of Students Chronically Absent from Schools in California . 143

Figure 3.5 California Share of Nation's Total Enrollment and Absenteeism..... 144

Figure 3.6 Average Chronic Absenteeism Rates in California and 49 Other States 145

List of Tables

Table 1.1 Pertussis Case Rate and DTP Vaccination Coverage: Pre- and Post-Mandate Comparison 24

Table 1.2 Measles Case Rate and MMR Vaccination Coverage: Pre- and Post-Mandate Comparison 27

Table 2.1 State Exemption Allowance and Major Policy Change..... 71

Table 2.2 Summary Statistics: California and Comparison States in 2015 73

Table 2.3 DiD Results: MMR Coverage and Measles Prevalence 74

Table 2.4. DiD Results: DTP Coverage and Pertussis Prevalence 75

Table 3.1. Average Chronic Absenteeism Rates in California and All Other States: School Year 2015-2016 125

Table 3.2. Pre and Post Average Chronic Absenteeism Rates: California and Other States 126

Table 3.3 Interrupted Time Series Parameters – California Schools Only..... 127

Table 3.4 Difference-in-Differences Results: California and 49 Other States 128

Table 3.5 Difference-in-Differences Results: California and 8 Comparison States..... 130

Table 3.6 Total Number Enrolled Students and Percentage Share by Gender and Race: California and 49 Comparison States in School Year 2015-2016 140

Table 3.7 Total Number of Enrolled Students and Distribution by Race in California.. 141

Essay 1: Pertussis and Measles in California: Trends in Incidence and Vaccination Coverage Before and After the 2016 Vaccine Mandate

1.1 Introduction

Pertussis and measles are vaccine-preventable diseases (VPDs). Pertussis is caused by the bacterium Bordetella pertussis and measles is caused by the morbillivirus (Centers for Disease Control and Prevention, 2022). Both diseases are airborne and highly contagious, introducing a high risk to infants and young children. In the United States (U.S.), vaccination against pertussis can trace back to 1914, when the first licensed pertussis vaccine was administered (Kuchar et al., 2016). By the 1940s, the pertussis vaccine began to be routinely administered in combination with vaccines for diphtheria and tetanus (DTP). Similarly, measles vaccines were developed in the 1960s (World Health Organization) and have since been commonly combined with mumps and rubella vaccines in the MMR formulations.[1]

Historically, the widespread use of these vaccines has contributed to meaningful declines in pertussis and measles incidence in the U.S. and globally (Forsyth et al., 2005; Meissner et al., 2004). However, despite the routine administration of both vaccines in recent decades, a resurgence of pertussis and measles cases is constantly being reported across the U.S., particularly over the past decade. The latest resurgence of VPDs in California has particularly renewed public concerns over the efficacy of childhood immunizations and spurred debates around state policies to exempt school-entry vaccination requirements. Unlike many other VPDs, pertussis is particularly harmful to infants under one year of age, prompting vaccination schedules to begin at two months of

[1] DTP vaccine combines vaccines that protect against diphtheria, tetanus, and pertussis. MMR vaccine protects against measles, mumps, and rubella.

age (Skoff et al., 2016; Carrasquilla et al., 2020). Measles, while affecting all age groups, is also more common among children under five.[2]

To curb transmission in early childhood settings, vaccination against pertussis, measles, and various other VPDs is mandatory for school entry in all U.S. states,[3] given the higher risk of disease transmission among this population. While medical exemptions are permitted in all states, many also allow non-medical exemptions based on philosophical or personal belief reasons. Resurgences of VPDs, often associated with loose vaccination allowances, frequently prompt government responses to tighten school-entry vaccination requirements, as a means to control disease outbreaks.

In response to a record-breaking measles outbreak in 2015, California became the first state in the most recent two decades to eliminate all non-medical exemptions to school-entry vaccination. Senate Bill 277 (SB277), adopted in 2015 and enacted in 2016, removed personal and philosophical exemptions starting school year 2016-2017, creating one of the most stringent vaccine mandate policy environments in the U.S.[4]

This essay provides a descriptive documentation and analysis of VPD trends prior to and following the implementation of SB277. Using a unique county-level dataset collected from the California Department of Public Health (CDPH), it examines changes in pertussis and measles incidence trends before and after the mandate. In addition to displaying disease trends, this study also investigates trends in DTP and MMR vaccination coverage rates and explores the relationship between vaccination coverage

[2] Centers for Disease Control and Prevention (CDC): Measles Cases and Outbreaks https://www.cdc.gov/measles/data-research/index.html
[3] Retrieved from Immunize.org https://www.immunize.org/official-guidance/state-policies/vaccine-requirements/mmr-child-school-2024/
[4] A more detailed background of California's vaccine mandate and requirements are presented in Essay 2 and Essay 3 of this Dissertation.

and disease prevalence. This study documents the direct health outcomes associated with the vaccine mandate in California, contributes to discussions on the effectiveness of vaccination mandates and linkages between immunization coverage and disease trends.

1.2 Data

This study employs a unique county-level VPD dataset on pertussis and measles, obtained directly from the CDPH. Adhering to the case definition and classification set by the U.S. Centers for Disease Control and Prevention (CDC) and the Council of State and Territorial Epidemiologists (CSTE), California, along with many other states, routinely monitors and reports their annual case count for a range of different VPDs, disaggregated by county and by year. For pertussis, California counts both confirmed and probable cases. For measles, only confirmed cases are considered.[5] Both disease records span all age groups and are available for each California county from 2001 to 2022.

In addition to VPD case data, this study also employs a county-level vaccination coverage dataset for DTP and MMR vaccines, also sourced from the CDPH. Vaccination coverage data are initially collected at the kindergarten school level, and I further streamlined and aggregated them to the county-level as average vaccination coverage rates. Doing so has increased the comparability between different datasets, ensuring consistent use of country-level data for the overall assessment. Specifically, vaccination rates indicate the annual percentage of kindergarteners in each California county[6] who are up to date with their vaccination, meaning they have completed all required doses of DTP

[5]California Department of Public Health Pertussis Case Definition https://www.cdph.ca.gov/Programs/CID/DCDC/CDPH%20Document%20Library/Immunization/PertussisCaseDefinition.pdf

[6] Vaccination coverage data are reported as the average across kindergartens within each county.

and MMR vaccines at each year's school-entry check point. The vaccination rate data span the period from 2001 to 2021.

Additionally, to calculate each county's annual disease incidence rates, such as case count reported per million population, this study also employs a county-level population estimate from the U.S. Census and applies it to the VPD prevalence data provided by the CDPH. The population dataset encompasses all the years for which VPD case data are available. While the standard measure of disease incidence in infectious disease surveillance is cases per 100,000 population (Pinner, 1996; Dong et al., 2020; Desai et al., 2018), in this study, I employ an amplified threshold and calculate cases per million population to allow for greater variation in measles incidence, which is typically low and difficult to observe when using the conventional 100,000 scale.

While both the VPD and population datasets are reported at the county level originally, the vaccination coverage dataset is provided at the school level. To harmonize the data, school-level vaccination rates are averaged within each county and year. After this data harmonization, a unique "county FIPS-year" identifier[7] is then created in each dataset to enable consistent merging across datasets.[8] The final dataset is thus structured at the "*county-year*" level, which serves as the unit of analysis for this study, and includes county-level case count of VPDs, average vaccination rates, and population.

1.3 Methodology

This study employs a series of visual presentations to illustrate changes in pertussis and measles cases and incidence rates across all age groups, along with changes

[7] Each county is labelled to a unique Federal Information Processing System (FIPS) code. This code is provided in the raw dataset.
[8] These three datasets include: VPD case count, vaccination coverage, and county-level population data.

in average vaccination rates of MMR and DTP among California's kindergarteners. It also explores the visual correlations between VPD cases and average vaccination rates, before and after the implementation of California's 2016 vaccine mandate.

Figure 1.1 presents California-aggregated trends in pertussis and measles case count, and incidence rates per one million population from 2001 to 2022. *Figure 1.2* further displays the first differences in these case counts, calculated as the year-to-year changes, for both pertussis and measles cases and incidence rates. The first differences are calculated by simply subtracting the earlier year's value from the value of the later year. Therefore, data in *Figure 1.2* are presented in two-year intervals, such as "year 2001-2002" indicates changes from 2001 to 2002. These first differences represent the slope of each line in *Figure 1.1* and visually highlight the year-to-year fluctuations in disease burden measured by case number and rate.

To illustrate the effect of the 2016 mandate on VPD prevalence, this study compares VPD trends before and after mandate's implementation. To capture the changes more accurately, the pre-period only includes observations between 2009 and 2015, and the post-period includes observations between 2016 to 2019. I choose a shortened pre- and post-period by excluding earlier years and years overlapping the COVID-19 pandemic based on two reasons. First, data reported in earlier years may have been less standardized, which is subject to a higher margin of error and reduced reliability compared to more recent data. Second, the impact of the COVID-19 pandemic on disease trends remains understudied, and school closures and the shift to online learning modalities have complicated the consistent reporting of pertussis and measles case counts during the pandemic period. *Table 1.1*and *Table 1.2* in the *Appendices* summarize

percentage changes in disease incidence. The analysis also includes a pre- and post-vaccination rates comparison.

Additionally, to explore the relationship between vaccination coverage and disease burden, I employ DTP and MMR vaccination rates among kindergarteners as a complementary measure. *Figure 1.3* illustrates statewide trends in DTP and MMR vaccination rates from 2001 to 2021, alongside total pertussis and measles burdens. I present pertussis data using incidence rates per million population, whereas for measles, I report total case counts. This difference in measurement units is necessary due to the low incidence of measles, which makes it difficult to visually detect trends when relying on incidence rates. Additionally, I present the data in three phases: *pre-mandate* (before 2016), *mandate implementation* (2016-2019), and years affected by the *COVID-19 pandemic* (2020 and beyond).

Moreover, I demonstrate changes pre- to post- in vaccination rates and their visual relationships with changes in disease rates through *Figure 1.4* and *Figure 1.5*. Similarly, the pre-period covers only 2009 to 2015, while the post-period covers only 2016 to 2019 to show more immediate changes from before to after the mandate.

Finally, changes in average county-level vaccination rates, calculated as the difference between pre- and post-vaccination rates for DTP and MMR vaccines, are presented in *Table 1.1* and *Table 1.2*. *Figure 1.6* and *Figure 1.7* in the *Appendices* provide additional details as heatmaps, by further incorporating the average vaccination rates for MMR and DTP, as well as the average disease incidence per one million population, from 2009 to 2021, for each California county.

1.4 Results

In California, pertussis displays a distinct cyclical pattern. Before 2009, pertussis case numbers remained relatively low and under control, with no large outbreaks, though there were occasional single-year spikes. After 2009, however, the overall trend shifted to a more regular cycle, characterized by large and growing outbreaks occurring approximately every three to four years, and each cycle is marked by a sharp increase in cases during a short-lived peak year, followed by a rapid decline of cases throughout the subsequent years. Between 2009 and 2016, overall pertussis cases increased considerably compared to the earlier period, with large fluctuations observed across years. Two peak years were observed: 9,159 cases in 2010 and 11,226 cases in 2014.

From 2016 to 2019, during the early years of the vaccine mandate implementation, overall pertussis case count continued to fluctuate but is showing a reduced level of intensity, with peak year case levels being notably much lower compared to pre-mandate years. During the COVID-19 pandemic, case counts declined substantially, potentially due to spillover effects from pandemic-related public health measures such as social distancing, demonstrating a much lower VPD activity than at any time before the pandemic. The incidence rate of pertussis per million population mirrors this cyclical pattern, with pronounced peaks taking place in 2010 and 2014. Based on these patterns, I divide the 2021-2022 observation period of pertussis into four analytical phases: 1. *Early stage* (2001-2009); 2. *Pre-Mandate* (2009-2016); 3. *Mandate implementation* (2016-2020); and 4. *The COVID-19 pandemic* (2020 onward).

In contrast to pertussis, measles in California displays a less cyclical and more sporadic pattern. Historically, and before 2014, overall measles incidence remained low and stable, with no outbreaks reported. However, in later years, California experienced a

surge in total measles cases, with the most severe number reported in 2015, when the confirmed cases increased to 125, representing ten times increase compared to just two years earlier. Similarly, these spikes are short-lived, and total cases dropped in years following the peak.

Between 2016 and 2019, there was a tendency for a resurgence of measles cases, although the number of cases remained far below the 2015 level. Moreover, 2019 recorded a modest increase in total cases, but the overall burden was still considered manageable. No measles cases were reported during the COVID-19 pandemic, likely the transmission was reduced due to pandemic measures such as lockdowns and social distancing. Based on these trends, I divide the twenty-year observation period of measles into four phases: 1. *Quiet period* (before 2014); 2. *Emergence phase* (2014-2015); 3. *Mandate implementation* (2016-2019); and 4. *The COVID-19 pandemic* (2020 onward).

Figure 1.2 illustrates differences in disease trends across distinct phases for both VPDs. For pertussis, *Early stage (2001-2009)* shows relatively stable trends with limited fluctuations in case counts. The *Pre-mandate (2009-2016)* period, on the other hand, is marked by increased volatility, with increases in 2010 and 2014 and declines in 2011 and 2015, which highlights the instability of pertussis incidence, with large year-to-year changes of case numbers. During the *Mandate implementation (2016-2020),* fluctuations persist but are more moderate, suggesting greater controls over disease spread. Year-to-year changes were largely negative during the in *COVID-19 (2020 and beyond)*.

For measles, the *Quiet period (pre-2014)* is characterized by low and stable case counts and minimal year-to-year change. The *Emergence phase (2014–2015)* experienced a sharp increase in cases, particularly in 2015. During the *Mandate Implementation*

(2016–2019) period, fluctuations remained, but the magnitude is smaller compared to the peak year of 2015. Like pertussis, the *COVID-19* phase experiences a steady decline in measles cases, with no increases observed.

Plotting disease prevalence alongside vaccination rates helps reveal patterns and visual relationships between these two indicators. As *Figure 1.3* illustrates, from 2001 to 2013, there is downward trend in the average vaccination rates of both MMR and DTP. At the beginning of this period, vaccination coverage rates were close to the 95% herd immunity threshold (Plans-Rubió, 2021). However, rates declined over the years, hitting the lowest point in 2013, when only about 90% of kindergarteners met the required vaccination and were fully vaccinated. This translates into a four to five percentage points shortfall from the minimum herd immunity threshold. It is also noteworthy that vaccination coverage began to increase in 2013, which may be associated with new requirements, such as the 2014 requirement mandating parental consultation with healthcare providers before opting out of childhood vaccination.

Concurrently, I observe an increase in pertussis and measles case counts, and a much higher level of disease fluctuation, particularly around 2009 and 2015 when vaccination rates experienced a sharp drop. Following the implementation of California's vaccine mandate in 2016, vaccination rates rebounded and remained consistently stable, close to the herd immunity threshold of 95% coverage. Meanwhile, I still observe a rise and fall of pertussis and measles cases, but the degree of cases fluctuating and peak levels are much reduced compared to before.

Despite the disruptions caused by the COVID-19 pandemic, average vaccination rates in California remained stable, with only a slight decline observed in 2020, which

may be attributable to pandemic-related school closures and reduced access to health services. Difficult access to healthcare and services may have reduced timely completion of vaccination requirements. Simultaneously, pertussis and measles activity also remained at a low level during the COVID-19 pandemic.

Moreover, when examining the visual correlations between vaccination rates and disease incidence before and after the 2016 vaccine mandate, *Figures 1.4* and *1.5* illustrate that both pertussis and measles were moving toward a favorable direction, characterized by an overall increase in vaccination rates before and after, coupled with an overall decrease in disease incidence, as most counties are falling inside the 4^{th} quadrant. The magnitude of correlation is visually more pronounced in pertussis than in measles, in part explained by the higher degree of variance in pertussis cases. It is also partly explained by the small number of measles cases observed in California. Overall, following the implementation of the vaccine mandate SB277, despite an upward trend observed in both pertussis and measles cases, the total VPD cases and the incidence rates per one million population were much lower compared to pre-mandate. This suggests that both diseases are still endemic even after the mandate but with a much-reduced burden and speed of transmission within populations.

Finally, when examining California counties, total pertussis cases were primarily influenced by larger counties measured by population size, such as Los Angeles County and San Diego County. Similarly, the burden of measles was primarily driven by Orange County and Los Angeles County. When assessing the disease burden by incidence per one million population, San Diego County carried the highest per-person burden of pertussis. In contrast, Orange County bore the largest burden of measles cases per one

million of its population. Such trends and patterns are presented in *Table 1.1* and *Table 1.2* and further detailed in the *Appendices* through *Figure 1.6* and *Figure 1.7*.

1.5 Discussions

The reemergence of VPDs is a complex issue with no single and straightforward cause and explanation. One key factor is a declining vaccination coverage: when population-level immunization rates fall below the herd immunity threshold, which for most VPDs is estimated at approximately 95%, the collective protection provided by vaccination begins to erode, leaving communities vulnerable to disease resurgence, particularly among those who are unvaccinated or face waning immunity. Another contributing factor is the diminished long-term effectiveness of certain vaccines. For example, concerns around the waning protection of the DTP vaccines over time.

Despite extensive vaccination efforts and other disease control strategies, pertussis and measles remain persistent threats. Public health interventions often aim to reduce the burden and transmission of these VPDs, such as the enactment of laws and legislation, for instance, California's 2016 vaccine mandate SB277. Although these diseases may not always pose an immediate threat, the risk of resurgence remains an ongoing concern. Despite current disease control efforts, for most VPDs, elimination, or eradication through current approaches such as expanded vaccination programs and coverage remains unattainable.

In this context, implementing a vaccine mandate, such as California’s SB277, demonstrates importance in mitigating scale of future outbreaks. While such mandates may not eliminate disease, they can help reduce the magnitude of future waves and buffer the health system against more severe disease surges. Vaccine mandates have profound

social and practical implications. First, mandates help maintain a high population-level vaccination coverage, especially among targeted populations such as school-eligible children and the elderly, therefore reducing the risk of further outbreaks. Second, they help prevent the sudden and simultaneous consumption of healthcare systems and resources, such as medical personnel, hospital beds, and medications, when a large population falls sick at the same time.

The infectious diseases literature, particularly studies focusing on the economic aspects of diseases, have argued that infectious diseases present a self-limiting trait, as individuals can adopt safer behaviors in response to higher perceived risks (Geoffard and Philipson, 1996; Philipson, 1999). This analysis, particularly leveraging historical disease data, to some extent demonstrates this self-limiting feature of diseases, as prevalence can decline naturally even in the absence of formal interventions. However, this study also reveals a tradeoff, as the natural self-limiting capacity of diseases is not always sufficient when the risk of transmission escalates. In California, the years leading up to 2016 experienced a growing imbalance between VPD self-limitation and risks of VPDs, with increasing susceptibility to large-scale outbreaks, which catalyzed the formulation and implementation of the 2016 vaccine mandate.

More important than verifying the VPD self-limitation feature is to acknowledge California's experience, which unveils the delicate and fragile aspects of diseases' self-regulation, as this self-limiting effect can get easily compromised and undermined by a combination of social, behavioral, and institutional factors. In contrast, while a vaccine mandate is not a panacea, it can stabilize the risks associated with the outbreaks at the population and society level. When implemented as a school-entry requirement, vaccine

mandates can broaden vaccination coverage among high-risk populations, helping to restore equilibrium between VPD transmission and control strategies.

Nevertheless, implementing vaccine mandates entails costs, which include both financial and human resource investments required to alter public behavior to promote compliance. Each stakeholder, in the case of California's mandate, such as students, parents, schools, and healthcare providers, incurs different costs and receives varying levels of benefits. Consequently, decisions about whether to modify vaccination requirements for school-entry, during a VPD endemic period, should also be guided by rigorous and evidence-supported evaluations that weigh both the costs and benefits to all parties involved. Such a deep-dive analysis helps maximize the public health benefits of vaccination policies while also minimize unintended social and economic risks, burdens, and adverse consequences.

1.6 Limitations

The Centers for Disease Control and Prevention acknowledged that reported VPD cases may not fully reflect the actual extent and scale of illness, such as the potential underreporting of pertussis.[9] Several factors contribute to this discrepancy, including delays in reporting, inadequate specimen collection or diagnostic testing, and underreporting by healthcare professionals and laboratories and parents. Consequently, this study is subject to the same data limitations, and it is possible that the true burden of pertussis and measles in California exceed the numbers presented in this paper. Moreover, because pertussis and measles primarily affect young children, case reporting,

[9] Retrieved from CDC Whooping Cough (Pertussis): https://www.cdc.gov/pertussis/php/surveillance/index.html

therefore, relies on second-hand sources including parents or healthcare providers, which further contributes to the underreporting.

Another limitation stems from the potential misalignment between the populations covered by the VPD and vaccination datasets. While California's VPD data encompass all age groups statewide, the vaccination data used in this study specifically focuses on kindergarteners. Although this discrepancy is notable, it is important to also highlight that infants and young children account for a large portion of and are particularly vulnerable to pertussis and measles, even though older children and adults can also get infected.[10] This study focuses on young age cohorts as the mandate was designed to regulate vaccination compliance of children at school-entry checkpoint. The use of kindergarten-level vaccination rate data, therefore, aligns with the intent of the mandate and the most directly affected populations.

Additionally, case definitions for pertussis and measles have evolved over time, following updates issued by CDC and CSTE. For example, in 2010, a confirmed case of pertussis only needed to satisfy one of the three conditions. By 2014, the criteria became more stringent and required additional testing to confirm a case. These revisions in diagnostic criteria may have influenced reported case numbers and partially explained the observed changes in disease prevalence.

1.7 Conclusions

This study documents trends in California from the early 2000s through 2022, focusing on total cases and incidence rates of every million population of pertussis and measles. Drawing on county-level data from the California Department of Public Health

[10] Retrieved from CDC Whooping Cough (Pertussis): https://www.cdc.gov/pertussis/php/surveillance/index.html

and aggregating them into state-level, I find that both total cases and case rates for these two VPDs, particularly pertussis, experienced sharp fluctuations and increased burdens prior to 2016, when the state enacted mandate Senate Bill 277, eliminating all non-medical exemptions for school-entry vaccinations.

Pertussis displayed a cyclical pattern, with largest peaks observed in 2010 and 2014, and Measles also experienced spikes in 2014 and 2015. A decline of these VPDs have been observed following the implementation of SB277 in 2016. While VPD cases still increased in subsequent years, the overall burden appeared more controlled, suggesting that the mandate played a role in mitigating the severity and intensity of post-mandate peaks. While causality cannot be established in this essay, the observed trends and correlations between vaccination coverage and disease prevalence warrant further and deeper examination, which is pursued in the next essay.

Vaccine mandates are generally not designed to eliminate or eradicate VPDs, but rather to reduce their impact, particularly in the context of cyclical outbreaks, which for certain VPDs occur every three to five years. Although infectious diseases often display a limited degree of self-limiting dynamics, such mechanisms depend on the public's rational engagement in risk-reducing behavior. When the risks posed by disease exceed the population's capacity for self-regulation, public health intervention may become essential.

Maintaining population-level vaccination rates near the herd immunity threshold remains a critical strategy, not only to protect vaccinated individuals but also to provide indirect protection to those who remain unvaccinated. Evidence presented in this study suggests that disease outbreaks often take place when population-level vaccination rate is

below the herd immunity level. These principles apply not only to DTP and MMR vaccination strategies to control pertussis and measles, but also more broadly as foundations and principles for controlling the spread of other VPDs across different populations.

References

Carrasquilla, G., Porras, A., Martinez, S., DeAntonio, R., Devadiga, R., Caceres, D. C., & Juliao, P. (2020). Incidence and mortality of pertussis disease in infants <12 months of age following introduction of pertussis maternal universal mass vaccination in Bogotá, Colombia. Vaccine, 38(46), 7384–7392. https://doi.org/10.1016/j.vaccine.2020.07.046

Centers for Disease Control and Prevention. (2022, August 4). Pertussis causes and how it spreads. Centers for Disease Control and Prevention. https://www.cdc.gov/pertussis/about/causes-transmission.html

Desai, S., Schanzer, D. L., Silva, A., Rotondo, J., & Squires, S. G. (2018). Trends in Canadian infant pertussis hospitalizations in the pre- and post-acellular vaccine era, 1981–2016. Vaccine, 36(49), 7568–7573. https://doi.org/10.1016/j.vaccine.2018.10.047

Dong, Y., Wang, L., Burgner, D. P., Miller, J. E., Song, Y., Ren, X., Li, Z., Xing, Y., Ma, J., Sawyer, S. M., & Patton, G. C. (2020a). Infectious diseases in children and adolescents in China: Analysis of National Surveillance Data from 2008 to 2017. BMJ, m1043. https://doi.org/10.1136/bmj.m1043

Forsyth, K., Tan, T., von König, C.-H. W., Caro, J. J., & Plotkin, S. (2005). Potential strategies to reduce the burden of pertussis. Pediatric Infectious Disease Journal, 24(5). https://doi.org/10.1097/01.inf.0000160917.29723.03

Geoffard, P.-Y., & Philipson, T. (1996). Rational epidemics and their public control. International Economic Review, 37(3), 603. https://doi.org/10.2307/2527443

Kuchar, E., Karlikowska-Skwarnik, M., Han, S., & Nitsch-Osuch, A. (2016). Pertussis: History of the disease and current prevention failure. Pulmonary Dysfunction and Disease, 77–82. https://doi.org/10.1007/5584_2016_21

Meissner, H. C., Strebel, P. M., & Orenstein, W. A. (2004). Measles vaccines and the potential for worldwide eradication of measles. Pediatrics, 114(4), 1065–1069. https://doi.org/10.1542/peds.2004-0440

Philipson, T. (1999). Economic Epidemiology and Infectious Diseases. https://doi.org/10.3386/w7037

Pinner, R. W. (1996). Trends in infectious diseases mortality in the United States. JAMA: The Journal of the American Medical Association, 275(3), 189. https://doi.org/10.1001/jama.1996.03530270029027

Plans-Rubió, P. (2021). Vaccination coverage for routine vaccines and herd immunity levels against measles and pertussis in the world in 2019. Vaccines, 9(3), 256. https://doi.org/10.3390/vaccines9030256

Skoff, T. H., Deng, L., Bozio, C. H., & Hariri, S. (2023). US infant pertussis incidence trends before and after implementation of the maternal tetanus, diphtheria, and pertussis vaccine. JAMA Pediatrics, 177(4), 395. https://doi.org/10.1001/jamapediatrics.2022.5689

World Health Organization. (n.d.). History of measles vaccination. World Health Organization. https://www.who.int/news-room/spotlight/history-of-vaccination

Figure 1.1 Trends in Total Case and Incidence Rate of Pertussis and Measles in California

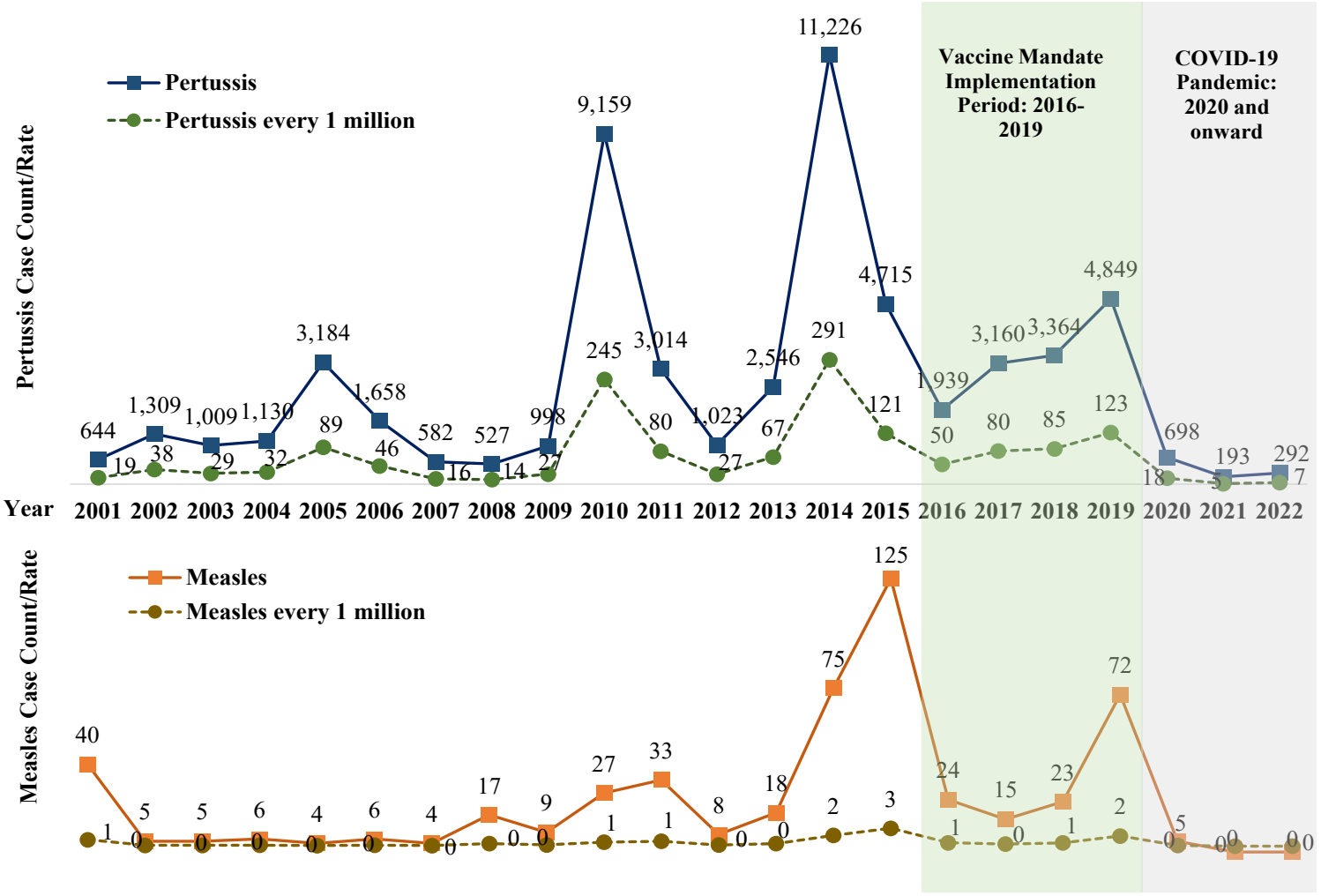


Figure 1.2 Year-to-Year Change in Total Case and Incidence Rate of Pertussis and Measles in California

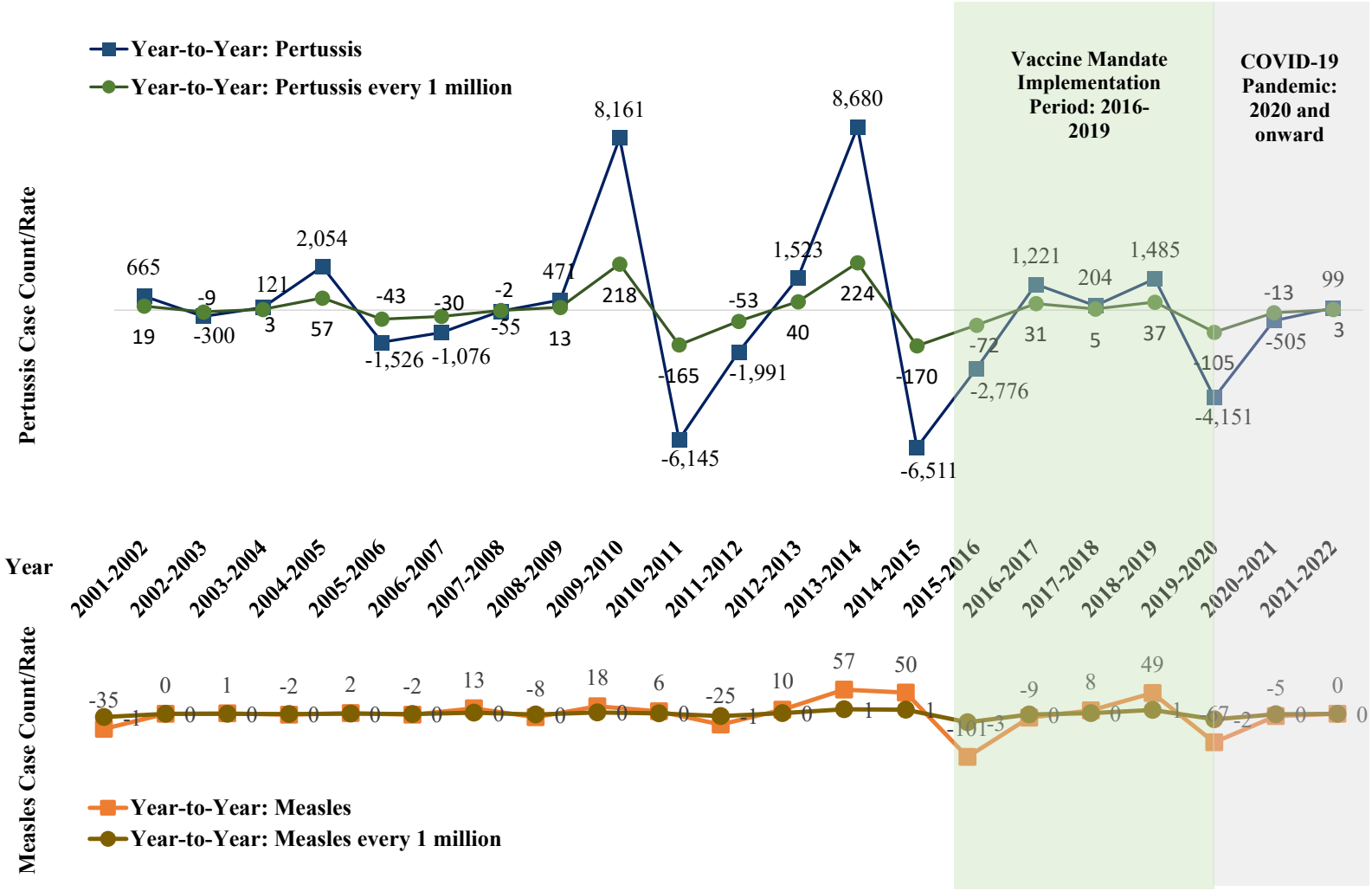


Figure 1.3 Vaccination Coverage and Prevalence of Pertussis and Measles in California

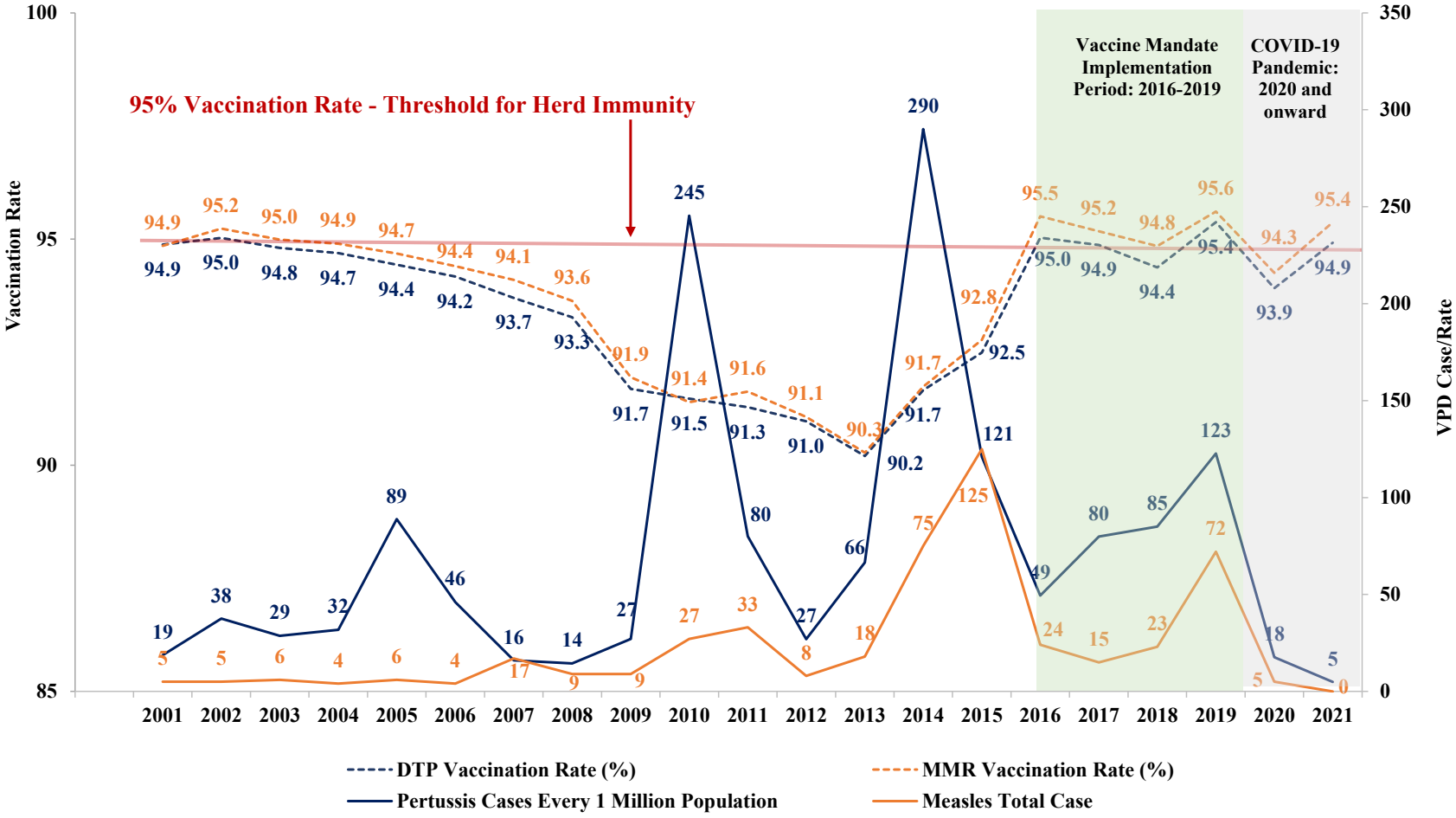
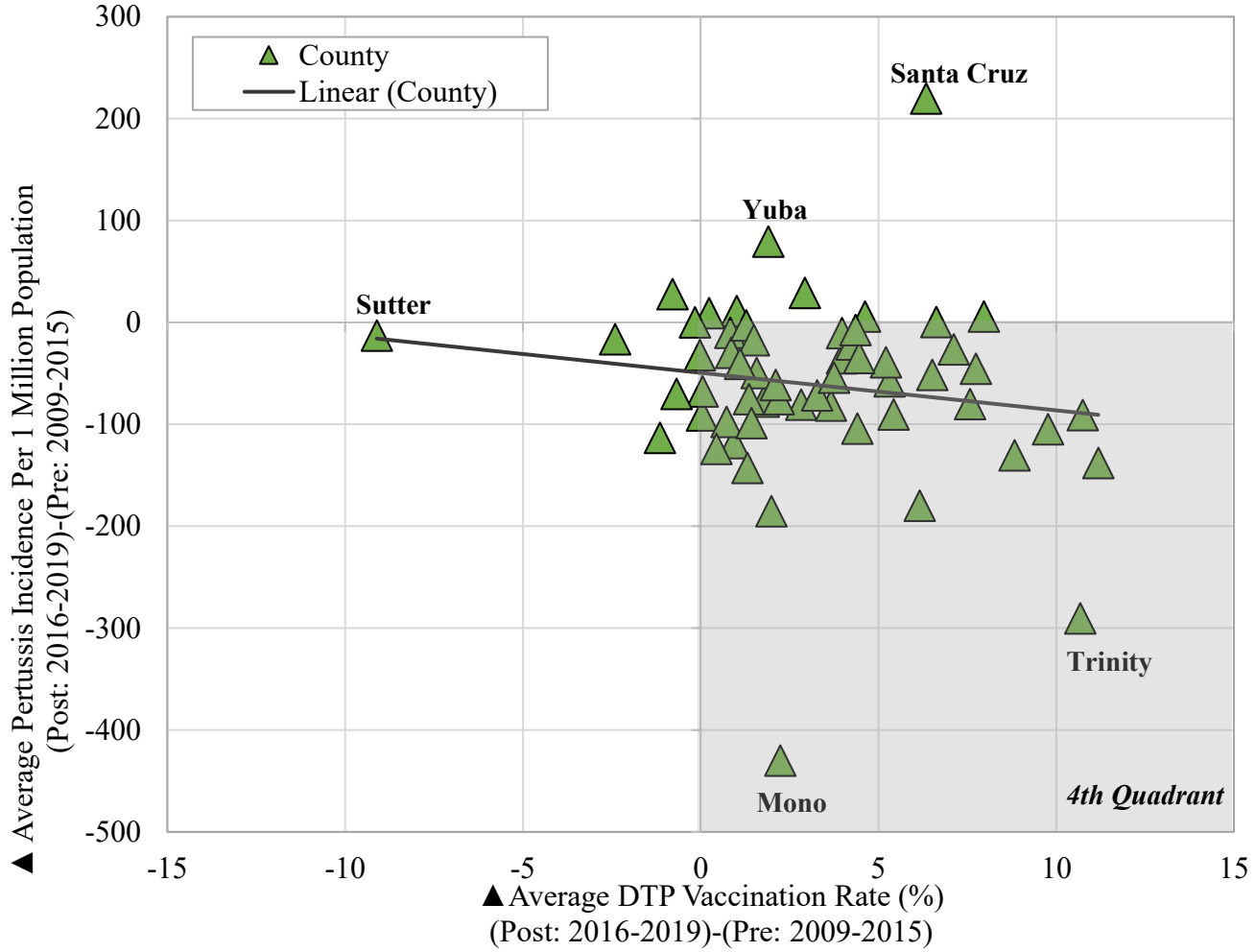
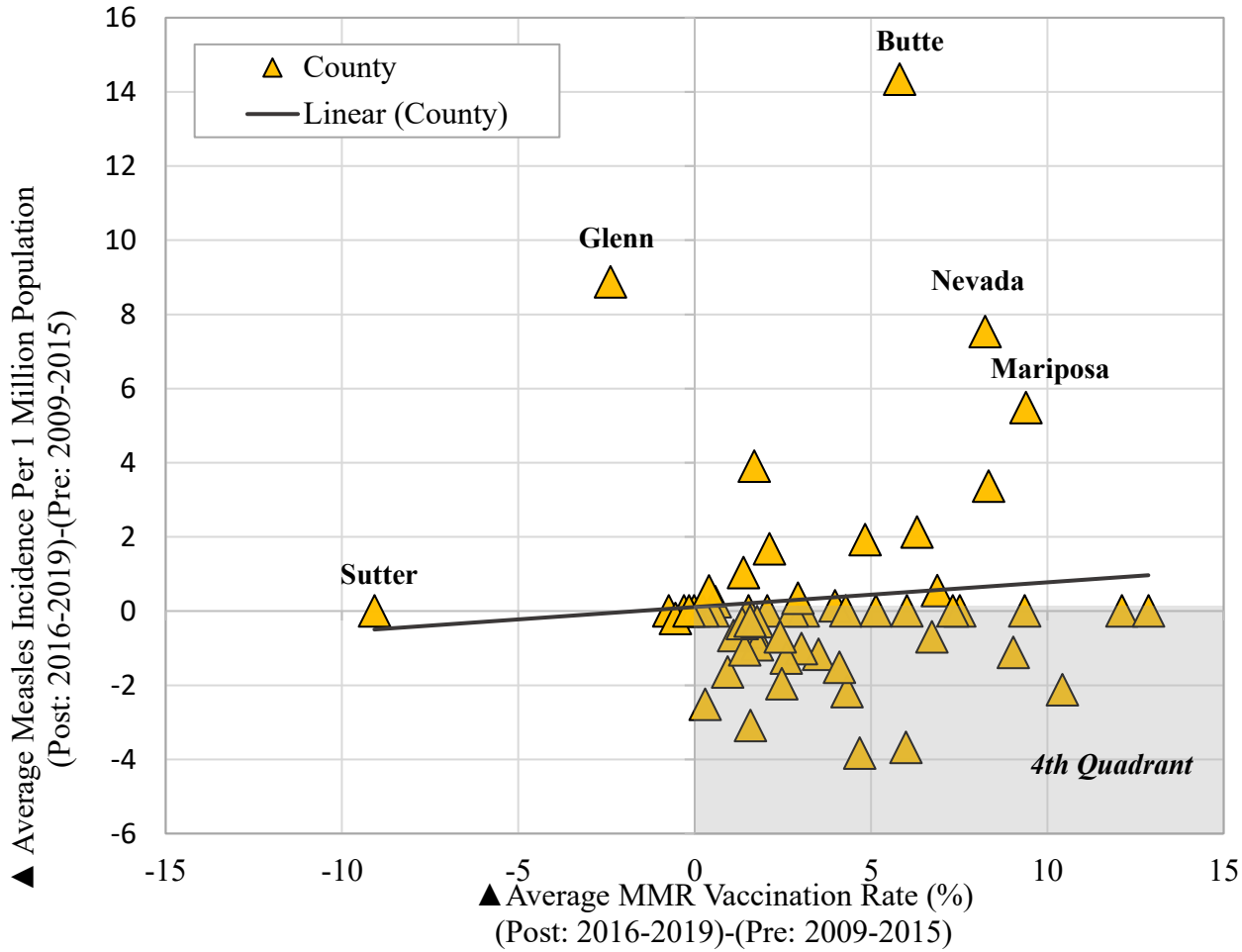


Figure 1.4 County-Level Change in DTP Coverage vs. Pertussis Incidence Before and After Mandate[11]



[11] Each bubble represents a county from before (2009-2015) to after (2016-2019) the implementation of California's vaccine mandate.

Figure 1.5 County-Level Change in MMR Coverage vs. Measles Incidence Before and After Mandate [12]



[12] Each bubble represents a county from before (2009-2015) to after (2016-2019) the implementation of California's vaccine mandate.

Appendices

Table 1.1 Pertussis Case Rate and DTP Vaccination Coverage: Pre- and Post-Mandate Comparison[13]

County	Pertussis Case Every 1 million Population: Pre (2009-2015)	Pertussis Case Every 1 million Population: Post (2016-2019)	% Reduction of Pertussis Case Every 1 million Population: Post vs. Pre	Average DTP Vaccination Rate: Post - Pre (Percentage Point)
Alameda	137	102	-25.9%	4.0
Alpine	0	0		
Amador	96	13	-86.5%	3.7
Butte	83	24	-70.5%	5.3
Calaveras	127	22	-82.7%	9.8
Colusa	114	0	-100.0%	-1.1
Contra Costa	144	65	-55.0%	1.8
Del Norte	92	0	-100.0%	5.4
El Dorado	108	26	-75.5%	2.8
Fresno	174	56	-68.0%	0.9
Glenn	26	9	-65.1%	-2.4
Humboldt	315	24	-92.4%	10.7
Imperial	35	46	30.5%	1.0
Inyo	70	98	39.3%	-0.8
Kern	130	39	-70.3%	0.0
Kings	61	28	-53.4%	0.0
Lake	49	55	11.4%	4.6

[13] Table 1.1 shows California counties from before (2010-2015) to after (2016-2019) implementation of California's vaccine mandate.

County	Pertussis Case Every 1 million Population: Pre (2009-2015)	Pertussis Case Every 1 million Population: Post (2016-2019)	% Reduction of Pertussis Case Every 1 million Population: Post vs. Pre	Average DTP Vaccination Rate: Post - Pre (Percentage Point)
Lassen	26	0	-100.0%	7.1
Los Angeles	89	78	-12.7%	4.0
Madera	187	120	-35.8%	0.1
Marin	505	374	-26.0%	8.8
Mariposa	88	86	-1.3%	6.6
Mendocino	100	60	-39.7%	5.2
Merced	119	22	-81.5%	0.7
Modoc	92	85	-7.7%	0.8
Mono	433	0	-100.0%	2.2
Monterey	154	82	-47.0%	3.3
Napa	263	117	-55.7%	1.3
Nevada	176	181	3.2%	8.0
Orange	71	49	-30.4%	4.2
Placer	147	110	-24.9%	4.5
Plumas	74	67	-9.8%	4.4
Riverside	93	43	-54.0%	1.6
Sacramento	110	57	-48.3%	6.5
San Benito	86	94	9.9%	0.2
San Bernardino	49	19	-61.8%	0.9
San Diego	233	228	-2.1%	1.3
San Francisco	89	34	-61.2%	3.8
San Joaquin	93	21	-76.9%	-0.7
San Luis Obispo	255	77	-69.8%	6.2
San Mateo	108	136	26.9%	2.9

County	Pertussis Case Every 1 million Population: Pre (2009-2015)	Pertussis Case Every 1 million Population: Post (2016-2019)	% Reduction of Pertussis Case Every 1 million Population: Post vs. Pre	Average DTP Vaccination Rate: Post - Pre (Percentage Point)
Santa Barbara	115	39	-66.3%	2.2
Santa Clara	130	112	-13.8%	1.5
Santa Cruz	246	464	88.5%	6.3
Shasta	95	49	-48.5%	7.7
Sierra	0	0		-0.2
Siskiyou	97	17	-82.3%	7.6
Solano	92	50	-45.5%	1.1
Sonoma	346	158	-54.4%	2.0
Stanislaus	103	27	-73.2%	1.4
Sutter	29	16	-45.7%	-9.1
Tehama	122	23	-80.9%	1.4
Trinity	127	40	-68.8%	10.7
Tulare	158	34	-78.5%	0.4
Tuolumne	170	32	-81.0%	11.2
Ventura	186	82	-56.1%	4.4
Yolo	184	119	-35.4%	2.1
Yuba	41	120	191.9%	1.9

Table 1.2 Measles Case Rate and MMR Vaccination Coverage: Pre- and Post-Mandate Comparison[14]

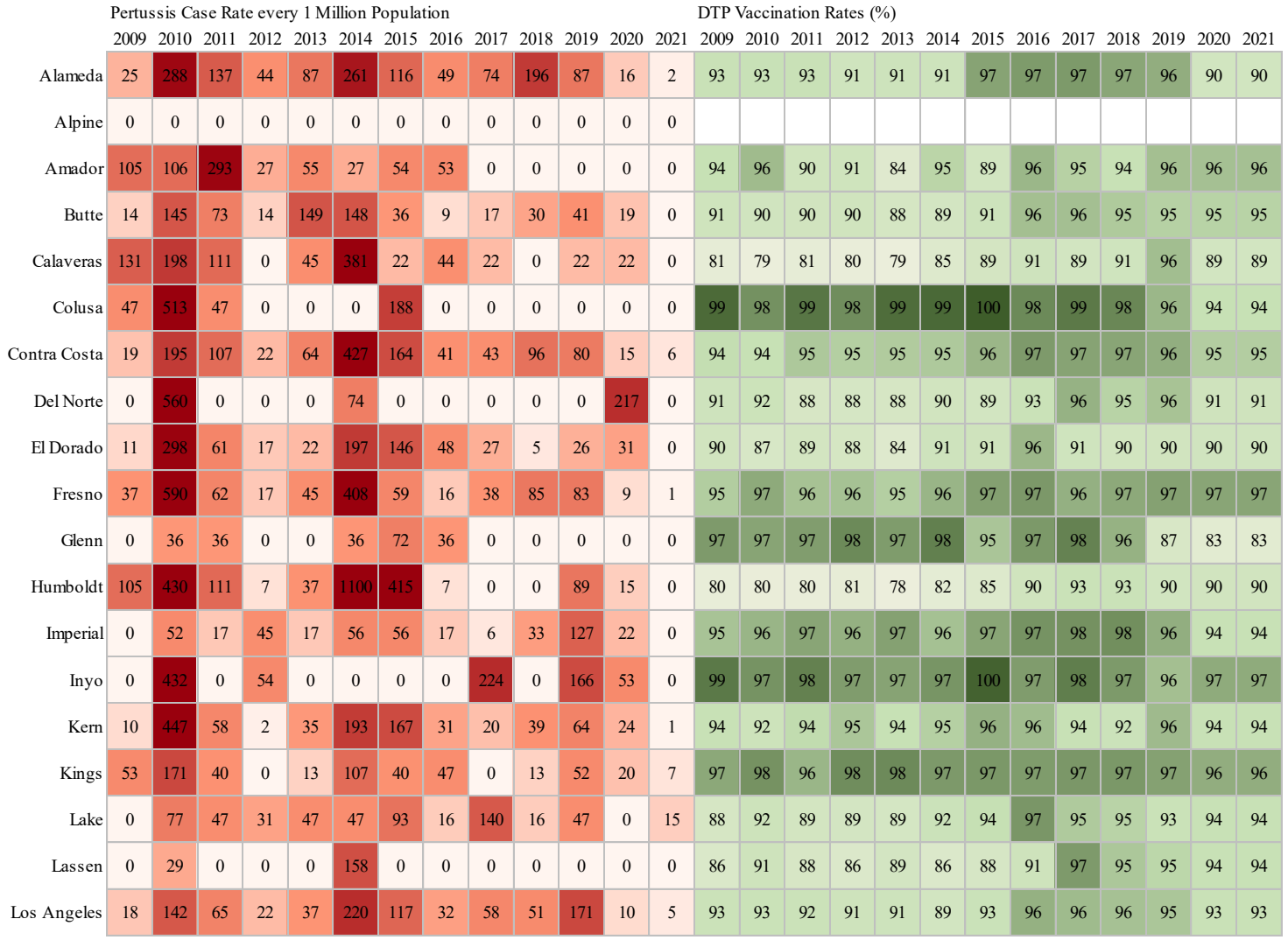
County	Measles Case Every 1 million Population: Pre (2009-2015)	Measles Case Every 1 million Population: Post (2016-2019)	% Reduction of Measles Case Every 1 million Population: Post vs. Pre	Average MMR Vaccination Rate: Post - Pre (Percentage Point)
Alameda	1	0	-79.5%	3.5
Alpine	0	0		
Amador	4	0	-100.0%	4.7
Butte	0	14		5.8
Calaveras	0	5		9.4
Colusa	0	0		-0.7
Contra Costa	1	0	-72.5%	1.7
Del Norte	0	0		6.0
El Dorado	0	0		3.1
Fresno	0	0		0.6
Glenn	0	9		-2.4
Humboldt	2	0	-100.0%	10.4
Imperial	0	0		1.5
Inyo	0	0		-0.3
Kern	0	0		0.5
Kings	0	0		0.0
Lake	0	0		5.1
Lassen	0	0		7.5
Los Angeles	1	1	25.2%	4.0
Madera	0	0		0.2
Marin	1	0	-100.0%	9.0

[14] Table 1.2 shows California counties from before (2010-2015) to after (2016-2019) implementation of California's vaccine mandate.

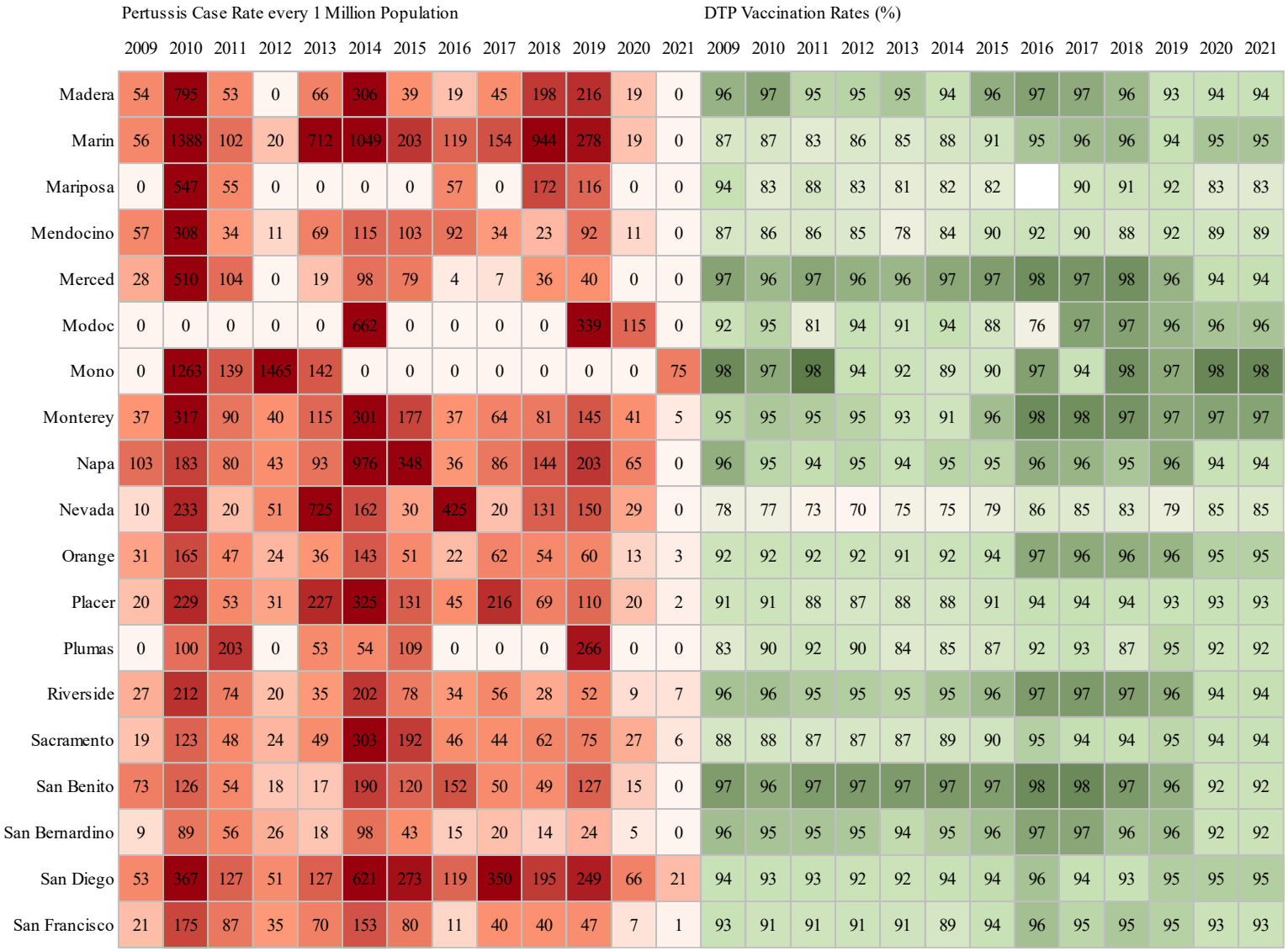
County	Measles Case Every 1 million Population: Pre (2009-2015)	Measles Case Every 1 million Population: Post (2016-2019)	% Reduction of Measles Case Every 1 million Population: Post vs. Pre	Average MMR Vaccination Rate: Post - Pre (Percentage Point)
Mariposa	0	0		9.4
Mendocino	7	3	-56.2%	6.0
Merced	2	0	-100.0%	0.9
Modoc	0	0		2.1
Mono	0	0		2.8
Monterey	1	0	-100.0%	3.0
Napa	3	0	-100.0%	1.6
Nevada	0	8		8.2
Orange	3	1	-75.4%	4.3
Placer	0	2		4.8
Plumas	0	0		4.3
Riverside	1	0	-89.8%	1.8
Sacramento	0	1	561.4%	6.9
San Benito	3	0	-100.0%	0.3
San Bernardino	1	0	-74.2%	1.1
San Diego	1	0	-77.7%	1.4
San Francisco	2	0	-81.6%	2.6
San Joaquin	0	0	-100.0%	-0.5
San Luis Obispo	1	3	408.6%	6.3
San Mateo	2	2	17.8%	2.9
Santa Barbara	0	2		2.1
Santa Clara	1	2	89.0%	1.4
Santa Cruz	2	1	-43.2%	6.7
Shasta	1	4	420.6%	8.3

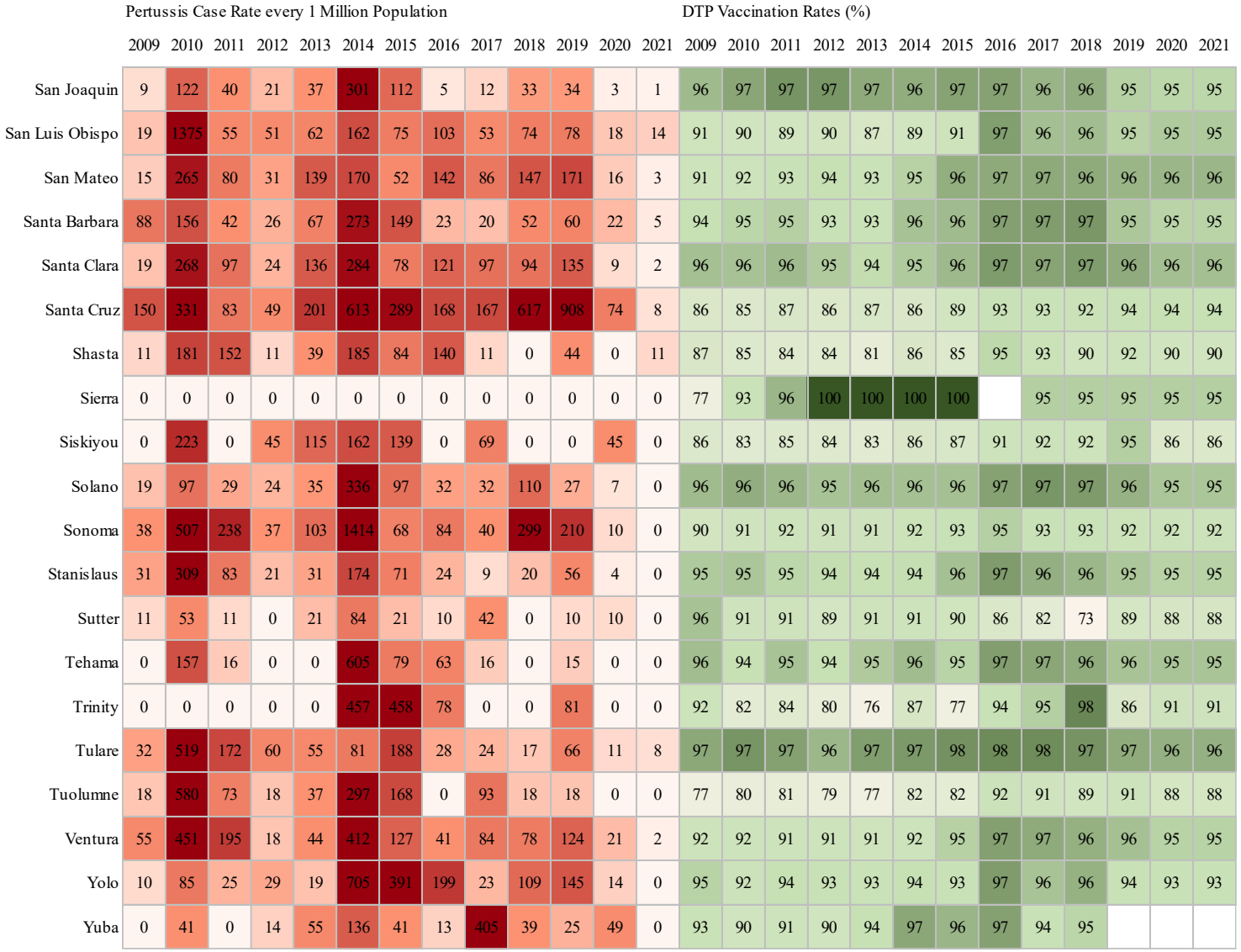
County	Measles Case Every 1 million Population: Pre (2009-2015)	Measles Case Every 1 million Population: Post (2016-2019)	% Reduction of Measles Case Every 1 million Population: Post vs. Pre	Average MMR Vaccination Rate: Post - Pre (Percentage Point)
Sierra	0	0		-0.2
Siskiyou	0	0		7.3
Solano	0	0	-100.0%	1.3
Sonoma	0	0	-100.0%	1.8
Stanislaus	0	0	-100.0%	1.6
Sutter	0	0		-9.1
Tehama	0	4		1.7
Trinity	0	0		12.1
Tulare	0	1		0.4
Tuolumne	0	0		12.9
Ventura	2	1	-63.2%	4.1
Yolo	1	0	-100.0%	2.4
Yuba	2	0	-100.0%	2.5

Figure 1.6 Heatmap: Pertussis Case Rate and DTP Vaccination Rate in California Counties



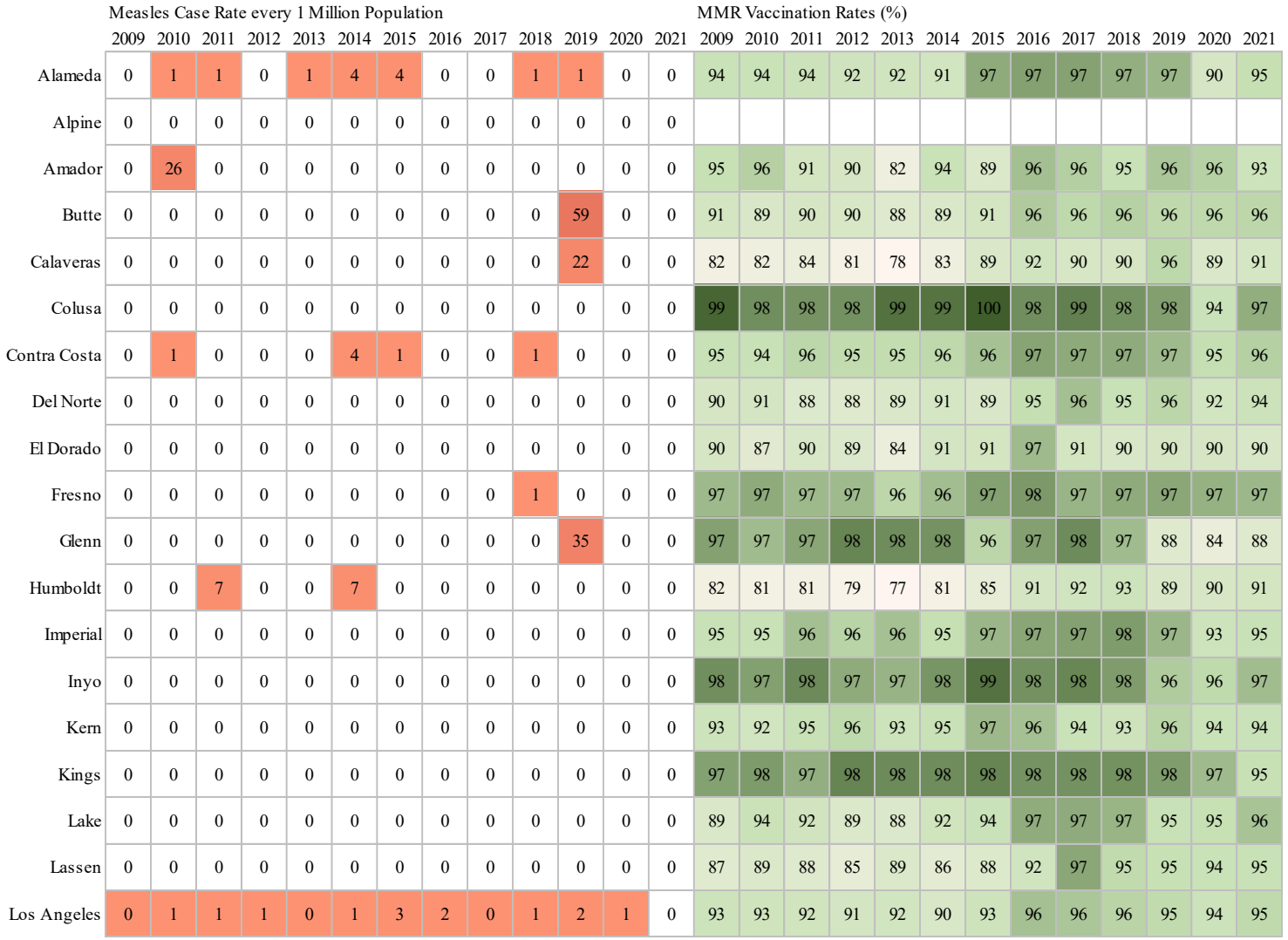
	Pertussis Case Rate every 1 Million Population													DTP Vaccination Rates (%)											
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Alameda	25	288	137	44	87	261	116	49	74	196	87	16	2	93	93	93	91	91	91	97	97	97	97	96	90	90
Alpine	0	0	0	0	0	0	0	0	0	0	0	0	0													
Amador	105	106	293	27	55	27	54	53	0	0	0	0	0	94	96	90	91	84	95	89	96	95	94	96	96	96
Butte	14	145	73	14	149	148	36	9	17	30	41	19	0	91	90	90	90	88	89	91	96	96	95	95	95	95
Calaveras	131	198	111	0	45	381	22	44	22	0	22	22	0	81	79	81	80	79	85	89	91	89	91	96	89	89
Colusa	47	513	47	0	0	0	188	0	0	0	0	0	0	99	98	99	98	99	99	100	98	99	98	96	94	94
Contra Costa	19	195	107	22	64	427	164	41	43	96	80	15	6	94	94	95	95	95	95	96	97	97	97	96	95	95
Del Norte	0	560	0	0	0	74	0	0	0	0	0	217	0	91	92	88	88	88	90	89	93	96	95	96	91	91
El Dorado	11	298	61	17	22	197	146	48	27	5	26	31	0	90	87	89	88	84	91	91	96	91	90	90	90	90
Fresno	37	590	62	17	45	408	59	16	38	85	83	9	1	95	97	96	96	95	96	97	97	96	97	97	97	97
Glenn	0	36	36	0	0	36	72	36	0	0	0	0	0	97	97	97	98	97	98	95	97	98	96	87	83	83
Humboldt	105	430	111	7	37	1100	415	7	0	0	89	15	0	80	80	80	81	78	82	85	90	93	93	90	90	90
Imperial	0	52	17	45	17	56	56	17	6	33	127	22	0	95	96	97	96	97	96	97	97	98	98	96	94	94
Inyo	0	432	0	54	0	0	0	0	224	0	166	53	0	99	97	98	97	97	97	100	97	98	97	96	97	97
Kern	10	447	58	2	35	193	167	31	20	39	64	24	1	94	92	94	95	94	95	96	96	94	92	96	94	94
Kings	53	171	40	0	13	107	40	47	0	13	52	20	7	97	98	96	98	98	97	97	97	97	97	97	96	96
Lake	0	77	47	31	47	47	93	16	140	16	47	0	15	88	92	89	89	89	92	94	97	95	95	93	94	94
Lassen	0	29	0	0	0	158	0	0	0	0	0	0	0	86	91	88	86	89	86	88	91	97	95	95	94	94
Los Angeles	18	142	65	22	37	220	117	32	58	51	171	10	5	93	93	92	91	91	89	93	96	96	96	95	93	93


Pertussis Case Rate every 1 Million Population
DTP Vaccination Rates (%)
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021
Madera 54 795 53 0 66 306 39 19 45 198 216 19 0 96 97 95 95 95 94 96 97 97 96 93 94 94
Marin 56 1388 102 20 712 1049 203 119 154 944 278 19 0 87 87 83 86 85 88 91 95 96 96 94 95 95
Mariposa 0 547 55 0 0 0 0 57 0 172 116 0 0 94 83 88 83 81 82 82 90 91 92 83 83
Mendocino 57 308 34 11 69 115 103 92 34 23 92 11 0 87 86 86 85 78 84 90 92 90 88 92 89 89
Merced 28 510 104 0 19 98 79 4 7 36 40 0 0 97 96 97 96 96 97 97 98 97 98 96 94 94
Modoc 0 0 0 0 0 662 0 0 0 0 339 115 0 92 95 81 94 91 94 88 76 97 97 96 96 96
Mono 0 1263 139 1465 142 0 0 0 0 0 0 0 75 98 97 98 94 92 89 90 97 94 98 97 98 98
Monterey 37 317 90 40 115 301 177 37 64 81 145 41 5 95 95 95 95 93 91 96 98 98 97 97 97 97
Napa 103 183 80 43 93 976 348 36 86 144 203 65 0 96 95 94 95 94 95 95 96 96 95 96 94 94
Nevada 10 233 20 51 725 162 30 425 20 131 150 29 0 78 77 73 70 75 75 79 86 85 83 79 85 85
Orange 31 165 47 24 36 143 51 22 62 54 60 13 3 92 92 92 92 91 92 94 97 96 96 96 95 95
Placer 20 229 53 31 227 325 131 45 216 69 110 20 2 91 91 88 87 88 88 91 94 94 94 93 93 93
Plumas 0 100 203 0 53 54 109 0 0 0 266 0 0 83 90 92 90 84 85 87 92 93 87 95 92 92
Riverside 27 212 74 20 35 202 78 34 56 28 52 9 7 96 96 95 95 95 95 96 97 97 97 96 94 94
Sacramento 19 123 48 24 49 303 192 46 44 62 75 27 6 88 88 87 87 87 89 90 95 94 94 95 94 94
San Benito 73 126 54 18 17 190 120 152 50 49 127 15 0 97 96 97 97 97 97 97 98 98 97 96 92 92
San Bernardino 9 89 56 26 18 98 43 15 20 14 24 5 0 96 95 95 95 94 95 96 97 97 96 96 92 92
San Diego 53 367 127 51 127 621 273 119 350 195 249 66 21 94 93 93 92 92 94 94 96 94 93 95 95 95
San Francisco 21 175 87 35 70 153 80 11 40 40 47 7 1 93 91 91 91 91 89 94 96 95 95 95 93 93

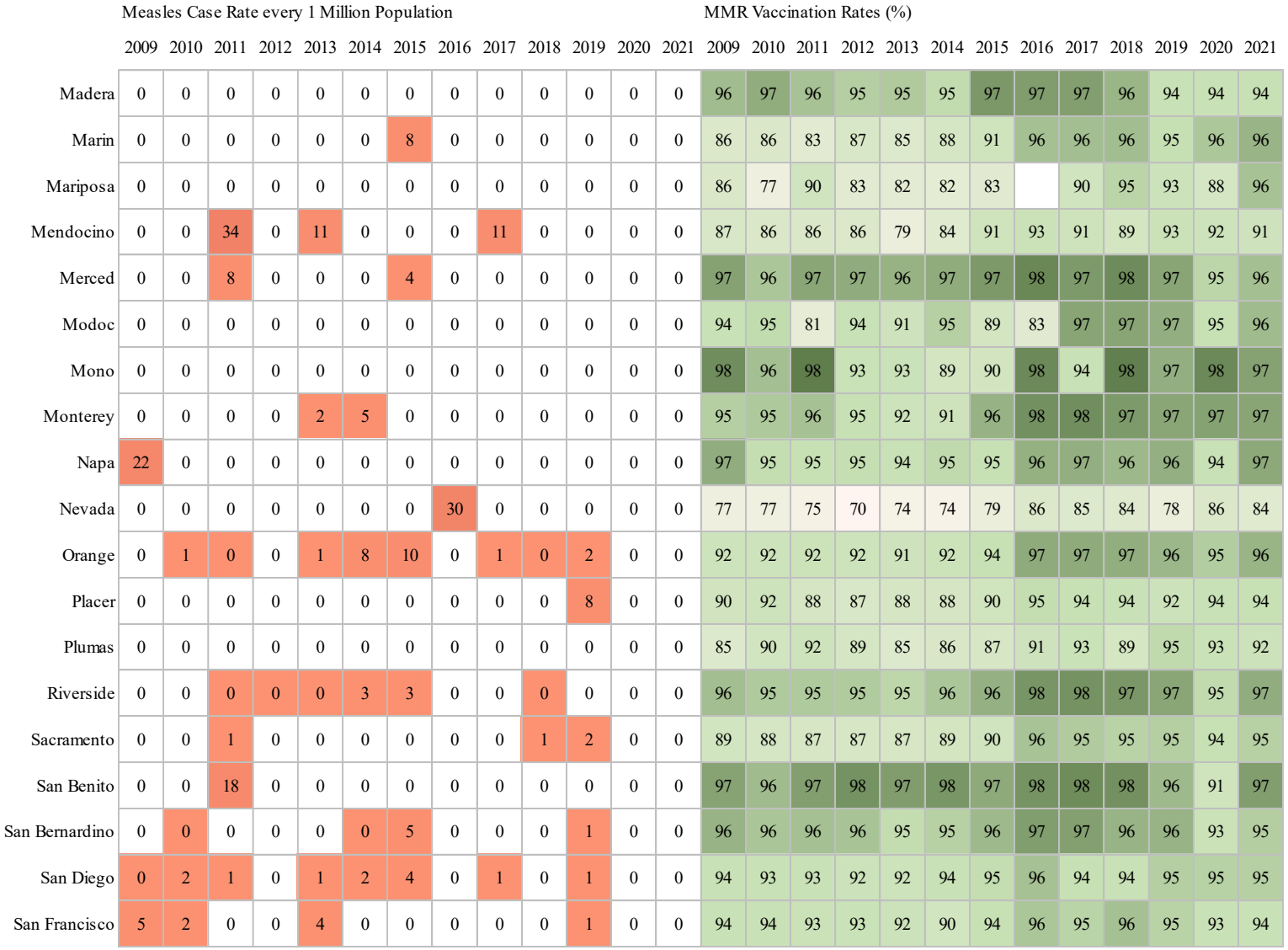


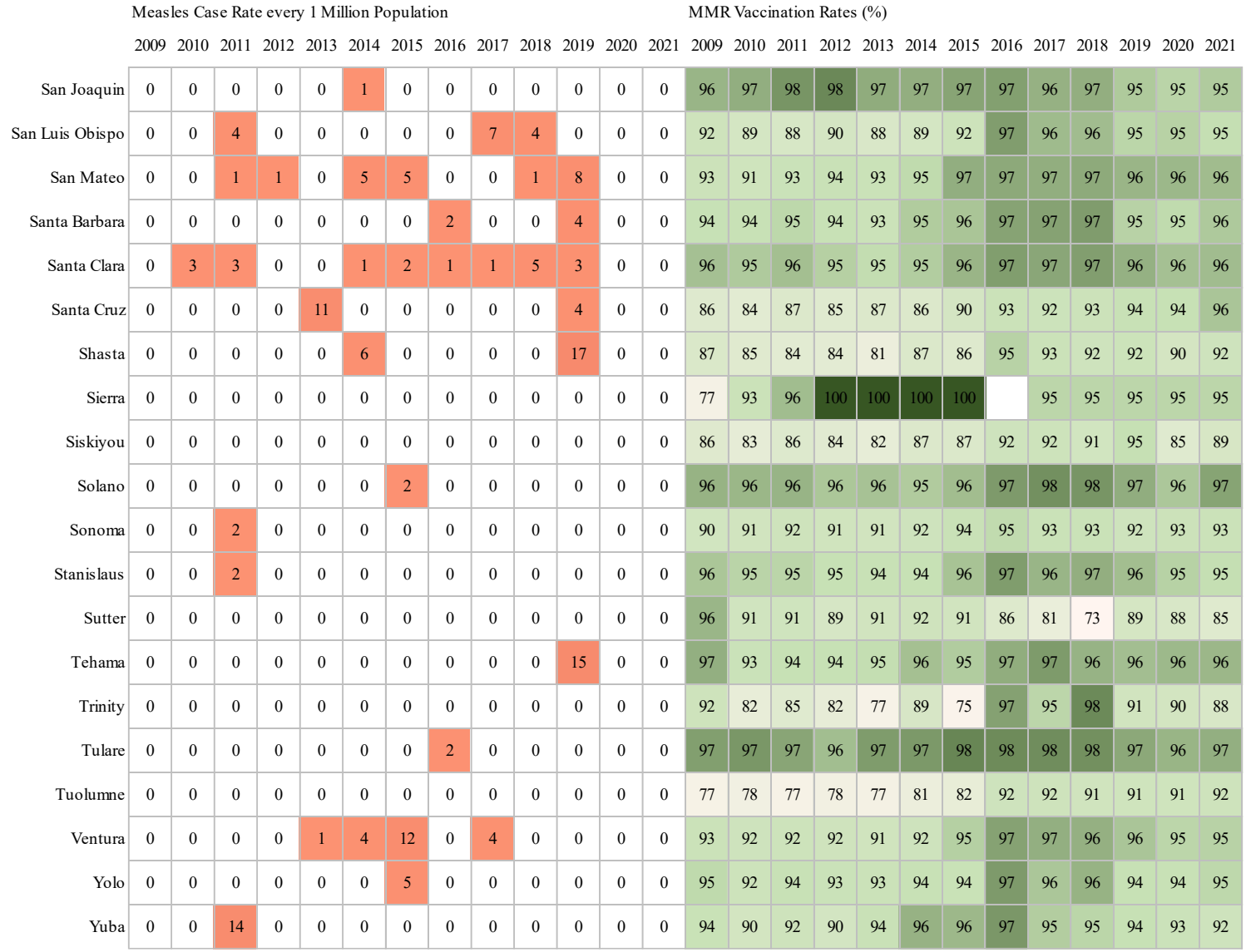
	Pertussis Case Rate every 1 Million Population													DTP Vaccination Rates (%)											
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
San Joaquin	9	122	40	21	37	301	112	5	12	33	34	3	1	96	97	97	97	97	96	97	97	96	96	95	95	95
San Luis Obispo	19	1375	55	51	62	162	75	103	53	74	78	18	14	91	90	89	90	87	89	91	97	96	96	95	95	95
San Mateo	15	265	80	31	139	170	52	142	86	147	171	16	3	91	92	93	94	93	95	96	97	97	96	96	96	96
Santa Barbara	88	156	42	26	67	273	149	23	20	52	60	22	5	94	95	95	93	93	96	96	97	97	97	95	95	95
Santa Clara	19	268	97	24	136	284	78	121	97	94	135	9	2	96	96	96	95	94	95	96	97	97	97	96	96	96
Santa Cruz	150	331	83	49	201	613	289	168	167	617	908	74	8	86	85	87	86	87	86	89	93	93	92	94	94	94
Shasta	11	181	152	11	39	185	84	140	11	0	44	0	11	87	85	84	84	81	86	85	95	93	90	92	90	90
Sierra	0	0	0	0	0	0	0	0	0	0	0	0	0	77	93	96	100	100	100	100		95	95	95	95	95
Siskiyou	0	223	0	45	115	162	139	0	69	0	0	45	0	86	83	85	84	83	86	87	91	92	92	95	86	86
Solano	19	97	29	24	35	336	97	32	32	110	27	7	0	96	96	96	95	96	96	96	97	97	97	96	95	95
Sonoma	38	507	238	37	103	1414	68	84	40	299	210	10	0	90	91	92	91	91	92	93	95	93	93	92	92	92
Stanislaus	31	309	83	21	31	174	71	24	9	20	56	4	0	95	95	95	94	94	94	96	97	96	96	95	95	95
Sutter	11	53	11	0	21	84	21	10	42	0	10	10	0	96	91	91	89	91	91	90	86	82	73	89	88	88
Tehama	0	157	16	0	0	605	79	63	16	0	15	0	0	96	94	95	94	95	96	95	97	97	96	96	95	95
Trinity	0	0	0	0	0	457	458	78	0	0	81	0	0	92	82	84	80	76	87	77	94	95	98	86	91	91
Tulare	32	519	172	60	55	81	188	28	24	17	66	11	8	97	97	97	96	97	97	98	98	98	97	97	96	96
Tuolumne	18	580	73	18	37	297	168	0	93	18	18	0	0	77	80	81	79	77	82	82	92	91	89	91	88	88
Ventura	55	451	195	18	44	412	127	41	84	78	124	21	2	92	92	91	91	91	92	95	97	97	96	96	95	95
Yolo	10	85	25	29	19	705	391	199	23	109	145	14	0	95	92	94	93	93	94	93	97	96	96	94	93	93
Yuba	0	41	0	14	55	136	41	13	405	39	25	49	0	93	90	91	90	94	97	96	97	94	95			

Figure 1.7 Heatmap: Measles Case Rate and MMR Vaccination Rate in California Counties



	Measles Case Rate every 1 Million Population													MMR Vaccination Rates (%)											
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Alameda	0	1	1	0	1	4	4	0	0	1	1	0	0	94	94	94	92	92	91	97	97	97	97	97	90	95
Alpine	0	0	0	0	0	0	0	0	0	0	0	0	0													
Amador	0	26	0	0	0	0	0	0	0	0	0	0	0	95	96	91	90	82	94	89	96	96	95	96	96	93
Butte	0	0	0	0	0	0	0	0	0	0	59	0	0	91	89	90	90	88	89	91	96	96	96	96	96	96
Calaveras	0	0	0	0	0	0	0	0	0	0	22	0	0	82	82	84	81	78	83	89	92	90	90	96	89	91
Colusa	0	0	0	0	0	0	0	0	0	0	0	0	0	99	98	98	98	99	99	100	98	99	98	98	94	97
Contra Costa	0	1	0	0	0	4	1	0	0	1	0	0	0	95	94	96	95	95	96	96	97	97	97	97	95	96
Del Norte	0	0	0	0	0	0	0	0	0	0	0	0	0	90	91	88	88	89	91	89	95	96	95	96	92	94
El Dorado	0	0	0	0	0	0	0	0	0	0	0	0	0	90	87	90	89	84	91	91	97	91	90	90	90	90
Fresno	0	0	0	0	0	0	0	0	0	1	0	0	0	97	97	97	97	96	96	97	98	97	97	97	97	97
Glenn	0	0	0	0	0	0	0	0	0	0	35	0	0	97	97	97	98	98	98	96	97	98	97	88	84	88
Humboldt	0	0	7	0	0	7	0	0	0	0	0	0	0	82	81	81	79	77	81	85	91	92	93	89	90	91
Imperial	0	0	0	0	0	0	0	0	0	0	0	0	0	95	95	96	96	96	95	97	97	97	98	97	93	95
Inyo	0	0	0	0	0	0	0	0	0	0	0	0	0	98	97	98	97	97	98	99	98	98	98	96	96	97
Kern	0	0	0	0	0	0	0	0	0	0	0	0	0	93	92	95	96	93	95	97	96	94	93	96	94	94
Kings	0	0	0	0	0	0	0	0	0	0	0	0	0	97	98	97	98	98	98	98	98	98	98	98	97	95
Lake	0	0	0	0	0	0	0	0	0	0	0	0	0	89	94	92	89	88	92	94	97	97	97	95	95	96
Lassen	0	0	0	0	0	0	0	0	0	0	0	0	0	87	89	88	85	89	86	88	92	97	95	95	94	95
Los Angeles	0	1	1	1	0	1	3	2	0	1	2	1	0	93	93	92	91	92	90	93	96	96	96	95	94	95


Measles Case Rate every 1 Million Population
MMR Vaccination Rates (%)
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021
Madera 0 0 0 0 0 0 0 0 0 0 0 0 0 96 97 96 95 95 95 97 97 97 96 94 94 94
Marin 0 0 0 0 0 0 8 0 0 0 0 0 0 86 86 83 87 85 88 91 96 96 96 95 96 96
Mariposa 0 0 0 0 0 0 0 0 0 0 0 0 0 86 77 90 83 82 82 83 90 95 93 88 96
Mendocino 0 0 34 0 11 0 0 0 11 0 0 0 0 87 86 86 86 79 84 91 93 91 89 93 92 91
Merced 0 0 8 0 0 0 4 0 0 0 0 0 0 97 96 97 97 96 97 97 98 97 98 97 95 96
Modoc 0 0 0 0 0 0 0 0 0 0 0 0 0 94 95 81 94 91 95 89 83 97 97 97 95 96
Mono 0 0 0 0 0 0 0 0 0 0 0 0 0 98 96 98 93 93 89 90 98 94 98 97 98 97
Monterey 0 0 0 0 2 5 0 0 0 0 0 0 0 95 95 96 95 92 91 96 98 98 97 97 97 97
Napa 22 0 0 0 0 0 0 0 0 0 0 0 0 97 95 95 95 94 95 95 96 97 96 96 94 97
Nevada 0 0 0 0 0 0 0 30 0 0 0 0 0 77 77 75 70 74 74 79 86 85 84 78 86 84
Orange 0 1 0 0 1 8 10 0 1 0 2 0 0 92 92 92 92 91 92 94 97 97 97 96 95 96
Placer 0 0 0 0 0 0 0 0 0 0 8 0 0 90 92 88 87 88 88 90 95 94 94 92 94 94
Plumas 0 0 0 0 0 0 0 0 0 0 0 0 0 85 90 92 89 85 86 87 91 93 89 95 93 92
Riverside 0 0 0 0 0 3 3 0 0 0 0 0 0 96 95 95 95 95 96 96 98 98 97 97 95 97
Sacramento 0 0 1 0 0 0 0 0 0 1 2 0 0 89 88 87 87 87 89 90 96 95 95 95 94 95
San Benito 0 0 18 0 0 0 0 0 0 0 0 0 0 97 96 97 98 97 98 97 98 98 98 96 91 97
San Bernardino 0 0 0 0 0 0 5 0 0 0 1 0 0 96 96 96 96 95 95 96 97 97 96 96 93 95
San Diego 0 2 1 0 1 2 4 0 1 0 1 0 0 94 93 93 92 92 94 95 96 94 94 95 95 95
San Francisco 5 2 0 0 4 0 0 0 0 0 1 0 0 94 94 93 93 92 90 94 96 95 96 95 93 94



	Measles Case Rate every 1 Million Population													MMR Vaccination Rates (%)											
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
San Joaquin	0	0	0	0	0	1	0	0	0	0	0	0	0	96	97	98	98	97	97	97	97	96	97	95	95	95
San Luis Obispo	0	0	4	0	0	0	0	0	7	4	0	0	0	92	89	88	90	88	89	92	97	96	96	95	95	95
San Mateo	0	0	1	1	0	5	5	0	0	1	8	0	0	93	91	93	94	93	95	97	97	97	97	96	96	96
Santa Barbara	0	0	0	0	0	0	0	2	0	0	4	0	0	94	94	95	94	93	95	96	97	97	97	95	95	96
Santa Clara	0	3	3	0	0	1	2	1	1	5	3	0	0	96	95	96	95	95	95	96	97	97	97	96	96	96
Santa Cruz	0	0	0	0	11	0	0	0	0	0	4	0	0	86	84	87	85	87	86	90	93	92	93	94	94	96
Shasta	0	0	0	0	0	6	0	0	0	0	17	0	0	87	85	84	84	81	87	86	95	93	92	92	90	92
Sierra	0	0	0	0	0	0	0	0	0	0	0	0	0	77	93	96	100	100	100	100		95	95	95	95	95
Siskiyou	0	0	0	0	0	0	0	0	0	0	0	0	0	86	83	86	84	82	87	87	92	92	91	95	85	89
Solano	0	0	0	0	0	0	2	0	0	0	0	0	0	96	96	96	96	96	95	96	97	98	98	97	96	97
Sonoma	0	0	2	0	0	0	0	0	0	0	0	0	0	90	91	92	91	91	92	94	95	93	93	92	93	93
Stanislaus	0	0	2	0	0	0	0	0	0	0	0	0	0	96	95	95	95	94	94	96	97	96	97	96	95	95
Sutter	0	0	0	0	0	0	0	0	0	0	0	0	0	96	91	91	89	91	92	91	86	81	73	89	88	85
Tehama	0	0	0	0	0	0	0	0	0	0	15	0	0	97	93	94	94	95	96	95	97	97	96	96	96	96
Trinity	0	0	0	0	0	0	0	0	0	0	0	0	0	92	82	85	82	77	89	75	97	95	98	91	90	88
Tulare	0	0	0	0	0	0	0	2	0	0	0	0	0	97	97	97	96	97	97	98	98	98	98	97	96	97
Tuolumne	0	0	0	0	0	0	0	0	0	0	0	0	0	77	78	77	78	77	81	82	92	92	91	91	91	92
Ventura	0	0	0	0	1	4	12	0	4	0	0	0	0	93	92	92	92	91	92	95	97	97	96	96	95	95
Yolo	0	0	0	0	0	0	5	0	0	0	0	0	0	95	92	94	93	93	94	94	97	96	96	94	94	95
Yuba	0	0	14	0	0	0	0	0	0	0	0	0	0	94	90	92	90	94	96	96	97	95	95	94	93	92

Essay 2: California's 2016 Vaccine Mandate on Vaccination Coverage and Disease Burden – A Causal Study

2.1 Introduction

2.1.1 School-Entry Vaccination Requirement and Hesitancy

School-entry vaccine mandates in the United States (U.S.) require children to be immunized against vaccine-preventable diseases (VPDs). This requirement serves as a prerequisite condition for students to enroll in public and private schools. Vaccination not only safeguards immunized individuals but also confers protection to the unvaccinated through herd immunity (Bullen et al., 2023; Mallory et al., 2018). In all states, public health laws stipulate that required immunization must be completed, before or at the beginning of each school year.

Despite having state-level mandates requiring a full vaccination compliance, medical or non-medical exemptions are commonly granted. Medical reasons include, for example, allergies to vaccine components, compromised immune systems such as immunity disorders, or chronic health conditions that make vaccination harmful.[15] Non-medical exemptions are typically granted based on religious, philosophical, or personal belief reasons (PBE) (Bednarczyk et al., 2019). Evidence points out that parents might have used these non-medical exemptions to skip vaccination requirements (Tomsick, 2020), which makes them controversial even today. As of August 2024, most states allow a combination of medical, religious, and philosophical exemptions. A small number of

[15] Retrieved from the Centers for Disease Control and Prevention (CDC): https://www.cdc.gov/vaccines/vpd/should-not-vacc.html

states, such as California, New York, and West Virginia, allow exemptions only for documented medical reasons.[16]

Vaccine hesitancy is widely recognized as a critical contributing factor behind the rise of non-medical exemptions (Goldstein et al., 2022). First, on childhood vaccination, a series of studies published in the late1990s and early 2000s provoked controversy by falsely linking vaccination to the development of autism. Although subsequent studies have proven this claim misleading, there is a lingering fear among parents, many of whom continue to believe and associate vaccination with negative health effects on early childhood development (Gabis et al., 2022; DeStefano et al., 2019). Second, while most religions in the U.S. do not explicitly oppose vaccination, certain religious beliefs have been invoked to express skepticism around the safety, necessity, and morality of childhood immunization (Tomsick, 2020). Third, refusal to vaccination is common among individuals who view mandatory vaccination as an opposition to personal liberty. Such individuals may frame objection based on their distrust in coercive government interventions and political motivates associated with mandatory vaccination programs, requirements, and compliance (Habakus et al., 2012; Attwell and Hannah, 2022).

The types of vaccination allowances states permit are subject to constant and ongoing revisions and policy changes. State authorities are often vested with autonomy to modify their school-entry immunization requirements in response to public health needs, such as to control the increasing disease outbreaks. These adjustments in turn reshape the policy landscapes surrounding vaccination and related requirements.

[16] Retrieved from The National Conference of State Legislatures: https://www.ncsl.org/health/state-non-medical-exemptions-from-school-immunization-requirements

2.1.2 Requirement and Mandate in California

Adjusting vaccination requirements for school-entry is not a novel policy instrument in California or other states. These adjustments are typically directional, reflecting each state's independent authority to either tighten or relax immunization requirements. For instance, states can expand exemptions: California introduced personal belief exemptions in 1995[17] and Texas followed the same path in 2003 (Hair et al., 2023). On the other hand, states may also remove or limit exemptions to strengthen vaccination compliance. For example, California's 2016 vaccine mandate repealed all non-medical exemptions. Similarly, New York and Maine also repealed religious exemptions in 2019, which demonstrates the state autonomy and leadership in shaping tailored vaccination policies, in response to a deteriorating public health environment (Correira et al., 2024).

Historically, California implemented its first school-entry vaccine mandate in 1961, requiring childhood immunization against polio to be completed for each child before school attendance (Conis and Kuo, 2011). In the 1970s, as part of a broader national movement to strengthen immunization coverage, California expanded its requirements to include the measles, mumps, and rubella (MMR) vaccine. Despite these mandates, non-medical exemptions have always been feasible. Throughout the 2000s, California authority continued to allow non-medical exemptions until the passage and adoption of the Senate Bill #277 (SB277) in 2016.

The allowance of non-medical exemptions before 2016 was widely recognized as a factor contributing to low vaccination coverage and an increasing trend of disease incidence in California (Delamater et al. 2017; Nyathi et al. 2019). Notwithstanding, a

[17] Retrieved from CA Bill Analysis on SB277: http://www.leginfo.ca.gov

critical tipping point came with the 2015 measles outbreak, which began at Disneyland Resort and spread quickly across twelve California counties between December 2014 and February 2015, resulting in a total number of more than 100 confirmed measles cases.

This outbreak primarily affected unvaccinated clusters of young children, highlighting a decreased immunization coverage at the population health level. Coupled with a rising trend of pertussis with a few outbreaks in years leading up to 2016, California authority responded promptly, by passing Senate Bill #277 in June 2015, eliminating the allowance of all non-medical exemptions. The mandate became effective in 2016, and starting school year 2016 and 2017, all students entering public or private elementary or secondary schools, childcare centers, day nursery, nursery school, daycare homes, and development centers,[18] were required to be fully vaccinated against specified VPDs,[19] unless they qualified for a medical exemption.

Before 2016, to file a personal belief exemption, parents or guardians could simply submit a standard form to schools stating their objection based on personal belief reasons. Then, their children could enroll in schools without immunization. In 2014, two years before the mandate, California authority introduced an amendment requiring parents seeking personal belief exemptions to first consult with a licensed healthcare provider on the risks of skipping immunization (Weithorn and Reiss, 2018). A signed confirmation form from the provider was required to activate the exemption. There were no major distinctions between stipulations on religious and personal belief exemptions,

[18] Retrieved from Legal Info CA: http://www.leginfo.ca.gov/pub/15-16/bill/sen/sb_0251-0300/sb_277_bill_20150630_chaptered.html
[19] Include shots against Diphtheria, Tetanus, and Pertussis, Polio, Hepatitis B, Measles, Mumps, and Rubella, and Varicella. Retrieved from CDPH: https://www.cdph.ca.gov/Programs/CID/DCDC/Pages/Immunization/School/tk-12-immunizations.aspx

and personal belief exemptions were broadly interpreted to also include religious reasons. Additionally, once granted, renewal or re-verification was only necessary when a child reached an educational transition point, such as entering 7th grade.

California's 2016 vaccine mandate specifically targets students advancing to the 7th grade or enrolling in schools for the first time.[20] Under the mandate, only statements from licensed physicians explaining that immunization is unsafe for the child due to medical circumstances could be accepted. Reasons for medical exemption required documentation stating the specific condition, which vaccines were being exempted, and whether such exemption was temporary or permanent, and the expiration date. Children with pre-existing non-medical exemptions obtained before 2016 were allowed to remain in schools until their admission to the next grade. In 2021, California enacted additional legislation requiring examination and audit on submitted medical exemptions.[21]

Despite California's landmark revision removing non-medical exemptions through Senate Bill #277 legislation, the mandate remained controversial and sparked a debate around personal liberties and measures to preserve public health. Opponents framed the bill as an infringement of parental rights, while proponents advocated for protection toward local communities. Consequently, different parental behavioral patterns would manifest regarding compliance with the new law and requirements following the removal of the non-medical exemptions. First, parents who previously opted out using non-medical exemptions would comply with the mandate. Second, vaccine-hesitant parents, who relied on non-medical exemptions, might instead seek medical exemptions

[20] Retrieved from https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB277
[21] Retrieved from the California Department of Public Health: https://www.cdph.ca.gov/Programs/CID/DCDC/Pages/Immunization/School/laws-exemptions.aspx

to skip vaccination. Third, vaccine hesitant parents who strongly opposed to mandatory vaccination, might withdraw their children from schools, or relocate to states that still allow non-medical exemptions, or where exemptions are easier to obtain. Finally, tightening vaccination allowance may also bolter the activities of anti-vaccination groups.

Many studies already show evidence to support these potential consequences. For example, Richwine et al. (2019) evaluate the causal impact of the mandate and find an improved vaccination coverage and increased medical exemptions. Similarly, Delamater et al. (2019) report a substantial decline in school-entering kindergarteners who were not up to date on required vaccinations following the mandate implementation. Relatedly, Delamater et al. (2017) also identify an association between counties with extensive personal belief exemptions before the mandate and those with increased medical exemptions after, suggesting that parents could have leveraged physicians to obtain medical exemptions when the mandate became legally bidding. Additionally, both Bald and Gold (2025) and Delamater et al. (2016) suggest that the elimination of non-medical exemptions may result in increased homeschooling and migration to other states. Correira et al. (2025), in their study of New York's 2019 removal of non-medical exemptions[22], find an increase of 0.1% to 0.4% in homeschooling rates.

California's vaccine mandate offers an adequate opportunity to study its effects following a natural experiment design. Given that the policy only affects California children starting 2016, it, therefore, allows for a quantitative comparative study between

[22] In June 2019, in response to measles outbreaks, New York state governor signed Senate Bill S5700 to remove the non-medical exemption from school-entry vaccination requirements. The law took effect immediately. Details of the law can be found in: https://www.nysenate.gov/legislation/bills/2025/S5700

California and other states without mandates, from before to after the policy, to causally examine the direct and indirect outcomes.

2.1.3 Literature Gap and Research Scope

Since the adoption of California's 2016 vaccine mandate, its effects on vaccine uptakes have been widely studied (Richwine et al. 2019; Delamater et al. 2019; Delamater et al. 2017). While the literature has extensively examined the impact of the mandate on vaccination coverage, far few studies have explored its direct effects on disease prevalence. A major challenge hinges on the disease burden itself being an endogenous factor associated with the passage and adoption of the mandate. Another challenge lies in data limitations. Whereas health policy research often relies on the state-level National Immunization Survey Data (NIS), administered by the U.S. Centers for Disease Control and Prevention (CDC), as data source on vaccination coverage, there are few similar and more granular data sources on VPD prevalence.

This study aims to provide novel causal evidence, disclosing the impact of California's 2016 vaccine mandate on vaccination coverage and the prevalence of associated VPDs. Before assessing disease burden, I first examine the impact of this mandate on vaccination coverage. Specifically, relying on a unique county-level vaccination coverage database and a VPD prevalence dataset collected across states, I conduct an empirical examination of how the California 2016 vaccine mandate impacts measles, mumps, and rubella (MMR) and diphtheria-tetanus-pertussis (DTP) vaccine uptakes. Subsequently, I study changes in measles and pertussis disease burden as a result of the mandate. This study makes a substantial contribution to the policy evaluation literature on vaccine mandates by being one of the first studies to causally examine its

impact on disease prevalence. The findings yield timely and practical insights for policymakers, in shaping state-level responses and vaccination policies to future disease outbreaks.

The remainder of this paper is organized as follows: First, I provide an overview on the prevailing theories and literature on vaccine mandate and assumptions. I then present data and methodologies, followed by the results of the analyses and additional robustness checks. Finally, I review and discuss the limitations of the overall research design and analyses and conclude with the policy implications and discussions.

2.2 Theory and Hypotheses

In the realm of epidemiology, emergency of vaccine-preventable diseases is frequently attributed to vaccine hesitancy and refusal, which are major barriers to achieve adequate immunization coverage (Atwell and Salmon, 2014; Wong et al., 2020; Kubin, 2019). Other contributing factors include incomplete vaccination, disease importation from other regions, and waning immunities, all of which can further compromise public health efforts of disease control and contribute to VPD outbreaks (Ruderfer and Krilov, 2015; Hamilton, 2020). Moreover, individual-level perceived risk factors and related vaccination behaviors can collectively shape societal health outcomes, as they influence immunization coverage at an aggregated community level, which is a critical determinant to achieving herd immunity. The individual-level behavioral patterns and health outcomes could also vary by race, ethnicity, gender, and other groups, which in turn further complicates the efforts and dynamics of vaccine uptake, equity, and effectiveness (Ahmed et al., 2016; Deal et al., 2021).

Policy interventions targeting vaccination are often associated with immediate, measurable effects on coverage. Empirical studies consistently discover that vaccine mandates increase immunization, while policy relaxations reduce coverage (Greenberg, 2015; Oster, 2016; Carpenter and Lawler, 2017; Abrevaya and Mulligan, 2011). For example, Carpenter and Lawler (2017) show that requiring a Tdap booster in schools increases vaccine uptake and reduces pertussis burden. Abrevaya and Mulligan (2011), similarly, find that mandating the varicella vaccines helps boost vaccination rates. Moreover, Hair et al. (2021) even demonstrate that granting personal belief exemptions, the flip side of mandating, could reduce vaccine uptake, particularly among black and low-income preschool-aged children.

With regard to disease prevalence, limited evidence supports a two-way relationship between vaccination coverage and the incidence of VPDs. On the one hand, higher vaccination coverage helps limit disease transmission, which in turn alleviates the burden of diseases. On the other hand, higher VPD prevalence, particularly during large outbreaks, encourages more vaccination. Lee (2012) shows that vaccination programs reduce morbidity and mortality rates of disease incidence. Greenberg (2015), similarly, identifies that nearly all deaths from pertussis still occurred in infants under six months, emphasizing the importance of achieving high coverage to protect this vulnerable group. Oster (2016) finds that pertussis vaccination rates among school-entry children increased following an outbreak in the preceding year, with a large outbreak associated with a 1.2 percentage point decrease in the share of unvaccinated children. The study suggests that disease outbreaks serve a signaling function, prompting parental concern over school

safety and child health, which in turn motivates more parents to bring their children to vaccination clinics.

Drawing on the literature, California's 2016 vaccine mandate, is expected to achieve two major outcomes. First, a measurable increase in vaccination coverage; Subsequently, a reduction in the prevalence of VPDs. Examining this assumption is analytically valuable: as multiple behavioral and demographic factors associated with vaccines and vaccinations may mediate or undermine the intended mandate effects, thereby limiting their impact on both health and non-health outcomes.

2.3 Data

This study examines two types of outcomes associated with California's 2016 vaccine mandate: vaccination coverage and disease prevalence. Data on both types were collected from state public health departments and official immunization and VPD websites of California and other states. For states without publicly available data, county-level information was obtained through direct requests to state health officials, mainly through emailing.[23]

Our vaccination coverage data assess the county-level percentage of kindergarten-aged children who are up to date on the MMR and DTP vaccination, at the beginning of each school year.[24] Data are reported at the county level from 13 states and cover each school year between 2012 and 2018. Although data collection covers a broad array of

[23] Data collection took place between 2022 and 2023, under the leadership of Dr. Ali Moghtaderi of the Milken Institute School of Public Health, at George Washington University, Washington, D.C.
[24] CDC recommends 2 doses of MMR vaccines to be considered up to date. 5 doses of DTP vaccines are recommended but, in some states, this threshold can be relaxed to 3 to 4 doses depending on the specific state requirement.

vaccines, this study only focuses on MMR and DTP vaccines, which are directly linked to measles and pertussis, two VPD parameters being assessed for disease prevalence.

Historical disease prevalence data are reported at the county level and cover calendar years from 2001 to 2022. The data collection efforts include fourteen VPD,[25] contingent on the public availability of case counts. While data collection methods vary across states, most follow uniform reporting, which allows for standardized cross-state comparisons. The final VPD dataset includes 25 states, depending on the availability of standardized, publicly available data over time. A standardization process was still applied to ensure consistency in disease definitions and year-to-year comparability, which excluded early years where data were available for only a few VPDs in a few states. Therefore, the VPD analysis is restricted to the 2010-2019 period. This shortened time frame corresponds to the highest quality of data with the most complete reporting.

Although most states report on a core set of fourteen VPDs, this analysis is limited to measles and pertussis only, which states reported consistently, demonstrated variation over time. Additionally, the selection of measles and pertussis is also motivated by their policy relevance: the 2015 measles outbreak in Disneyland and Orange County and earlier pertussis outbreaks were key endogenous factors associated with and accelerated the adoption of California's 2016 vaccine mandate.

Even though most states collect a complete list of VPDs, the format and labelling of the data vary considerably across states and years. A major challenge in data harmonization is variation in terminology and formats across states. For example, Maryland reports "measles rubeola," while most other states use "measles." Moreover,

[25] We collected 14 VPDs from each state: measles, mumps, rubella, diphtheria, tetanus, pertussis, acute hepatitis b, hepatitis a, polio, influenza, Haemophilus influenza, meningococcal, and varicella.

data availability can be inconsistent: a disease may be reported in some years but omitted in others. Furthermore, distinguishing between “data not available’”, “data not collected”, and “zero cases reported” entails different coding implications. To address the lack of uniformity, we conducted a due diligence exercise using the limited information available on the state health department website and, where necessary, we verified data authenticity through direct communication with state health authorities. For example, in Colorado, missing values for measles were coded as zero cases, based on the identified data patterns and confirmation from the Colorado Department of Public Health and Environment.

Our vaccination coverage data reflect immunization status of kindergarteners each school year. In contrast, the VPD prevalence dataset captures the total number of reported cases throughout each calendar year. Ideally, the analysis would align calendar-year VPD data with school-year vaccination coverage data. However, because most state health departments report VPD cases only by calendar year, I was unable to disaggregate these data to match the school-year calendar. Furthermore, vaccine coverage data are age-sensitive, capturing immunization status among kindergarten-aged and school-eligible children. By contrast, VPD data are not specific to any age group, although both pertussis and measles are most prevalent among young children eligible for kindergartens and primary schools and are thus suitable for comparison with school-entry immunization data.

In addition to the outcome variables, I also include a series of covariates to control for potential confounding factors. For the vaccination coverage analysis, I incorporate demographic and socio-economic variables at the county level. These include the percentage of the population by age group, the percentage of White, Black, and

Hispanic populations, the percentage of male and female, the unemployment rate, median household income, and the highest level of education attained by female household members, etc.

The final vaccination coverage dataset includes 13 states,[26] comprising 607 counties spanning 2012 and 2018. The unit of analysis is "county-year", resulting in a total of 2,933 "country-year" units. For measles prevalence, the final dataset includes 984 counties across 22 states, spanning 2010 and 2018, and consists of 7,234 "county-year" observations. On pertussis, the final dataset comprises 1,305 counties from 25 states,[27] spanning 2010 and 2019, with a total of 10,695 "county-year" observations.

2.4 Methodology

2.4.1 Outcome Measure

I construct outcome variables to measure the causal impact of California's 2016 vaccine mandate on vaccination coverage and disease burden. For vaccination coverage, the outcome is defined as the county-level percentage of kindergarten-aged children who are up to date on the MMR and DTP vaccines at the beginning of each school year. Data used for the immunization coverage indicators cover school years between 2012 and 2018. To capture disease burden, I develop three outcome measures on a calendar-year basis. First, I measure the year-to-year case change, which reflects the absolute change in the number of reported VPD cases in a given county from one year to the next, capturing short term fluctuations in the infection level. Second, I calculate each county's annual

[26] Arizona, California, Connecticut, Kansas, Maine, Maryland, Massachusetts, Minnesota, North Dakota, Ohio, South Dakota, Texas, Washington.
[27] Arizona, California, Colorado, Connecticut, Delaware, Florida, Hawaii, Illinois, Iowa, Kansas, Maine, Maryland, Massachusetts, Minnesota, New Jersey, New York, North Carolina, North Dakota, Ohio, South Dakota, Texas, Virginia, Washington, West Virginia, and Wyoming,

case burden relative to its own 25th percentile VPD case count across all years. This 25th percentile value serves as a low-incidence benchmark, allowing for comparison of yearly disease burden and variation within each county.[28] Finally, I calculate case rates measured as VPD cases per 100,000 population for each county each calendar year. Data for the disease prevalence analysis covers years between 2010 and 2019.[29]

Among the three disease outcome variables, both the year-to-year change in VPD cases and relative cases count against each county's 25th percentile is designed to capture disease variability. VPD rate per certain population measures the standardized disease scale accounting for population size.

2.4.2 Difference-in-Differences (DiD)

To estimate the causal impact of the mandate on vaccination coverage and disease burden, I rely on a two-way fixed effects of the Difference-in-Differences (DiD) model. This approach leverages the 2016 policy change in California by comparing outcomes in California to those as comparison states without similar mandates, before and after policy implementation. Specifically, the DiD main specification for vaccination coverage is as follows:

$$V_{cst} = \alpha_c + \lambda_t + \delta X_{ct} + \mu VPD_{incidence} + \eta VPD_{incidence-1} + \beta Mandate + \varepsilon_{cst}$$

In the above specification, V_{cst} is the primary outcome variable, which are the MMR and DTP vaccination coverage rates. The subscripts *c* and *t* indicate county and year fixed effects, controlling for time-invariant differences across counties and shocks

[28] 25th percentile is also known as the 1st quartile. In this research context, it takes the first quartile of disease count (from lowest to highest case count), for a given county across all years where the disease data are available.
[29] On measles disease measure, I excluded observations from 2019 due to outbreaks in New York and Maine.

and changes over time. X_{ct} is a vector of county-level covariates as control variables. $VPD_{incidence}$ and $VPD_{incidence-1}$ represent the current year and the lagged VPD burden, which is expressed as VPD rate per 100,000 population. *Mandate* is the primary binary policy variable that equals one for California counties beginning in 2016. The DiD model for disease prevalence (*P*) is slightly adapted to reflect differences in outcome construction. It is specified as follows:

$$P_{cst} = \alpha_c + \eta VPD_{incidence-1} + \gamma CAHighBurden_{st} + \lambda Year * CA_{VPDShare_{st}} + \beta Mandate + \varepsilon_{cst}$$

Similarly, the disease prevalence model includes county fixed effects through subscript *c*, to account for time-invariant county-specific differences. The lagged VPD variable $VPD_{incidence-1}$ indicates the disease burden from the previous year and is constructed using the same format as the outcome variable. For instance, when the outcome is VPD case rate per 100,000 population, the lagged control is defined using the same metric. Additionally, I also include an interaction term $Year * CA_{VPDShare}$ to control for annual share of California's VPD cases relative to the total VPDs reported from both California and comparison states. β remains the primary policy variable, a binary indicator capturing the effect of the mandate on disease burden. The model also includes a *CAHighBurden* variable as control, which is a dummy variable indicating California during years with noticeable higher VPD burdens. Specifically, for the pertussis model, it equals one for California in the years 2010, 2014, and 2019. For the measles model, it equals one in the years 2015 and 2019. Additionally, as the interaction term $Year * CA_{VPDShare}$ already accounts for year-based variation, the model does not separately include a year fixed effect.

In both models, standard errors are clustered at the state level. Given that the mandate applies uniformly to all counties within California, there is no variation in policy exposure across counties within the same state. State-level clustering of the standard errors is essential to account for potential within-state autocorrelations.

Implementing the DiD approach as an unbiased estimator of causal effects requires, at minimum, satisfaction of the parallel pre-trend assumption. In other words, California and the comparison states should display a similar trend in the primary outcome variables during the pre-treatment period. While the assumption cannot be tested directly, a regression-based event study is commonly used to visually verify this assumption, through a series of leads and lags. The following equation presents the regression-based event study on vaccination coverage:

$$V_{cst} = \alpha_c + \lambda_t + \delta X_{ct} + \mu VPD_{incidence} + \eta VPD_{incidence-1} + \sum_{\tau=1}^{4} £_{-\tau} Mandates, \text{ t-}\tau + \sum_{\tau=0}^{2} £_{+\tau} Mandate \text{ s, t+}\tau + \varepsilon_{cst}$$

And the following, on disease prevalence:

$$P_{cst} = \alpha_c + \delta X_{ct} + \eta VPD_{incidence-1} + \gamma CAHighBurden_{st} + \lambda Year * CA_{VPDShare_{st}} + \sum_{\tau=1}^{6} £_{-\tau} Mandates, \text{ t-}\tau + \sum_{\tau=0}^{3} £_{+\tau} Mandate \text{ s, t+}\tau + \varepsilon_{cst}$$

In both specifications, *Mandates, t-* equals one if the observation occurs τ years before repealing non-medical exemptions. Similarly, *Mandates, t-+*τ equals one τ years after implementation start of the mandate. I continue to include the county and year fixed effects in both specifications. In the vaccination rate specification, I continue to include the same vector of control variables used in the main specification.

2.4.3 Synthetic Control Method

A major limitation of conducting a DiD design is its reliance on the average outcomes of untreated units as counterfactual for the treated unit. The validity of DiD estimates, therefore, always requires satisfaction with the parallel pre-trend assumption that in the absence of treatment, treated and untreated units would have followed the same trajectory over time. However, in practice, it is not always intuitive to validate this assumption, particularly when the treated and comparison units differ substantially in observable and unobservable traits. The synthetic control method, therefore, is designed to address this limitation by constructing a weighted combination of untreated units (donor pool) that closely approximates characteristics and outcome trajectory of the treated unit. The synthetic unit could yield a credible counterfactual, improving the reliability of causal inference. It is also well-suited in single unit treatment and small-sample, aggregated-level studies by offering comparative advantages compared to the DiD.

Applying the synthetic control method is meaningful and appropriate in the context of this study. On the one hand, it alleviates the potential violation of the DiD parallel pre-trend assumption, if the same pattern does not hold before intervention for both treated and untreated units. One the other hand, because California is the only treated unit, the synthetic control method is suitable to help construct a weighted synthetic unit using all available states from the donor pool, which closely mirrors California on major outcomes during the pre-treatment period.

In this study, I apply the synthetic control method to further assess the impact of California's 2016 mandate on pertussis prevalence outcomes. This approach is valuable as the potential volatility and year-to-year variation in disease trends, particularly

pertussis, may weaken the parallel-trend assumption required for the DiD design. Following the approach outlined in Abadie and Gardeazabal (2003), I first aggregated data to the state level by collapsing key disease prevalence indicators including scale and variance measures along with population data to the state mean. Then I relied on pertussis measures for three years preceding the mandate[30] and population data to construct the weighted average as synthetic California. Weights are assigned using the default algorithm of command "synth" in STATA. In addition, to ensure data quality and consistency, I excluded states with incomplete disease reporting and limit the analysis to the 2013-2018 period, which has the best data quality. Although the synthetic control method is operated at the state level, a complete panel dataset is still strictly required. Therefore, the selection of states helps minimize concerns related to missing data.[31]

In addition to simply showing the synthetic control results through charts that differentiate outcome trends between California and synthetic California, I also run a placebo robustness test by calculating the root mean squared prediction error (RMSPE) values for pre- and post- treatment period of both California and each placebo state, to test the method's statistical significance, following Abadie's approach. To operationalize, the same synthetic control algorithm is first applied on each state in the donor pool to generate a distribution of placebo effects. The RMSPE ratio is then calculated for both pre- and post- treatment period across all placebo units. Finally, California's ratio is compared to the distribution of all placebo units to generate the p-value. A p-value of less than 0.05 indicates that the observed treatment effect is unlikely to be random.

2.5 Results

[30] Following the guidance of Abadie et al. (2010) on controlling pre-treatment outcome variables.
[31] Excludes Illinois, Iowa, Maine, New Jersey, North Carolina, West Virginia, Kansas, and Florida.

2.5.1 Descriptive Statistics

Table 2.1 presents exemption allowances by state for school-entry vaccination requirements and the salient policy changes observed between 2001 and 2022 in California and comparison states. Only California, Connecticut, New York, Maine, and West Virginia removed all forms of non-medical exemptions. In contrast, most other states allow religious exemptions, or a combination of religious and personal belief exemptions. Among states that prohibit non-medical exemptions, most have repealed non-medical exemptions in response to VPD outbreaks, such as California's 2016 mandate, New York and Maine's 2019 mandate, and Colorado's additional requirements on education. Overall, the prevailing policy direction across states has favored tightening vaccination requirements to improve protection.

Table 2.2 presents descriptive statistics between California and comparison states for key outcomes and covariate variables in 2015. Before the mandate, California and comparison states demonstrate similar levels of vaccination coverage. However, California reports a higher prevalence of both measles and pertussis, except for the measles rate of every 100,000 population, which may be explained by the large population of California that has diluted the measles case rate per capita. Additionally, in terms of socio-economic and demographic conditions, California has a higher proportion of Hispanic residents, a lower proportion of white populations, and a higher unemployment rate, relative to the average of the comparison states.

Figure 2.1 and *Figure 2.2* display the county-level average of vaccination rate and state-aggregated total number of VPD cases across California and other comparison states. Before 2016, California demonstrated an overall upward trend in MMR and DTP

immunization coverage, although average rates remained below the herd immunity threshold of a 95%. Following the mandate, coverage increased to approximately 96% and has remained stable since. Additionally, California experienced a measles outbreak in 2015, which was rapidly mitigated one year later. The comparison states collectively experienced an outbreak in 2013 and a record-high in 2018, which was primarily driven by the outbreaks in New York and Maine. Additionally, California has also experienced three waves of pertussis outbreaks in 2010, 2014, and 2019.

2.5.2 Difference-in-Differences (DiD)

Table 2.3 presents the DiD estimates of California's 2016 mandate on MMR vaccination coverage and measles disease burden. The results show that the mandate increased California's MMR vaccination rates by 3.13 percentage points, on average, relative to the comparison states without a similar policy, which is equivalent to a 3.4% increase of the average MMR rate before the mandate. Regarding measles prevalence, the mandate produced a statistically significant reduction in two out of three disease measures. Specifically, it reduced the number of measles cases by 0.43 cases (20% decrease from before mandate) relative to each county's 25^{th} percentile baseline, and by 0.06 cases (50% decrease from before mandate) per 100,000 population.

Table 2.4 displays the same DiD estimates of the mandate on DTP vaccination coverage and pertussis burden. The mandate is associated with a 3.36 percentage point increase in the average DTP vaccination rate, equivalent to a 3.6% increased of the average DTP rate before the mandate. Moreover, the mandate is also associated with a significant reduction across two out of three measures of pertussis burden. Specifically, a drop of 19 pertussis cases based on the measure of each county's 25^{th} percentile (26%

decrease from before mandate), and a drop of 40 cases of the year-to-year pertussis case change (35% decrease from before mandate). The mandate has also decreased the pertussis rate in every 100,000 Californian population by 2 cases on average (18% decrease). The magnitude of reduction in pertussis burden is notably greater than that observed for measles.

Overall, the post-mandate improvements in MMR and DTP vaccine coverage and the reduction in measles and pertussis incidence, are noticeably substantial, consistent with expectations and comparable to findings from other studies. For example, Richwine et al. (2019) find a more than 3 percentage point increase in MMR and DTP vaccination rates from the same California vaccine mandate, and Bald and Gold (2025) find that repealing non-medical exemptions increased vaccination rate by 2-5 percentage points, while Carpenter and Lawler (2017) find a 32% reduction in pertussis burden after the state mandate requiring students to receive a tetanus, diphtheria, and pertussis (Tdap) before entering middle school.

2.5.3. Event Study

Figure 2.3 presents the results from the regression-based event study examining MMR coverage rates and measles burden. The first panel displays the event study estimates for MMR vaccination rates, with the year preceding the 2016 vaccine mandate set as zero as benchmark. Each marker represents the estimated difference in vaccination rates between California and the comparison states in that year, and the vertical green areas indicate the 95% confidence intervals. The results demonstrate no statistically significant differences in trends during the pre-mandate period, and following the

mandate, California shows a statistically significant increase in MMR vaccination coverage.

The remaining three panels display event study estimates for the measles burden measures. While the coefficients suggest a general increase in measles burden before 2016 and a decline post-mandate, the pre-treatment trends are less consistent than those observed for MMR coverage. The year-to-year case change and measles incidence rate per 100,000 population display relatively parallel pre-trends. However, results based on case related to the 25th percentile lack a clear pattern, also showing a small magnitude of post-mandate decline in disease burden.

Figure 2.4 presents the results of the event study on the DTP vaccination coverage and pertussis burden. Similar to the MMR analysis, the average DTP vaccination coverage by roughly 3 percentage points post mandate. Notably, the parallel pre-trends appear well-supported: in the four years leading up to 2016, California and comparison states display a similar trajectory along DTP vaccination coverage, despite a modest upward trend in California closer to 2016. However, both MMR and DTP results should be interpreted carefully, given their upward trend in California before mandate.

When assessing the event study results on the pertussis burden measures, lamentably, the event study results present less conclusive evidence. Across three measures of pertussis, there is no consistent pre-trend, primarily due to the cyclical nature of pertussis outbreaks, with each peak of infections arriving every three to four years, which undermines the assumption of parallel trends. The coefficients for 2014 are consistently large and positive across all charts, reflecting California's major pertussis outbreaks in 2014, with more than 11,000 cases reported statewide. The cyclical outbreak

patterns, thereby, further complicate the interpretation of policy effects using event study method alone.

While the pre-treatment disease variability undermines causal explanations, the post-2016 coefficients for pertussis measures are generally negative or declining, suggesting that the mandate may have reduced the scale and severity of subsequent outbreaks, compared to those before 2016. Although pertussis remains endemic in California, the post-mandate trends imply a potential mitigated effect.

Overall, the event study results complement findings from the DiD analysis. Consistent with the DiD estimates for MMR and DTP vaccination rates, the event study confirms a post-mandate increase in immunization coverage among California's kindergartners. Nevertheless, results from event studies on measles and pertussis disease burdens are more mixed. For measles, there is evidence of parallel trends, particularly for year-to-year case change and incidence rates per 100,000 population. For pertussis, the events study does not particularly reveal a clear pre-trend, making it difficult to satisfy the parallel trend assumption. California experienced large-scale surges of pertussis every three to four years, a pattern not observed in the comparison states.

2.5.4 Synthetic Control

The synthetic control results (*Figure 2.5*) on three pertussis disease burden measures indicate that California experienced a decline in pertussis prevalence following the implementation of the SB277 mandate in 2016, relative to its synthetic control group. Across all three measures, particularly the year-to-year change in pertussis case counts and cases relative to each county's 25th percentile, California displays a higher burden compared to synthetic control before the mandate. After 2016, however, California's

infection trajectory and curves are much flattened, contrasting with the synthetic California, which showed an increasing pertussis trend particularly from 2017 to 2018. These results suggest that California's vaccine mandate may have helped mitigate pertussis burden by reducing the magnitude and slowing the spread of infections, potentially diminishing the next peak in the post-mandate infection cycles. One limitation is that in two specifications, respectively pertussis year-to-year case change and case relative to the 25th percentile, weights are assigned exclusively to one comparison state, in which case is Delaware. In the pertussis rate model, weights are assigned to three states: 2.4% to Colorado, 60.5% to Delaware, and 37% to Washington. These results are presented in *Figure 2.5* and align with observed pertussis disease patterns in California.

Figure 2.6 presents placebo tests of the three pertussis prevalence measures. P-value on all three pertussis measures is smaller than 0.05, indicating that none of the placebo units had a post-pre RMSPE ratio greater than or equal to California's. This suggests that the observed treatment effects in California are unusual compared to placebo units, and the observed treatment effect is likely not due to random chance. However, in *Panel A* and *Panel B* of *Figure 2.6*, California displayed a much higher disease level than the synthetic unit during the pre-treatment period. This is partially explained by the fact that the model has assigned all weight to one state, in both cases, Delaware. *Panel C*, on the other hand, assigned weights to three states and presented a more pronounced result.

2.6 Policy Implications

Adjusting vaccination requirements associated with school-entry through legislative and regulatory measures is a common public health practice across many

states, particularly in response to heightened public health crises, facing a risk of further disease outbreak. This study illustrates positive effects using California's 2016 mandate as an example, an improved vaccination coverage rates, followed by a statistically significant reduction in the disease burden. This reduction in disease burden confirms the mandate's impact on direct health outcomes. These results highlight the relevance and significance in encouraging vaccination compliance and advancing herd immunity within schools and communities. It further helps reduce the overall possibility of disease transmission and mitigate the impact of disease outbreaks on students, their families, and school environments.

On the one hand, mandating vaccination entails certain costs, including the legislative efforts to draft and pass a bill, resources devoted to informing and educating guardians about the new requirements, and the additional time and administrative burden placed on schools and health professionals to verify students' vaccination records rigorously. Accurately estimating the total cost of implementation is a complex task, if not ultimately infeasible. It, therefore, raises questions about the cost-effectiveness and efficiency of such mandates, since both costs and benefits are often uncertain and difficult to quantify. On the other hand, vaccine mandates also generate positive externalities. Such externalities include, for instance, a boost in vaccination compliance, which may offset some of the costs associated promotional and educational efforts, while improved parental knowledge and awareness about the importance of childhood vaccination can reduce the resources and time needed for outreach and training. In addition, a reduced disease burden can further translate into reduced demand and intensity in consuming goods and services, such as patients' need on medicines and

hospital beds, particularly during the peak incidence periods. The mandate, therefore, helps maintain a functioning healthcare system amid public health challenges. Finally, healthier children mean fewer interruptions to parents on their jobs and duties, which broadly supports social productivity and a stable level of economic outputs. Given these considerations, it is difficult to classify the mandate as simply beneficial or detrimental. Rather, the implementation should involve a balance of identifiable costs and benefits.

There is no doubt that a vaccine mandate like California's 2016 SB277 will result in debate and controversy, centering around the tradeoff between personal freedom and the goal to control VPDs. Potential consequences resulting from a vaccine mandate include, for example, families relocating to states with less stringent vaccination requirements and an increase in homeschooling driven by persistent vaccine hesitancy. Moreover, the equity and fairness aspects and concerns associated with the mandate need to be addressed further, particularly if the vaccine hesitancy is concentrated within specific racial or ethnical groups, populations that may be disproportionally affected by the implementation. On a related note, policymakers should, therefore, approach such mandates with careful deliberations and thoughtful planning to ensure fair outcomes.

Finally, California's 2016 vaccine mandate leaves an important policy legacy. When New York and Maine experienced similar measles outbreaks in 2019, both states decided to replicate California's legislative model by legally removing religious exemptions. Adopting similar mandates in New York and Maine helps address concerns around the limited external validity of California's mandate. Moreover, California's experiences also offer broader implications for other VPDs and vaccine types. First, both measles and pertussis are highly vaccine-preventable, with MMR and DTP vaccines

providing over 90% clinical efficacy, particularly among children who are eligible for attending primary schools and daycares (Barrabeig et al., 2011; Bisgard et al., 2005). These vaccines confer long-lasting immunity, and no annual boost is required. The durability particularly makes such vaccines suitable as a school-entry requirement. On the other hand, there are foreseeable challenges associated with mandating vaccines that are less effective, provide shorter of immunity, and require annual boosters, such as the influenza vaccine.

Moreover, both pertussis and measles are known for being most transmissive among school-aged children, which further rationalizes the mandate of such vaccines for school-entry purposes. Other diseases, such as the COVID-19 infection and Human papillomavirus infection (HPV), may not directly target or transmit through school-aged children, making it difficult to carry mandatory nature. Expanding vaccine mandates beyond existing ones requires careful consideration of disease characteristics, vaccine effectiveness and administration requirements, as well as population risk profiles.

As of July 2025, a total of 1,288 confirmed measles cases have been reported across U.S., affecting 39 states and jurisdictions. They stem from 27 outbreaks, of which 88% are outbreak-associated. In comparison, 285 cases were confirmed in 2024, of which 69% are outbreak-associated. At this critical juncture marked by resurgence measles burden, states may replicate California's experience, by considering and adopting legislative interventions, such as a vaccine mandate, to control VPD outbreaks.[32]

2.7 Limitations

[32] Data retrieved from the Centers for Disease Control and Prevention (CDC): https://www.cdc.gov/measles/data-research/index.html

First, measurement precision issues may affect the validity and trustworthiness of this study. Specifically, whether the selected outcome indicators, such as disease case count and rates, are the most appropriate for capturing the true impact of the mandate on VPDs. The overall trend of VPDs, particularly on pertussis, demonstrates that VPDs remain endemic even after the policy implementation, the post-mandate period is characterized by a reduction in disease severity. This study relies on conventional public health measures, such as VPD case scale and case rate per 100,000 population. Nevertheless, such measures may not sufficiently and fully address the extent of disease variability, volatility, and level of dispersion over time.

Relatedly, results from the event study do not fully satisfy the parallel pre-trend assumption required for the DiD, particularly in the case of pertussis outbreaks. This limitation is primarily driven by the cyclical outbreak patterns with peaks of pertussis infections occurring every three to four years. Clearly, there is a downward trend in the pertussis burden following the mandate, but it is difficult to fully and exclusively attribute this decline to the 2016 mandate. Obstacles in fully verifying the parallel trend assumptions have weakened the statistical conclusion validity of the DiD estimates and limits the causal inference.

Additionally, a key challenge in evaluating disease outbreak and level of prevalence as outcomes of a vaccine mandate hinges upon the endogeneity of disease control responses. As a result, both state responses to outbreaks through alterations of the regulations, as well as individual protections through immunization, could be influenced by the disease level in earlier years. Even after controlling for previous years' VPD cycle, the endogeneity issue may not be fully addressed, which is linked to one of the

fundamental difficulties in measuring disease prevalence as a direct outcome of vaccine mandates. Furthermore, few states have experienced measles and pertussis outbreaks at the scale of California from 2010 to 2020, particularly pertussis, where record-high outbreaks take place following a three to four-years cycle. The variability further complicates the selection of the appropriate comparison groups and limits the generalizability of the findings.

Finally, although the 2016 California vaccine mandate has reduced disease burdens, the magnitude of many estimates remain relatively modest, raising questions about the practical and real-world significance. This is particularly true for measles, where California experienced a total of more than 100 cases in 2015, which prompted state legislative reaction to public health crisis through a tighter school-entry vaccine mandate, effective a year after. It remains unclear whether the cost of implementation will be fully offset by its benefits. Additional evidence and more data are needed to better assess the full range of trade-offs and long-terms implications for such mandates.

2.8 Discussions & Conclusions

This study evaluates California's 2016 vaccine mandate, which repealed non-medical exemptions for school-entry. Employing a Difference-in-Differences and a synthetic control methodology, the findings reveal the mandate's positive causal impact on vaccination coverage and disease prevalence. Specifically, on average, the mandate has increased the average MMR and DTP vaccination coverage among kindergarten-aged students by three percentage points, and it has also reduced the VPD scale and rate of both measles and pertussis, with a larger scale on pertussis. Despite these positive results, the analysis faces several methodological challenges. The most glaring limitation is the

cyclical nature of VPD outbreaks, especially pertussis, and the endogeneity of disease burden, which may itself influence legislative responses such as the mandate. These factors complicate causal explanation and highlight the need for cautious interpretation of the results.

California's 2016 vaccine mandate offers implications for other states more broadly. As of 2024, California remains to be one of the very few states within the U.S. that does not allow any form of non-medical exemptions for school-entry. The usefulness of vaccines and vaccinations in combating public health crises and disease outbreaks further demonstrates itself through the COVID-19 global pandemic. Vaccine and vaccination laws can affect disease control strategies directly and relate to broader pandemic preparedness, particularly when disease elimination is infeasible. In this context, the role of vaccine and vaccination becomes central to achieve the herd immunity, and reduces the burden of existing disease outbreaks, and further mitigates the risks of more extensive larger-scale outbreaks. Vaccination laws for school-entry will continue to be a politically sensitive weapon that states can leverage. However, the state government, as the primary guardian of public health, is also responsible for adjusting the exemption allowance, especially during periods of heightened disease risks, to protect and safeguard the well-being of children, families, and communities.

This study contributes to the literature of policy evaluations surrounding vaccines and vaccination mandates by providing empirical evidence on the impact of mandates not only on vaccination coverage, but also on disease burden. Utilizing unique county-level vaccination coverage and disease prevalence data collected from state health department, the analysis shows that overall, the mandate improved vaccination coverage and reduced

disease burdens measured by disease variability and scale, across Californian counties. This study also lays the ground for future research to explore the nuanced direct and spillover effects of the mandates, particularly across diverse racial, ethnic, and socio-economic profiles, asl well as across a diverse cluster of geographic locations, and distinctions between urban and rural settings.

Vaccines and vaccination are not the only policy instrument to address public health crises and challenges faced by heightened VPD threats. Nevertheless, the important role of vaccines and vaccination can never be underestimated. It is, therefore, a collective responsibility to recognize the reliability and safety of vaccination and uphold compliance with the related immunization requirement. Parents should understand the importance of vaccination and comply with school-entry requirements for their children. Doing so not only helps protect individual children but also facilitates society's achievement of hard immunity. State authorities should, therefore, continue to nudge the public to achieve better vaccination outcome, especially during disease outbreak seasons and in preparation of future crises.

State authorities, being pillars and decision-makers within a state’s public health system, should continue grounding public health decision-making in rigorous scientific evidence, robust data, and analytically sound and trustworthy research outcomes. State health officials should closely monitor the evolution and development of vaccination coverage and disease burdens and prevalence. They should also be prepared to intervene timely and appropriately with caution and vigilance, balancing individuals’ freedom and choices while promoting the well-being of populations and societies.

References

Abadie, A., & Gardeazabal, J. (2003). The economic costs of Conflict: A Case Study of the basque country. American Economic Review, 93(1), 113–132. https://doi.org/10.1257/000282803321455188

Abadie, A., Diamond, A., & Hainmueller, J. (2010). Synthetic Control Methods for Comparative Case Studies: Estimating the Effect of California's Tobacco Control Program. Journal of the American Statistical Association, 105(490), 493–505. https://doi.org/10.1198/jasa.2009.ap08746

Abrevaya, J., & Mulligan, K. (2011). Effectiveness of state-level vaccination mandates: Evidence from the varicella vaccine. Journal of Health Economics, 30(5), 966–976. https://doi.org/10.1016/j.jhealeco.2011.06.003

Ahmed, A., Lee, K. S., Bukhsh, A., Al-Worafi, Y. M., Sarker, Md. M., Ming, L. C., & Khan, T. M. (2018). Outbreak of vaccine-preventable diseases in Muslim majority countries. Journal of Infection and Public Health, 11(2), 153–155. https://doi.org/10.1016/j.jiph.2017.09.007

Attwell, K., & Hannah, A. (2022). Convergence on Coercion: Functional and Political Pressures as Drivers of Global Childhood Vaccine Mandates. International journal of health policy and management, 11(11), 2660–2671. https://doi.org/10.34172/ijhpm.2022.6518

Atwell, J. E., & Salmon, D. A. (2014). Pertussis resurgence and vaccine uptake: Implications for reducing vaccine hesitancy. Pediatrics, 134(3), 602–604. https://doi.org/10.1542/peds.2014-1883

Bald, A., & Gold, S. (n.d.). ms, Harvard University, Cornell University. Retrieved August 24, 2025, from http://efaidnbmnnnibpcajpcglclefindmkaj/https://anthonybald.com/papers/vaccine.pdf.

Barrabeig, I., Rovira, A., Muñoz, P., Batalla, J., Rius, C., Sánchez, J. A., & Domínguez, À. (2011). MMR vaccine effectiveness in an outbreak that involved day-care and primary schools. Vaccine, 29(45), 8024–8031. https://doi.org/10.1016/j.vaccine.2011.08.056

Bednarczyk, R. A., King, A. R., Lahijani, A., & Omer, S. B. (2019). Current landscape of nonmedical vaccination exemptions in the United States: Impact of policy changes. Expert Review of Vaccines, 18(2), 175–190. https://doi.org/10.1080/14760584.2019.1562344

Bisgard, K. M., Rhodes, P., Connelly, B. L., Bi, D., Hahn, C., Patrick, S., Glodé, M. P., & Ehresmann, K. R. (2005). Pertussis vaccine effectiveness among children 6 to 59 months of age in the United States, 1998–2001. Pediatrics, 116(2). https://doi.org/10.1542/peds.2004-2759

Bullen, M., Heriot, G. S., & Jamrozik, E. (2023). Herd immunity, vaccination and moral obligation. Journal of Medical Ethics, 49(9), 636–641. https://doi.org/10.1136/jme-2022-108485

Carpenter, C., & Lawler, E. (2017). Direct and spillover effects of middle school vaccination requirements. https://doi.org/10.3386/w23107

Correira, J. W., Kamstra, R., Zhu, N., & Doll, M. K. (2024). School vaccine coverage and medical exemption uptake after the New York State Repeal of Nonmedical Vaccination Exemptions. JAMA Network Open, 7(2). https://doi.org/10.1001/jamanetworkopen.2023.54710

Correira, J. W., Morrison, K. T., & Doll, M. K. (2025). *Homeschooling Trends before and after the New York State Repeal of Nonmedical Vaccination Exemptions*. https://doi.org/10.1101/2025.08.11.25333447

Conis, E., & Kuo, J. (2021). Historical origins of the personal belief exemption to vaccination mandates: The view from California. Journal of the History of Medicine and Allied Sciences, 76(2), 167–190. https://doi.org/10.1093/jhmas/jrab003

Deal, A., Halliday, R., Crawshaw, A. F., Hayward, S. E., Burnard, A., Rustage, K., Carter, J., Mehrotra, A., Knights, F., Campos-Matos, I., Majeed, A., Friedland, J. S., Edelstein, M., Mounier-Jack, S., & Hargreaves, S. (2021). Migration and outbreaks of vaccine-preventable disease in Europe: A systematic review. The Lancet Infectious Diseases, 21(12). https://doi.org/10.1016/s1473-3099(21)00193-6

Delamater, P. L., Leslie, T. F., & Yang, Y. T. (2016). A spatiotemporal analysis of non-medical exemptions from vaccination: California schools before and after SB277. *Social Science & Medicine*, *168*, 230–238. https://doi.org/10.1016/j.socscimed.2016.08.011

Delamater, P. L., Leslie, T. F., & Yang, Y. T. (2017). Change in medical exemptions from immunization in California after elimination of personal belief exemptions. JAMA, 318(9), 863. https://doi.org/10.1001/jama.2017.9242

Delamater, P. L., Pingali, S. C., Buttenheim, A. M., Salmon, D. A., Klein, N. P., & Omer, S. B. (2019). Elimination of nonmedical immunization exemptions in California and school-entry vaccine status. Pediatrics, 143(6). https://doi.org/10.1542/peds.2018-3301

DeStefano, F., Bodenstab, H. M., & Offit, P. A. (2019). Principal controversies in Vaccine Safety in the United States. Clinical Infectious Diseases, 69(4), 726–731. https://doi.org/10.1093/cid/ciz135

Goldstein, N. D., & Suder, J. S. (2022). Towards eliminating nonmedical vaccination exemptions among school-age children. Delaware Journal of Public Health, 8(1), 84–88. https://doi.org/10.32481/djph.2022.03.014

Dow, W., Holmes, J., Philipson, T., & Sala-i-Martin, X. (1995). Disease Complementarities and the Evaluation of Public Health Interventions. https://doi.org/10.3386/w5216

Gabis, L. V., Attia, O. L., Goldman, M., Barak, N., Tefera, P., Shefer, S., Shaham, M., & Lerman-Sagie, T. (2022). The myth of vaccination and autism spectrum. European Journal of Paediatric Neurology, 36, 151–158. https://doi.org/10.1016/j.ejpn.2021.12.011

Greenberg, D. P., von König, C. H. W., & Heininger, U. (2005). Health burden of pertussis in infants and children. The Pediatric infectious disease journal, 24(5), S39-S43.

Habakus, L. K., Holland, M., & Rosenberg, K. M. (2012). Vaccine epidemic: How corporate greed, biased science, and coercive government threaten our human rights, our health, and our children. Skyhorse.

Hair, N. L., Gruber, A., & Urban, C. (2021). Personal belief exemptions for school-entry vaccinations, vaccination rates, and academic achievement. Journal of Health Economics, 78, 102464. https://doi.org/10.1016/j.jhealeco.2021.102464

Hamilton, J. L. (2020). Recognizing vaccine-preventable diseases and managing outbreaks. Primary Care: Clinics in Office Practice, 47(3), 467–481. https://doi.org/10.1016/j.pop.2020.05.003

Kubin, L. (2019). Is there a resurgence of vaccine preventable diseases in the U.S.? Journal of Pediatric Nursing, 44, 115–118. https://doi.org/10.1016/j.pedn.2018.11.011

Lee, D. N. (2012). The impact of childhood health on adult educational attainment: Evidence from mandatory school vaccination laws. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.1987898

Mallory, M. L., Lindesmith, L. C., & Baric, R. S. (2018). Vaccination-induced herd immunity: Successes and challenges. Journal of Allergy and Clinical Immunology, 142(1), 64–66. https://doi.org/10.1016/j.jaci.2018.05.007

Nyathi, S., Karpel, H. C., Sainani, K. L., Maldonado, Y., Hotez, P. J., Bendavid, E., & Lo, N. C. (2019). The 2016 California policy to eliminate nonmedical vaccine exemptions and changes in vaccine coverage: An empirical policy analysis. PLOS Medicine, 16(12). https://doi.org/10.1371/journal.pmed.1002994

Philipson, T. (1999). Economic Epidemiology and Infectious Diseases. https://doi.org/10.3386/w7037

Richwine, C., Dor, A., & Moghtaderi, A. (2019). Do Stricter Immunization Laws Improve Coverage? Evidence from the Repeal of Non-Medical Exemptions for School Mandated Vaccines. https://doi.org/10.3386/w25847

Ruderfer, D., & Krilov, L. R. (2015). Vaccine-preventable outbreaks: Still with us after all these years. Pediatric Annals, 44(4), e76-81. doi: https://doi.org/10.3928/00904481-20150410-08

Tomsick E. (2020). The Public Health Demand for Revoking Non-Medical Exemptions to Compulsory Vaccination Statutes. Journal of law and health, 34(1), 129–154.

Oster, Emily. 2016. “Does Disease Cause Vaccination? Disease Outbreaks and Vaccination Response.” National Bureau of Economic Research (NBER) Working Paper 22464.

Weithorn, L. A., & Reiss, D. R. (2018). Legal approaches to promoting parental compliance with childhood immunization recommendations. Human Vaccines & Immunotherapeutics, 14(7), 1610–1617. https://doi.org/10.1080/21645515.2018.1423929

Wong, L. P., Wong, P. F., & AbuBakar, S. (2020). Vaccine hesitancy and the resurgence of vaccine preventable diseases: The way forward for malaysia, a Southeast Asian country. Human Vaccines & Immunotherapeutics, 16(7), 1511–1520. https://doi.org/10.1080/21645515.2019.1706935

Table 2.1 State Exemption Allowance and Major Policy Change

Exemption allowances for school-entry vaccination requirements as of August 2024, along with major policy changes on the exemption allowance between 2000 and 2020. Data retrieved from the National Conference of State Legislatures.[33]

Latest Exemption Allowance for School Entry (2024)					*Major Vaccination Policy Change Since 2000*	*Policy Change Description*
	Both Religious and PBE Allowed	Only Allowed PBE	Only Allowed Religious Exemption	No non-medical Exemptions Allowed		
California				TRUE	2016 Vaccine Mandate	Repealed Non-medical Exemptions
Arizona	TRUE					
Connecticut				TRUE	2021 Public Act 21-6	Repealed Non-medical Exemptions
Kansas			TRUE			
Maine				TRUE	2019 Mandate	Repealed Non-medical Exemptions
Maryland			TRUE			
Massachusetts			TRUE			
Minnesota		TRUE				
North Dakota	TRUE					
Ohio	TRUE					
South Dakota			TRUE			
Texas			TRUE		2003 House Bill 2292	Enabled PBEs
Washington	TRUE					

[33] Retrieved from: https://www.ncsl.org/. PBE: Personal-belief exemptions.

States Unique to the VPD Prevalence Study					*Major Vaccination Policy Change Since 2000*	*Policy Change Description*
	Both Religious and PBE Allowed	Only Allowed PBE	Only Allowed Religious Exemption	No non-medical Exemptions Allowed		
Colorado	TRUE				2020 Senate Bill 163	Introduced education requirement for PBEs
Delaware			TRUE			
Florida			TRUE			
Hawaii			TRUE			
Illinois			TRUE			
Iowa			TRUE			
New Jersey			TRUE			
New York				TRUE	2019 Vaccine Mandate	Repealed Non-medical Exemptions
North Carolina			TRUE			
Virginia			TRUE			
West Virginia				TRUE		
Wyoming			TRUE			

Table 2.2 Summary Statistics: California and Comparison States in 2015

*, **, *** indicates statistical significance at the 90%, 95%, and 99% confidence level. Data show state-level averages using county-level data. N shows the number of counties, which is indicator-specific, and depends on the availability of the 2015 data, which may be smaller than that reported in the main text.

		2015	
Mean/Sum	***California***	***Comparison States***	***T-Statistics***
Vaccination Coverage (mean)			
	N=57	N=504	
MMR: % up to date	92.77	92.81	0.04**
DTP: % up to date	92.49	92.8	0.30
VPD Prevalence (sum)			
	N=58	N=903	
Measles Scale: Year-to-Year Change	1.13	0.16	-5.01***
Measles Scale: Case Count Based on 25th Percentile Baseline	2.13	0.05	-9.15***
Measles Rate every 100,000 Population	0.11	0.18	2.48***
	N=58	N=1,060	
Pertussis Scale: Year-to-Year Change	114.29	7.08	-14.52***
Pertussis Scale: Case Count Based on 25th Percentile Baseline	71	5.32	-11.70***
Pertussis Rate every 100,000 Population	11.18	7.61	-1.19***
Covariates (mean)			
	N=57	N=504	
% of population age 0 to 24	31.96	32.33	0.53
% of population age 25 to 34	13.08	11.65	-4.61***
% of population age 35 to 44	11.98	11.21	-3.72***
% of population age 45 to 54	12.95	12.97	0.11*
% of population age 55 to 64	13.63	14.04	1.28
% of population age 65+	16.41	17.79	2.07**
% of population black	4.316	4.351	0.04**
% of population white	83.68	90.14	3.57***
% of population Hispanic	30.43	9.325	-10.08***
% of population male	50.45	50.03	-2.11**
% of female population with college degree	24.13	22.12	-1.83**
Population	684,085	148,025	-6.43***
% Unemployed	7.505	4.811	-9.33***
Median Household Income	57,770	53,687	-2.24**

Table 2.3 DiD Results: MMR Coverage and Measles Prevalence

Difference-in-differences estimates of the effect of California's 2016 vaccine mandate on childhood vaccination rates and VPD prevalence. Models include county and year fixed effects. *, **, *** indicates statistical significance at the 90%, 95%, and 99% confidence level. Vaccination rate data cover school years from 2012 to 2018. Disease prevalence indicators cover calendar years from 2010 to 2018.

	(1)	(2)	(3)	(4)
Outcome Variables	MMR Vaccination Rate (%)	Measles Scale: Year-to-Year Change	Measles Scale: Case Relative to 25th Percentile Baseline	Measles Rate every 100,000 Population
Mandate	3.13***	-0.24	-0.43***	-0.06*
(Robust Std. Err.)	(0.32)	(0.20)	(0.14)	(0.03)
Observations	1,430	6,152	6,705	6,704
R-squared	0.77	0.39	0.26	0.13

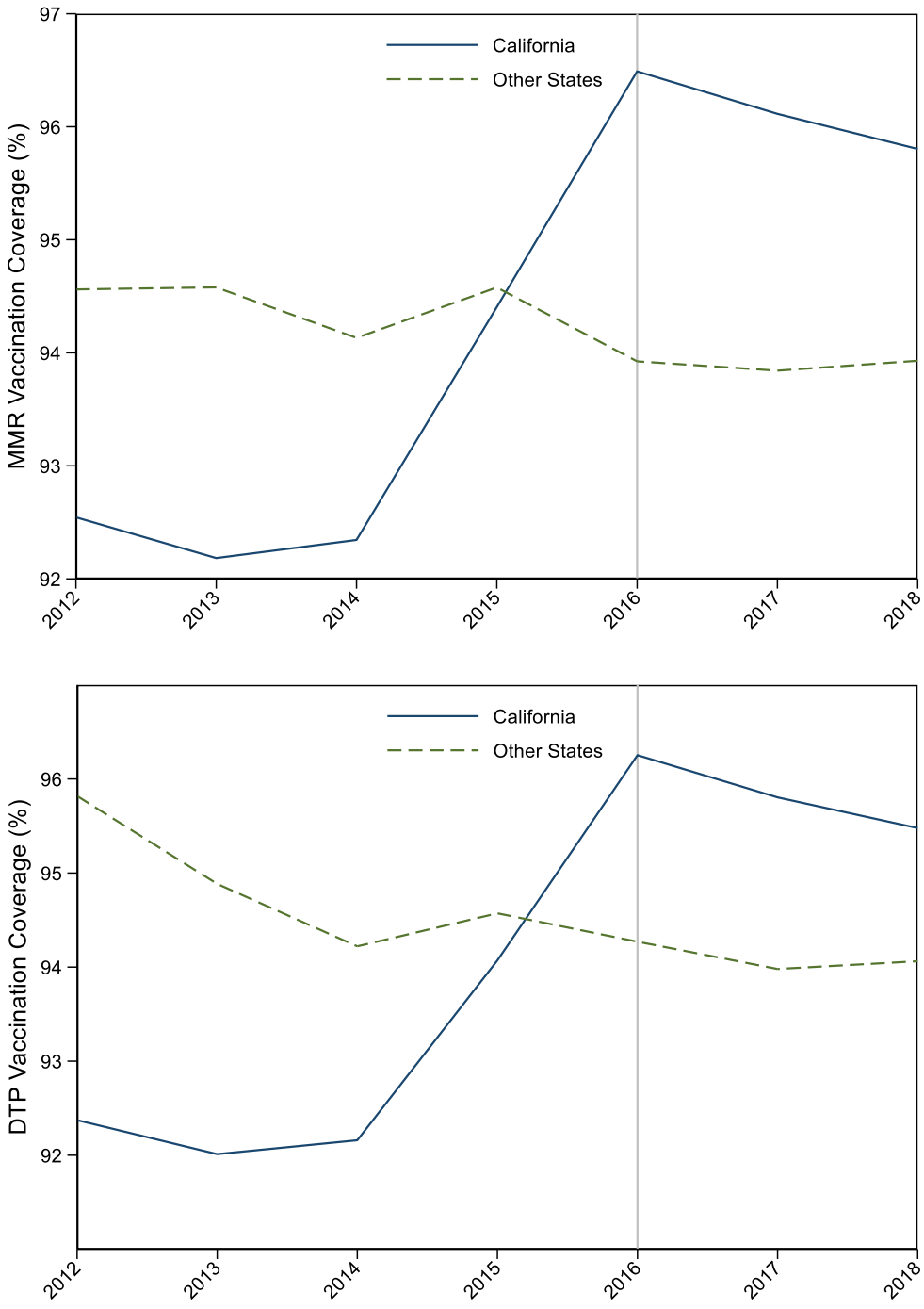
Table 2.4. DiD Results: DTP Coverage and Pertussis Prevalence

Difference-in-differences estimates of the effect of California's 2016 vaccine mandate on childhood vaccination rates and VPD prevalence. Models include county and year fixed effects. *, **, *** indicates statistical significance at the 90%, 95%, and 99% confidence level. Vaccination rate data cover school years from 2012 to 2018. Disease prevalence indicators cover calendar years from 2010 to 2019.

	(1)	(2)	(3)	(4)
Outcome Variables	DTP Vaccination Rate (%)	Pertussis Scale: Year-to-Year Change	Pertussis Scale: Case Relative to 25th Percentile Baseline	Pertussis Rate every 100,000 Population
Mandate	3.36***	-39.91***	-19.06***	-2.01
(Robust Std. Err.)	(0.41)	(2.73)	(2.83)	(1.32)
Observations	2,215	9,669	10,225	10,223
R-squared	0.74	0.57	0.55	0.26

Figure 2.1 MMR and DTP Coverage Rates: California and Other States[34]

Average MMR and DTP vaccination coverage: percentage of kindergarteners who are up to date on MMR and DTP vaccination each school year. Population-weighted at the county-level.



[34] 13 other states serve as the comparison group. Total number of observations: 2,933.

Figure 2.2. Measles and Pertussis Total Cases: California vs. Other States

Total Measles and Pertussis case count reported in California and other comparison states, from 2000 to 2022.

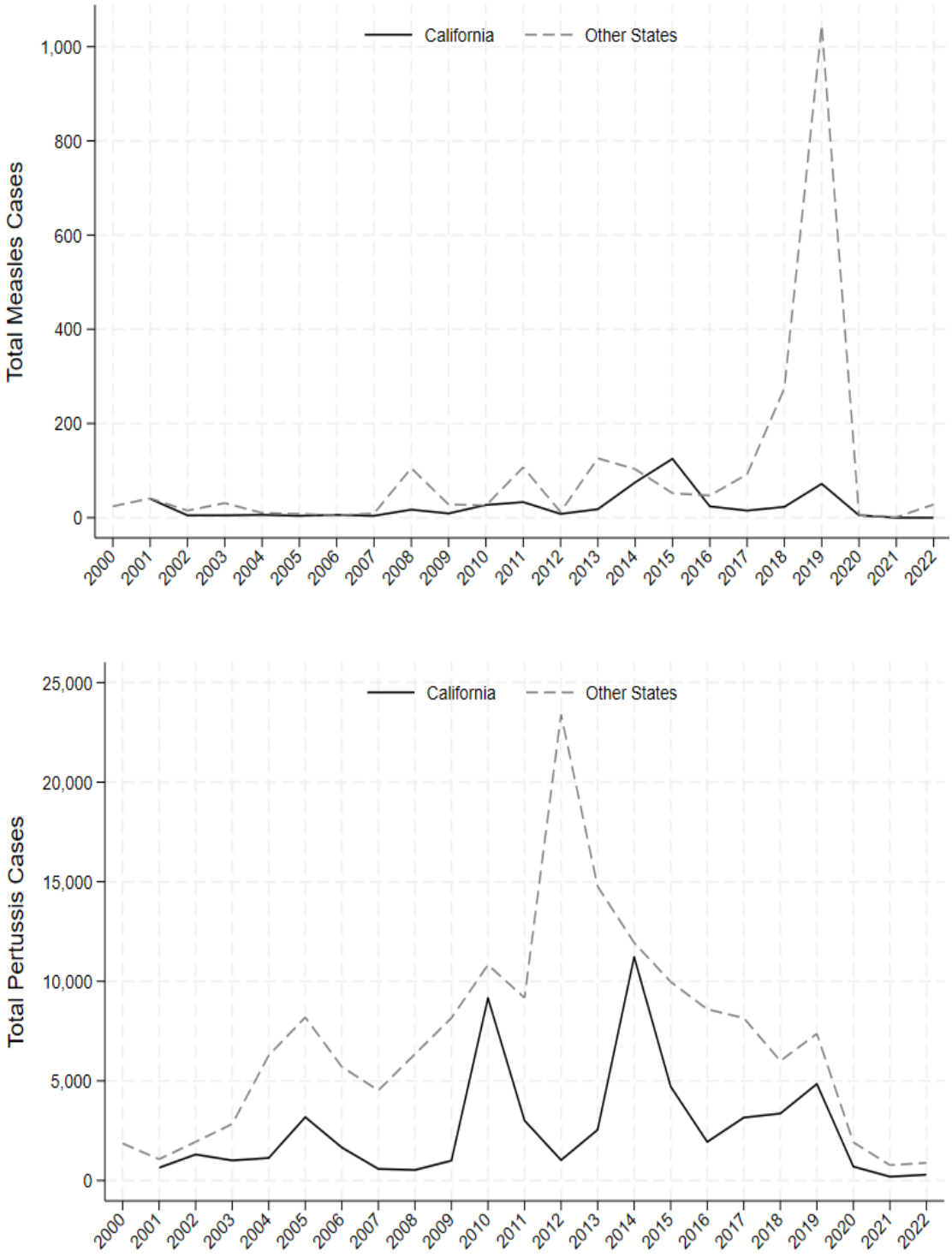
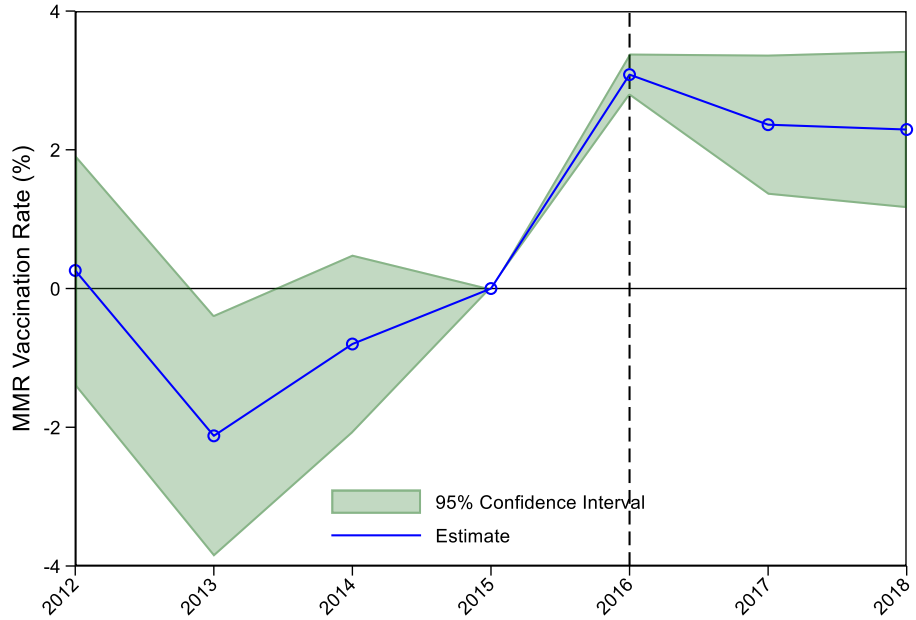


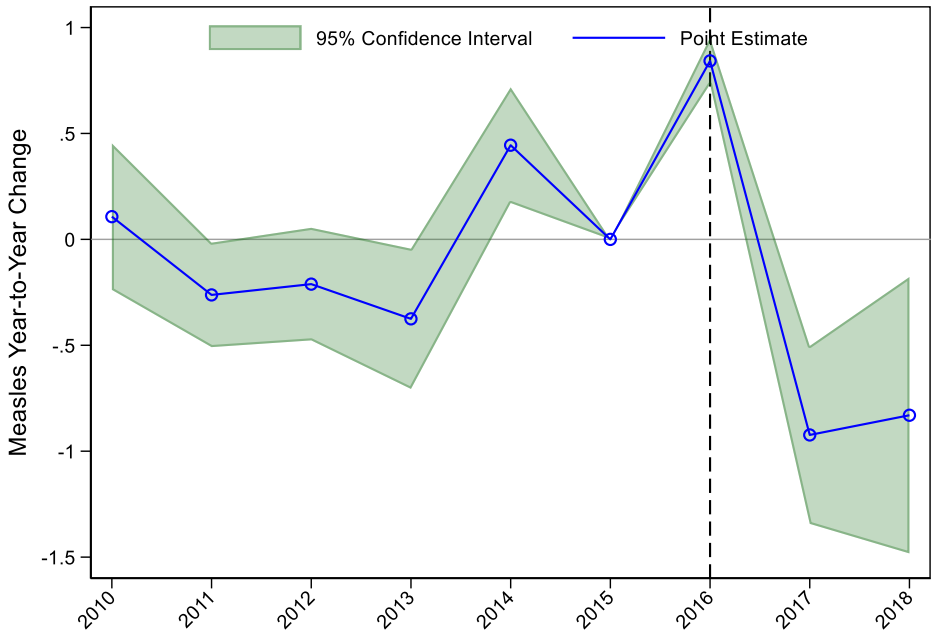
Figure 2.3 Event Study Results: MMR Coverage and Measles Prevalence

Leads and lags regression parameters on MMR vaccination rate and measles prevalence. Models include county and year fixed effects, with standard errors clustering at the state level. Y axis displays coefficients on lead and lag dummies; green bandwidth shows 95% confidence intervals around coefficients. Coefficient for the year 2015 is set as zero to serve as comparison.

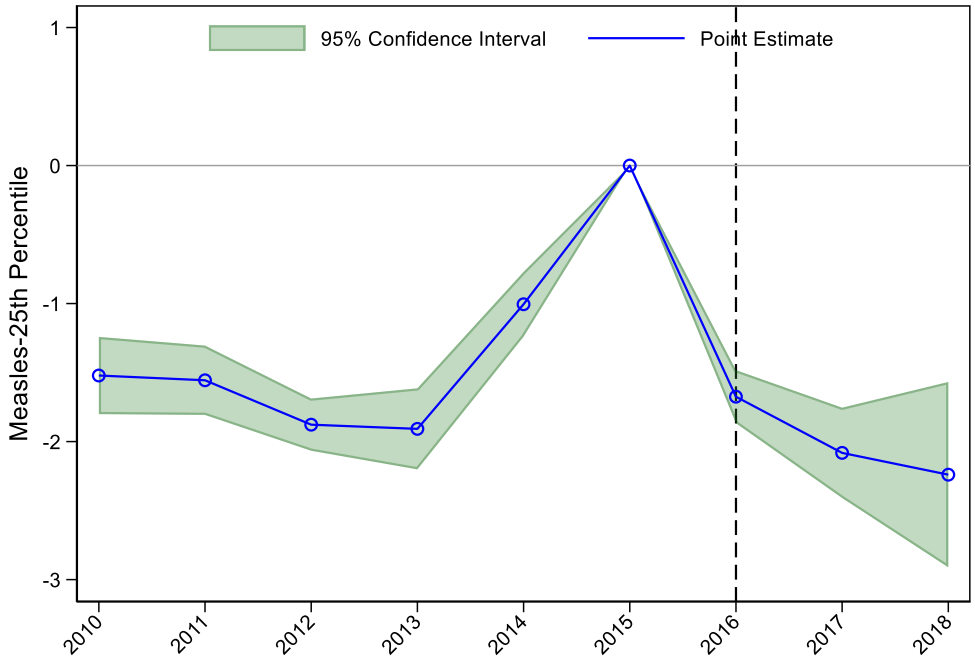
Panel A: MMR Vaccination Rate (%)



Panel B: Measles Year-to-Year Case Change



Panel C: Measles Relative to the 25th Percentile Case Count



Panel D: Measles Rate Per 100,000 Population

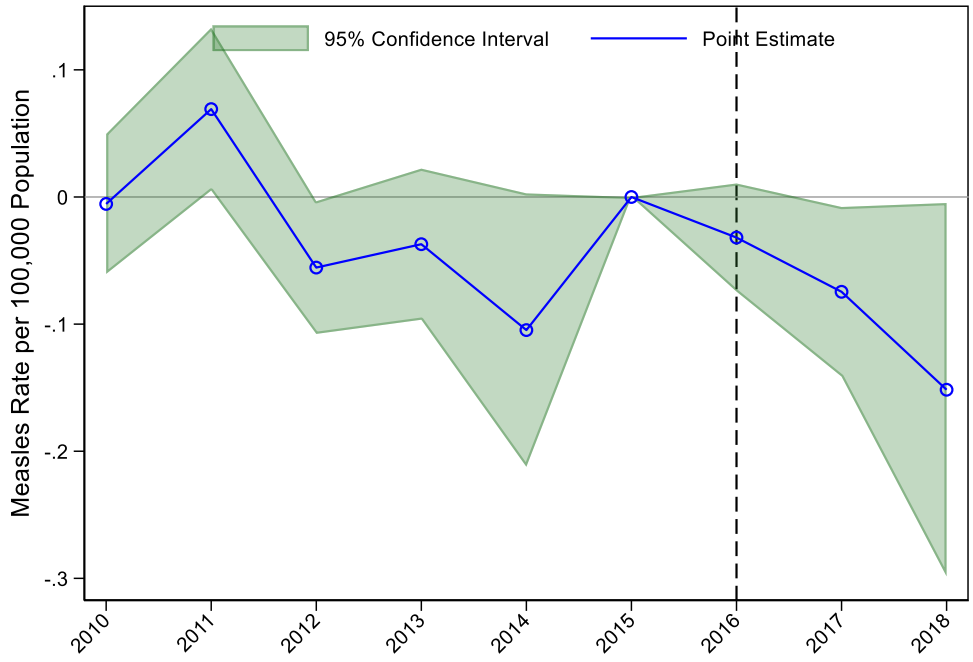
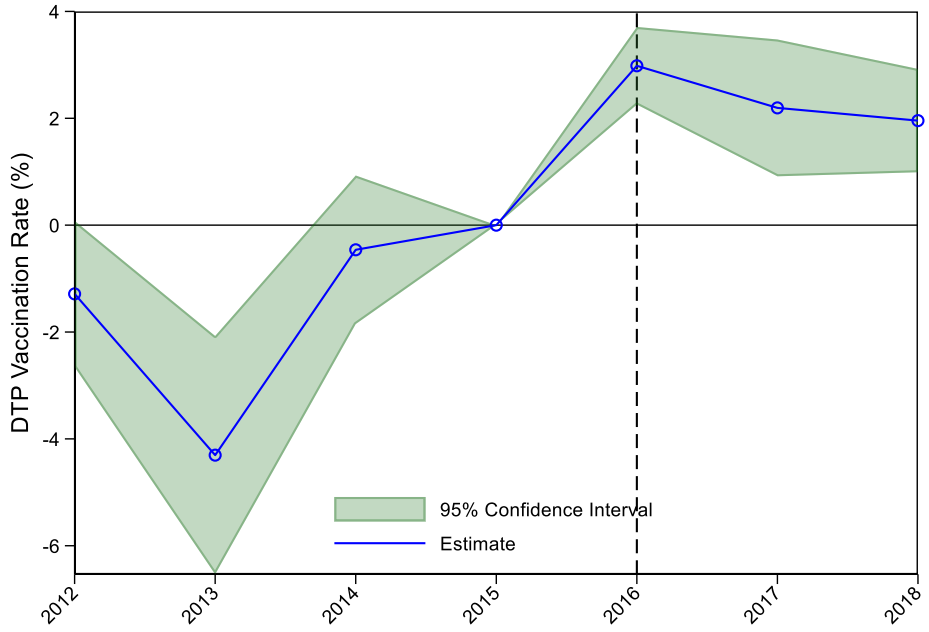


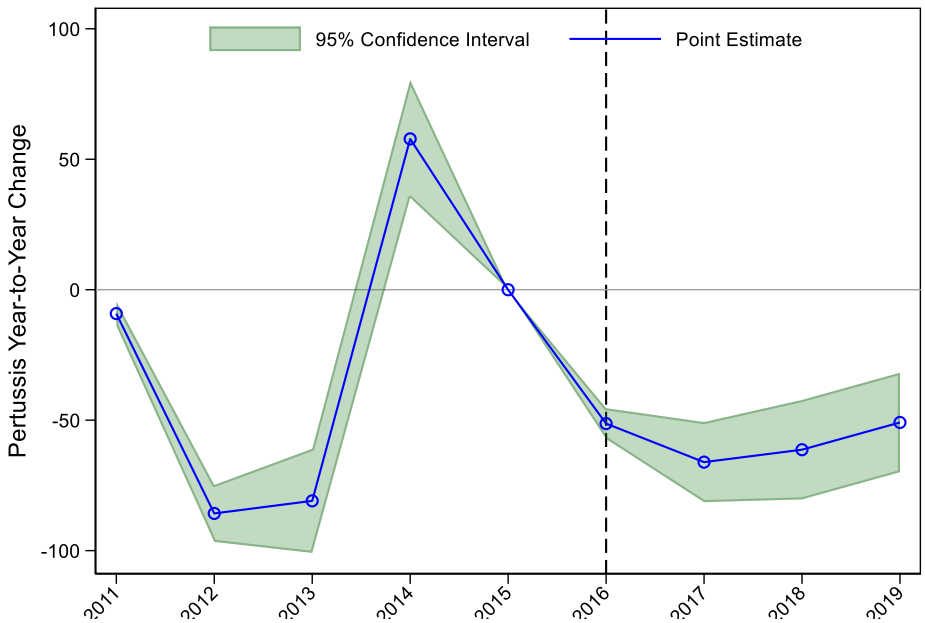
Figure 2.4 Event Study Results: DTP Coverage and Pertussis Prevalence

Leads and lags regression parameters on DTP vaccination rate and pertussis prevalence. Models include county and year fixed effects, with standard errors clustering at the state level. Y axis displays coefficients on lead and lag dummies; green bandwidth shows 95% confidence intervals around coefficients. Coefficient for the year 2015 is set as zero to serve as comparison.

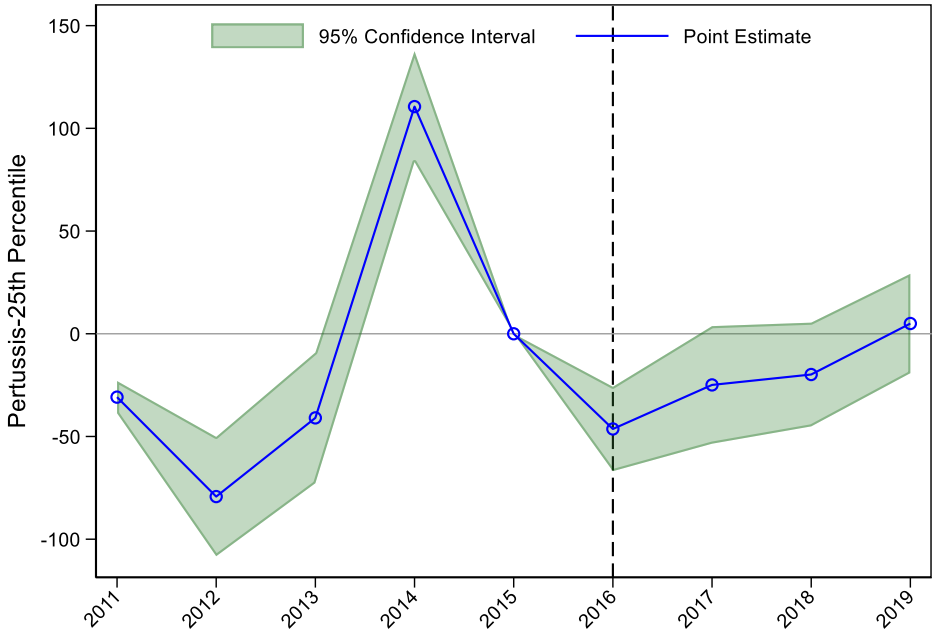
Panel A: DTP Vaccination Rate (%)



Panel B: Pertussis Year-to-Year Case Change



Panel C: Pertussis Relative to the 25th Percentile Case Count



Panel D: Pertussis Rate Per 100,000 Population

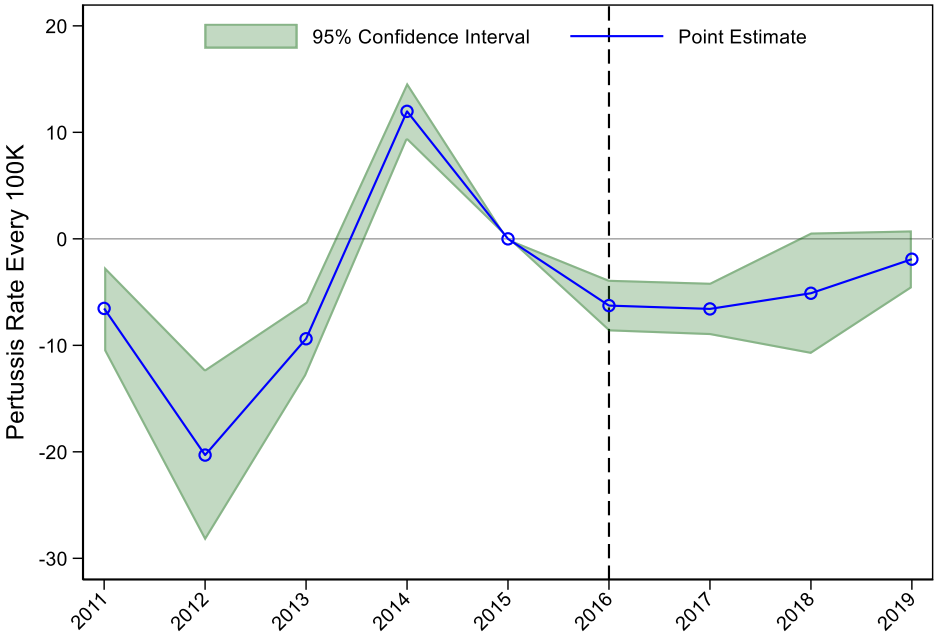
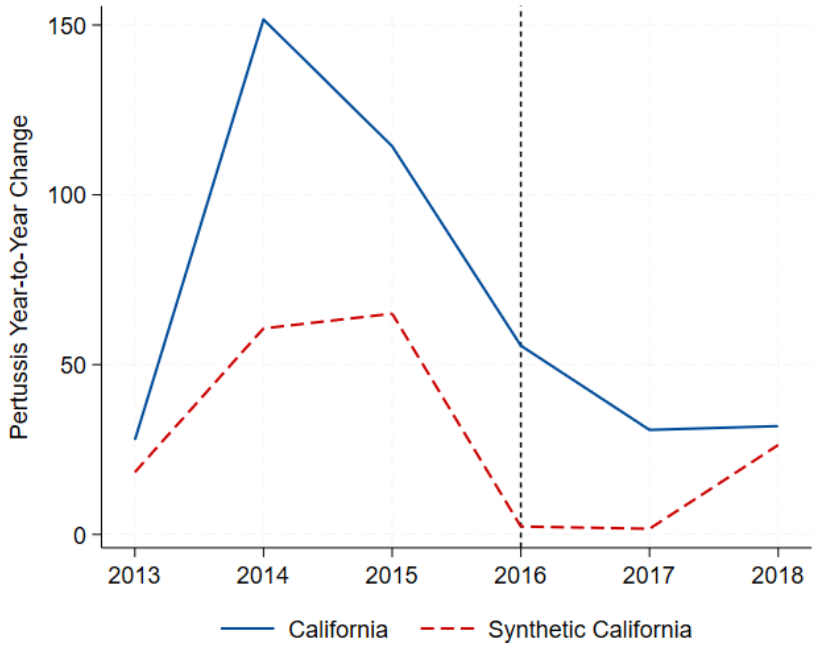
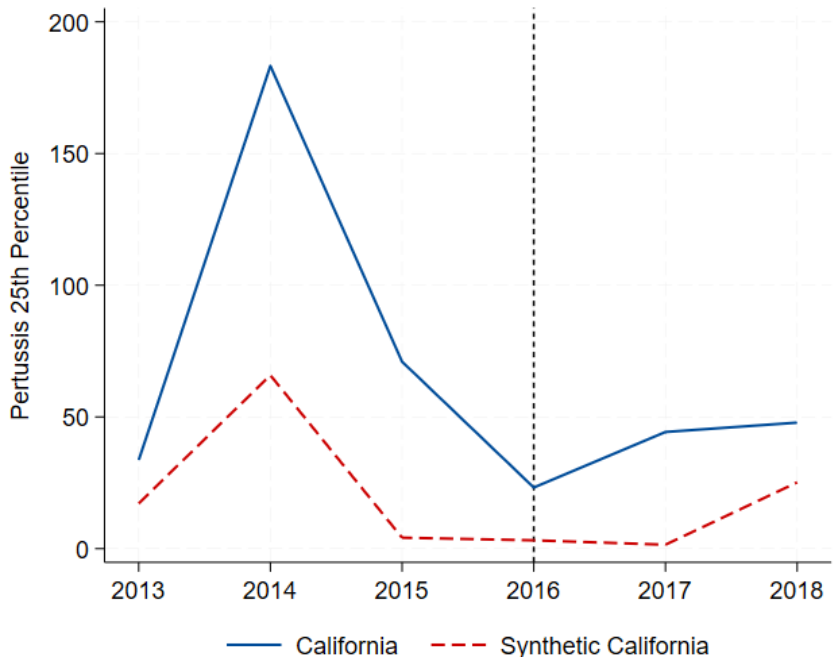


Figure 2.5 Synthetic Control Results: Pertussis Prevalence Measures[35]

Panel A. Pertussis Year-to-Year Change



Panel B. Pertussis Relative to the 25th Percentile Case Count



[35] Panel A and B assigned 100% of weight to Delaware. Panel C assigned 2.4% to Colorado, 60.5% to Delaware, and 37% to Washington.

Panel C. Pertussis Case Rate Per 100,000 Population

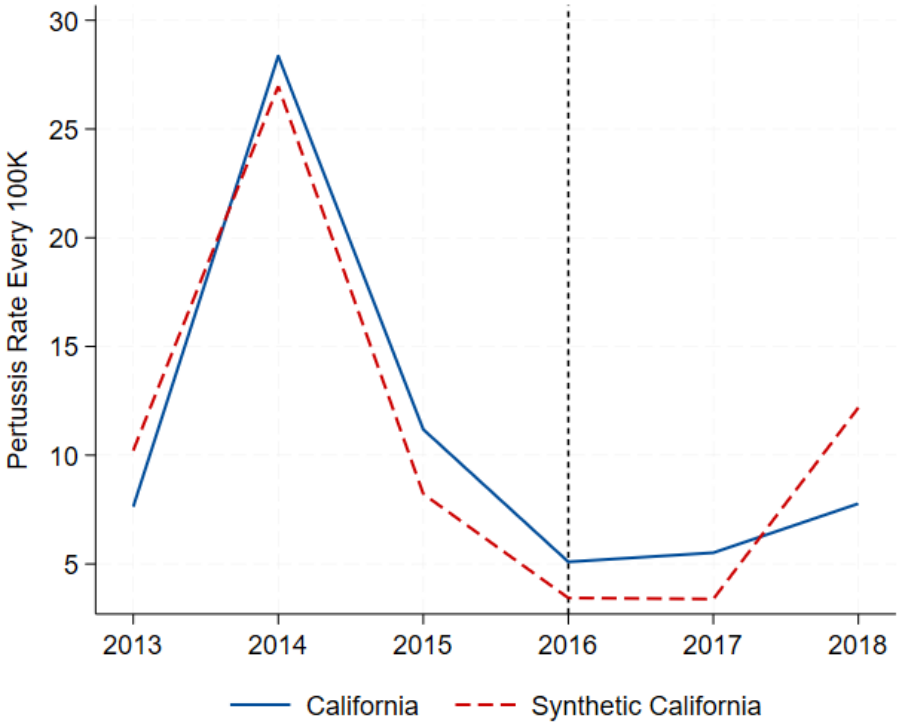
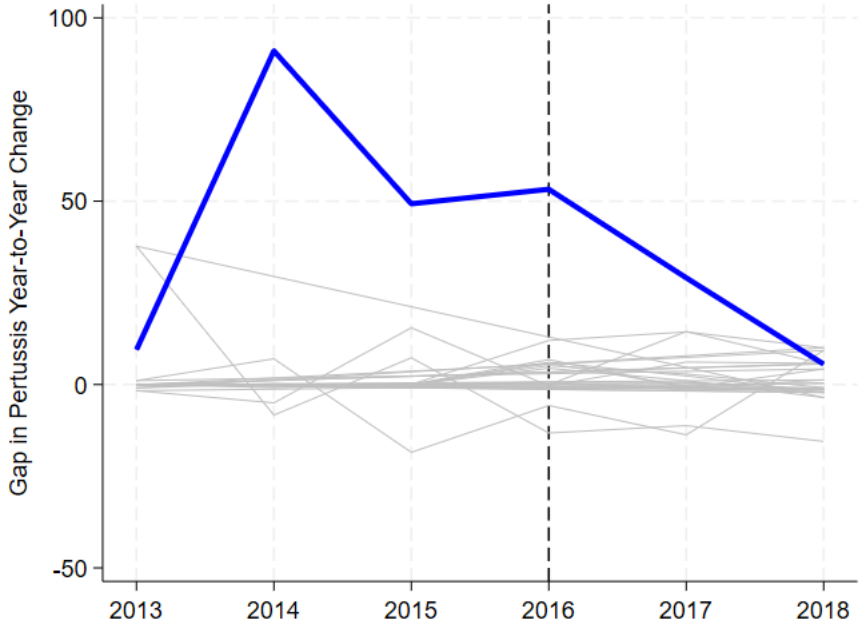


Figure 2.6 Placebo Test: Synthetic Control Gaps in Pertussis Measures

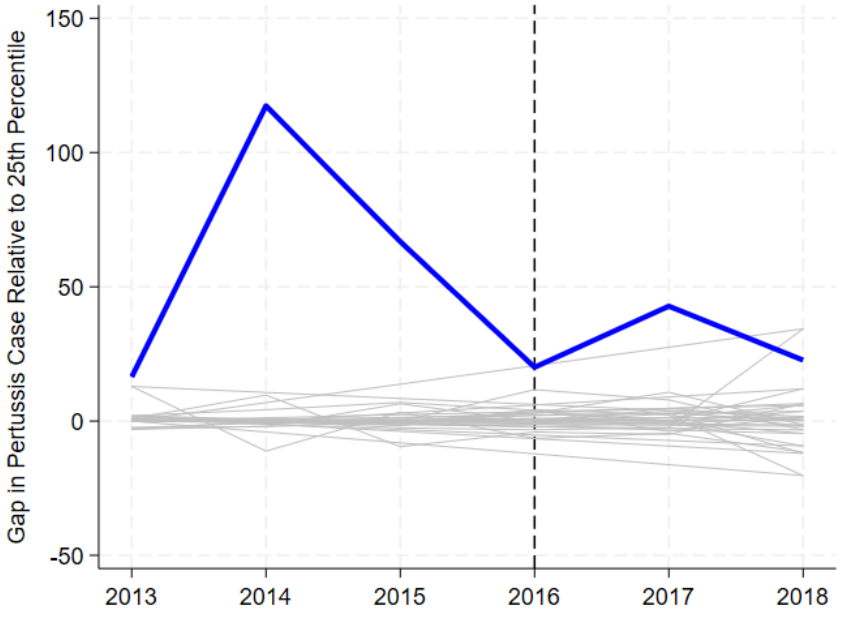
Panel A. Pertussis Year-to-Year Change

P-value < 0.05. Blue line indicates California; Grey lines display placebos.



Panel B. Pertussis Relative to the 25th Percentile Case Count

P-value < 0.05. Blue line indicates California; Grey lines display placebos.



Panel C. Pertussis Case Rate Per 100,000 Population

P-value < 0.05. Blue line indicates California; Grey lines display placebos.

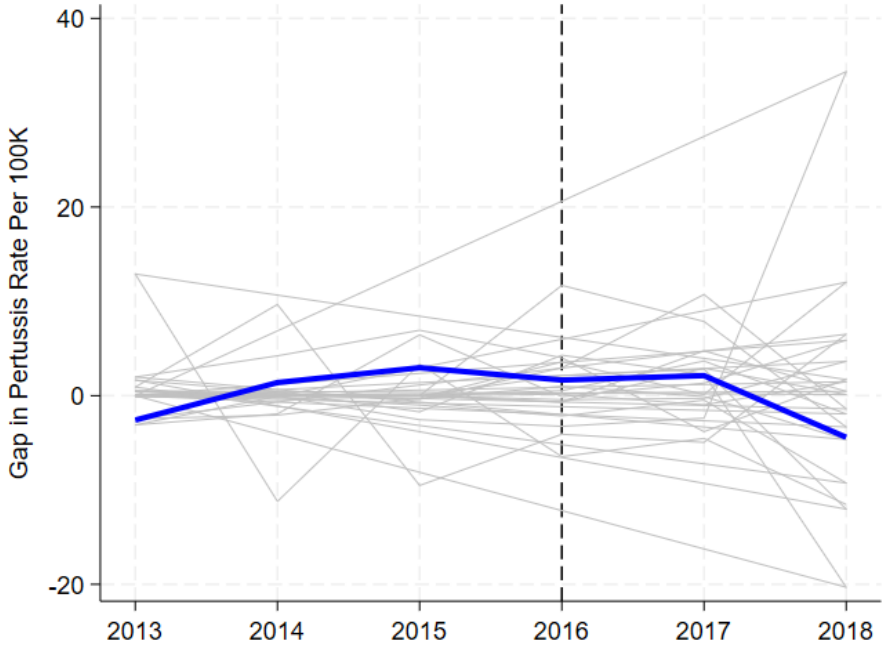
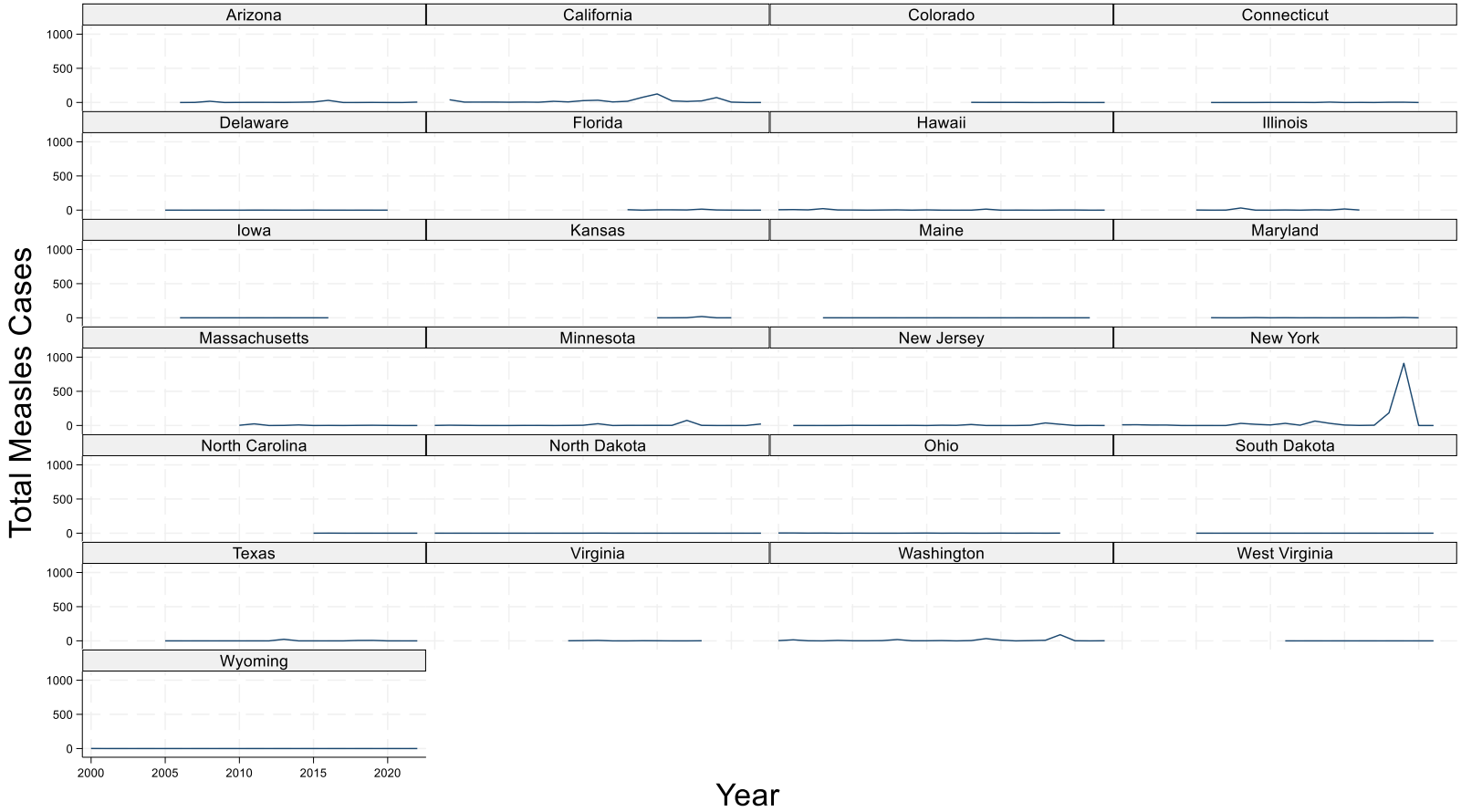
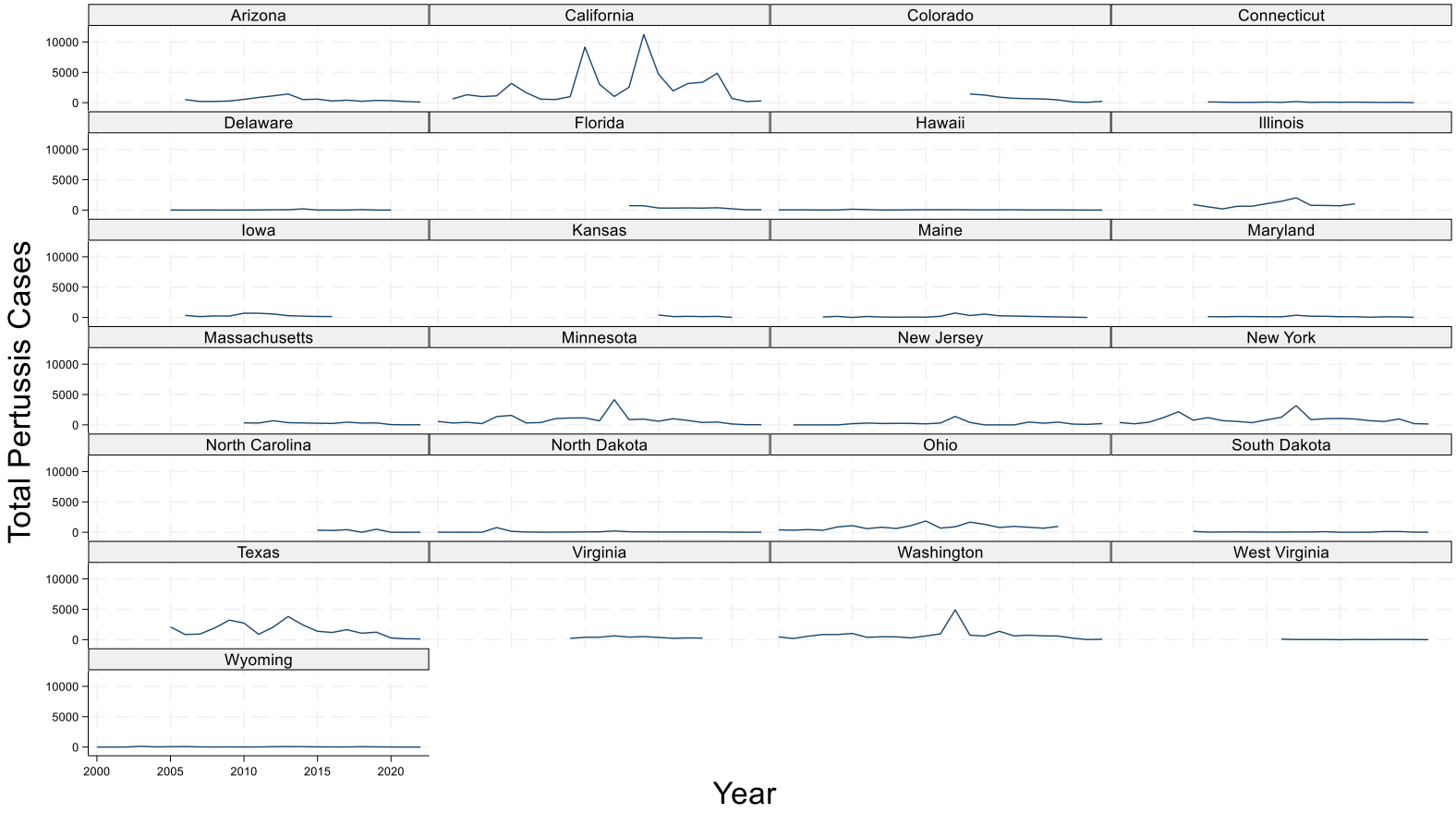


Figure 2.7 Total Number of Measles Reported by Each State: 2000-2022



Data source: State Health Department

Figure 2.8 Total Number of Pertussis Reported by Each State: 2000-2022

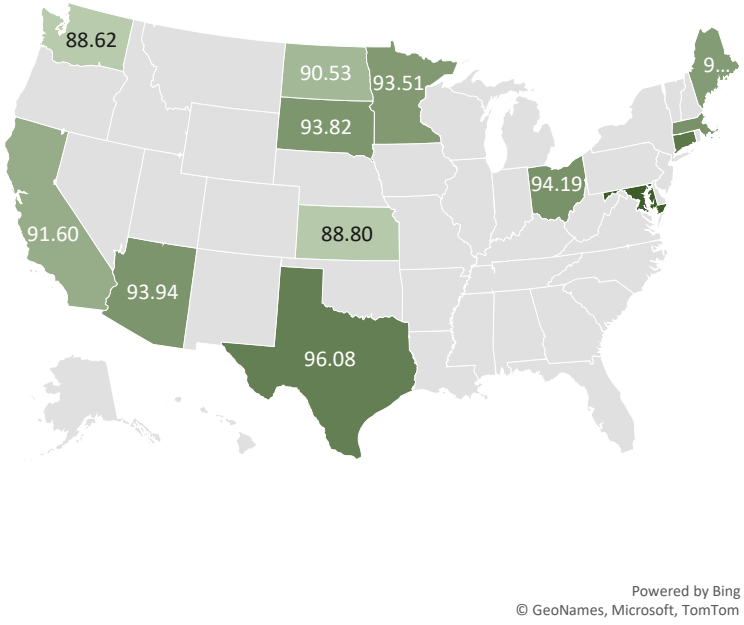


Data source: State Health Department

Figure 2.9 Average MMR Coverage Rates: Before and After

Average MMR vaccination coverage rates (%) three year before and after the 2016 repeal of non-medical exemption

Before: 2013, 2014, 2015



After: 2016, 2017, 2018

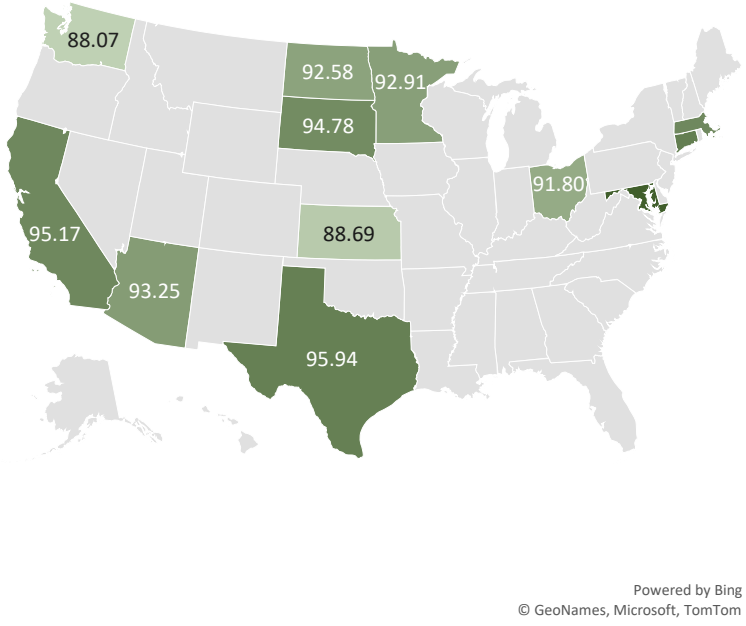
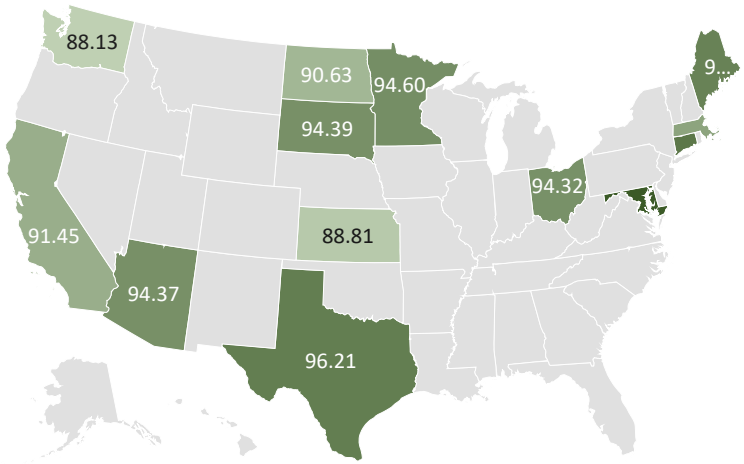


Figure 2.10 Average DTP Coverage Rates: Before and After

Average DTP vaccination coverage rates (%) three year before and after the 2016 repeal of non-medical exemption

Before: 2013, 2014, 2015



After: 2016, 2017, 2018

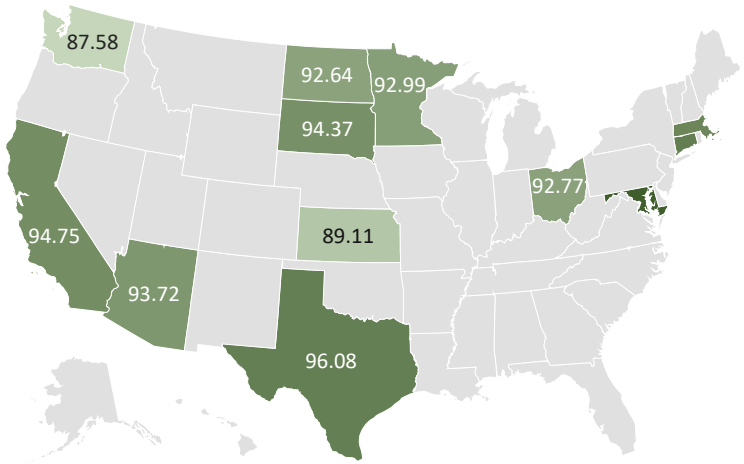
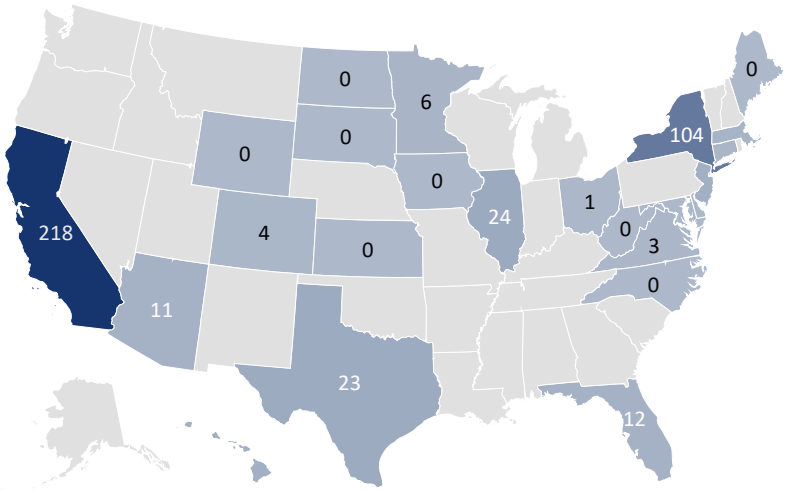


Figure 2.11 Total Number of Measles Reported by States: Before and After

Before: 2013, 2014, 2015



After: 2016, 2017, 2018

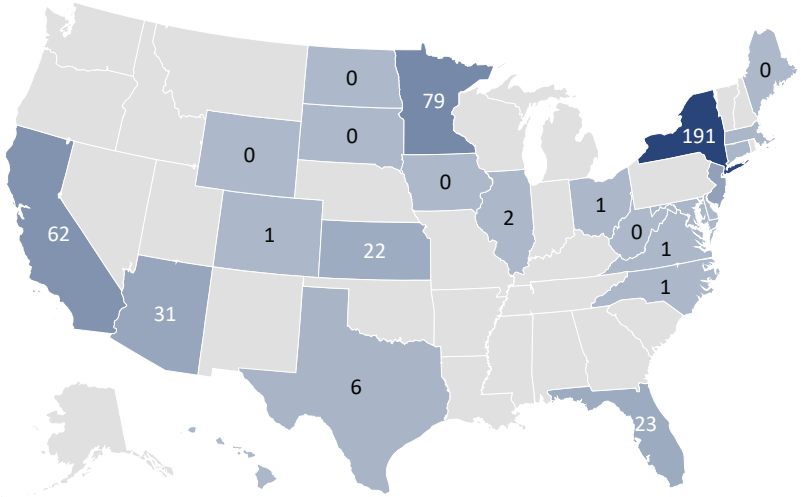
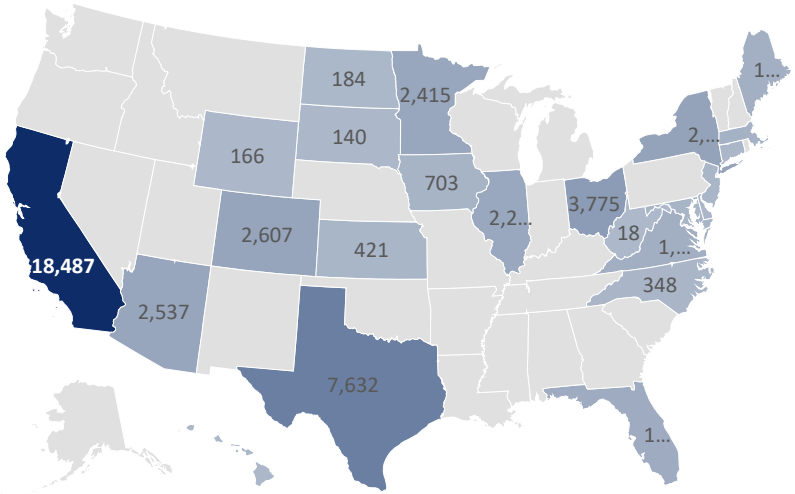
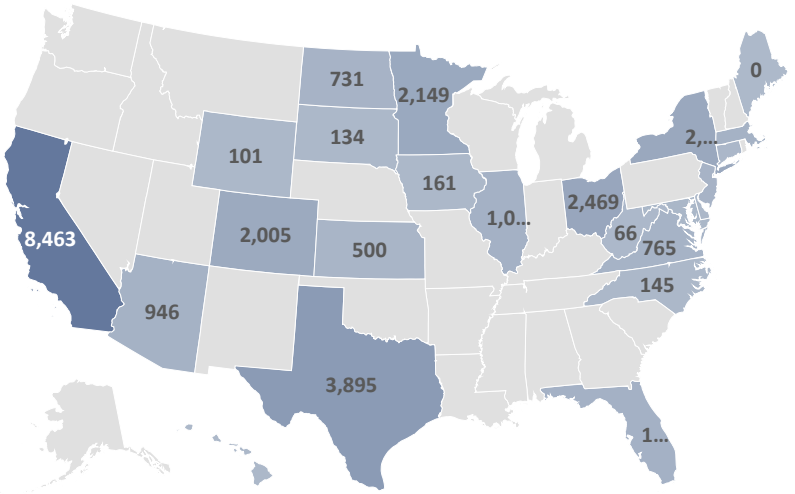


Figure 2.12 Total Number of Pertussis Reported by States: Before and After

Before: 2013, 2014, 2015



After: 2016, 2017, 2018



Essay 3: From Clinics to Classrooms: How California's 2016 Vaccine Mandate Affects Chronic School Absenteeism

3.1 Introduction

3.1.1 Vaccine Mandate and Chronic Absenteeism

Vaccine mandates for school-entry aim to improve vaccination uptake, promote the attainment of herd immunity, and mitigate the risks of vaccine-preventable disease (VPD). Despite the extensive examination on the direct health and health sector outcomes, the spillover effects of such mandates on other sectors, including education and school settings, remain underexplored. In this paper, I fill this gap by assessing the impact of California's 2016 vaccine mandate on its chronic school absenteeism.

There is an intrinsic motivation to study how school-entry vaccine mandates influence educational outcomes: such policies not only reduce the risk of VPDs among school-eligible children but also boost their early childhood development through improved physical health. Enhanced health enables more consistent school attendance, allowing students to better engage in both curricular and extra-curricular activities (Lachini and Anderson-Butcher, 2012; Ricci et al. 2020). An extended and more effective school presence also fosters meaningful learning, facilitates peer interactions, and contributes to cognitive and socioemotional developments, which in turn helps promote children's overall well-being (Nandi and Shet, 2020; Stevens 2017; Tate et al., 2019; Bloom et al., 2011).

Researchers employ various metrics to evaluate student success in educational settings. Common indicators include, for instance, students' test score, graduation rate, attendance and retention rate. Among such measures, school attendance and chronic absenteeism serve as complementary metrics for assessing both the sufficiency of

students' school participation and the degree to which health-related or other factors hinder regular attendance. Chronic absenteeism is defined as students missing 10% or more of school during a given school year.[36] While it is difficult to directly measure students' physical health in a school setting, attendance and chronic absenteeism rates are often employed as proxy indicators to assess children's physical wellness at school, given that illness remains one of the primary barriers to consistent school attendance (Allison et al., 2019; Lissack, 2021).

Chronic school absenteeism rate is also an emerging measure that has attracted an increasing scholarly attention in recent years. Since the COVID-19 pandemic, researchers in the education field have particularly focused on examining how the pandemic has impacted attendance, finding that the COVID-19 pandemic has curbed school attendance, with post-COVID chronic absenteeism rates increased considerably at both the elementary and secondary school levels within the U.S. education systems (Dee, 2023; Evans et al., 2024; Chang et al., 2021).

Chronic absenteeism fluctuates due to the varying federal and state education policies and requirements that directly impact school attendance. It is also indirectly influenced by cross-sectoral policies that affect student behavior attending schools. A vaccine mandate policy may reduce chronic absenteeism through multiple pathways. On the one hand, increasing vaccination coverage can directly decrease illness-related absence, thereby reducing VPD sickness-related absence and in turn, promote school

[36] Retrieved from the U.S. Department of Education Website: https://www.ed.gov/teaching-and-administration/supporting-students/chronic-absenteeism
Before school year 2017-2018, chronic absenteeism was defined as students missing at least 15 school days. Starting school year 2017-2018, it was revised to students missing at least 10% school days, or 18 school days.

attendance. On the other hand, a mandate may alleviate parental concerns about school safety in disease-endemic environments. Previously hesitant parents, who avoided sending their children to school due to fears of VPDs, may demonstrate greater compliance with attendance once population-level VPDs are under control and school safety is back to normal. Finally, a vaccine mandate may also reduce chronic absenteeism, if vaccine hesitant parents choose to homeschool their children or relocate to states that allow non-medical exemptions, contributing to a decline in overall enrollment and a higher proportion of fully immunized school children.

Disparities in chronic absenteeism are common across students with different profiles. Studies demonstrate such disparities in relation to students' race, socioeconomic status, and disability status. Overall, African American, Hispanic, and multiple racial students experience a higher chronic absenteeism compared to their White and Asian counterparts. Students from low-income households and those with disabilities are also more likely to experience chronic absenteeism (Gee, 2018; Liu and Lee, 2022; Patnode et al. 2018). There is not a single explanation for chronic absenteeism, but economic hardship, limited access to healthcare, housing instability, homelessness, etc. are often associated with disparities and unequal opportunities associated with absenteeism.[37]

Studying disparities in chronic absenteeism is particularly important. First, it discloses systemic inequalities and differences in educational opportunities and outcomes, helping to identify economically and socially disadvantaged subgroups. Second, it informed the design of targeted interventions to better support populations who

[37] Retrieved from the Upstream Public Health: https://www.attendanceworks.org/wp-content/uploads/2017/08/Chronic-Absence-and-Health-Review-10.8.14-FINAL-REVISED.pdf

do not equally benefit from existing interventions, thereafter, promoting social welfare, fairness, and justice.

3.1.2 California Vaccine Mandate

After having experienced the worst measles and pertussis outbreaks in years leading up to 2016, attributed to a declining vaccination coverage among school-aged children,[38] California state legislators responded quickly by passing a new law ("Senate Bill #277") in 2015 eliminating non-medical exemptions[39] from school-entry vaccination requirements. Previously, non-medical exemptions, such as those based on religious or philosophical reasons, were accepted by California schools. Effective in 2016, the new law removed all non-medical exemptions and only allows exemptions to those with valid medical justifications.

Before school year 2016-2017, California permitted non-medical exemptions for school-entry vaccinations based on religious or personal belief reasons. Before the mandate, the California health authority had begun gradually tightening exemption policies through modest regulatory measures, even though such measures were less radical compared to a mandate. In 2012, California passed the Assembly Bill 2109 (AB2109) requiring parents who seek non-medical exemptions to submit an attestation, signed by a healthcare provider, confirming that they had received education about responsibilities and risks of not vaccinating their children (Jones and Buttenheim, 2014). During this time, the exemption process remained relatively accessible and could be filed on a temporary or permanent basis.[40] Parents were only required to obtain renewal of

[38] Refer to *Essay 1: Pertussis and Measles Incidence Trends and Vaccination Coverage* of this dissertation.
[39] Include personal belief exemptions and religious exemptions.
[40] Retrieved from Los Angeles County Government:
http://publichealth.lacounty.gov/chel/library/topics/schoolimmunization/CDCP-IP-0011-01.pdf

their temporary exemptions once the current one expires. Moreover, there were no additional third-party verifications of the filed exemptions. In some cases, schools could provisionally admit students who had initiated the first dose but not completed vaccination requirement on any of the vaccines required for school-entry.[41] Similarly, schools were required to accept non-medical exceptions without putting additional terms and requirements on parents. The allowance of non-medical exemptions is associated with a lower vaccination coverage, and the various VPD outbreaks in California before 2016.

The 2016 vaccine mandate eliminated all non-medical exemptions and established stricter requirements for filing medical exemptions. Under the new policy, parents seeking exemption must obtain a written statement from qualified healthcare providers and should specify the specific medical conditions applied to skip vaccination and the expected duration. Parents also needed to submit valid documentations to schools for verification.

The new law applies to both public and private elementary or secondary schools, childcare centers, day nursery, nursery school, family day care home, or development centers. It is required among pupils who are to be enrolled for the first time or in the next grade until the 7th grade level. Students with an already submitted letter or affidavit and a valid exemption on file before school year 2016-2017 were allowed to remain in schools until they were admitted to the next grade. However, the mandate does not apply to students in home-based private schools or independent study programs.

[41] Retrieved from Los Angeles County Government: http://publichealth.lacounty.gov/chel/library/topics/schoolimmunization/CDCP-IP-0011-01.pdf Mandatory vaccination is required against the following VPDs: Diphtheria, Tetanus, Pertussis, Measles, Mumps, Rubella, Poliomyelitis, Varicella, and Haemophilus influenzae type b

The 2016 mandate maintained the existing scope of school-entry vaccination requirements without modifying the covered VPDs. California's 2016 mandate only applies to vaccination against nine VPDs already required for school-entry even before 2016. These VPDs cover Diphtheria, Tetanus, Pertussis, Measles, Mumps, Rubella, Poliomyelitis, Varicella, and Haemophilus influenzae type b. Vaccines such as influenza and HPV remain excluded from California's school-entry vaccination requirements.[42] Nationwide, the same array of vaccines are consistently required for school-entry before and after the implementation of California's mandate.

3.1.3 Objectives and Results

California's 2016 vaccine mandate demonstrates effectiveness in increasing vaccination rates among school-aged children (Richwine et al., 2019). It also helps reduce both the incidence and severity of VPDs.[43] However, empirical evidence examining the direct relationship between the mandate and associated educational outcomes remains limited. This research gap introduces a timely window and opportunity to investigate the policy's impact on school-related results, particularly related to attendance patterns and chronic school absenteeism behaviors.

In this study, I explore the relationship between California's 2016 vaccine mandate and chronic school absenteeism through multiple perspectives. First, I conduct a literature review to identify evidence of vaccine and vaccination policies on school outcomes and educational settings. Second, I empirically examine chronic school absenteeism data and overall trends covering all U.S. states and jurisdictions including

[42] Retrieved from the California Legislative Information: https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160SB277

[43] Refer to *Essay 2 California's 2016 Vaccine Mandate on Vaccination Coverage and Disease Burden – A Causal Study*, of this dissertation.

California. Finally, I explore the causal impact of the mandate on chronic school absenteeism, the extent to which chronic absenteeism has fluctuated as a result of implementing the 2016 vaccine mandate, by comparing California to other states.

As this study represents a novel area of exploration, existing literature offers limited empirical evidence. To this end, my study addresses this gap by conducting quasi-experimental examinations, comparing California to states without major vaccine policy change using a difference-in-differences (DiD) design. Employing school-level data, this study quantifies the policy's effect on chronic absenteeism rates among school-age children. Chronic school absenteeism rate, which is defined as the percent share of students missing more than 10% or more of school during one school year, serves as the primary outcome variable.

Robust empirical evidence points out that California's 2016 vaccine mandate reduced average chronic absenteeism rates, particularly among younger age cohorts. Difference-in-differences estimates leverage school-level data, which indicate an overall reduction of 1.09 percentage points in chronic absenteeism rate, or a 10.8 percentage reduction of the average absenteeism rate prior to the pandemic. There is also a slightly more pronounced effect of the mandate on male students than female students. Moreover, racial heterogeneity analysis reveals particularly strong impacts of the mandate on reported White students, showing a 2 percentage-point reduction of average chronic absenteeism rate of both White male and female students, suggesting that the mandate was most effective for certain racial profiles, while highlighting the need for a more targeted intervention to further address racial gaps.

3.1.4 Mandate During the COVID-19 Pandemic

Most states, including California, maintained their pre-pandemic school-entry vaccination requirements throughout the COVID-19 pandemic. However, California distinguishes itself from other states through stringent pandemic response measures and displays a high level of discretion to reduce the pandemic's impact on education settings. California is among the first few states that immediately closed physical learning facilities at the onset of the COVID-19 pandemic and moved all teaching activities to online modalities. Starting school year 2020-2021, most Californian schools started to implement a hybrid model allowing both online and in-person options for school attendance. The COVID-19 vaccine was temporarily required for teachers and students during the 2021-2022 school year but was quickly rescinded before the beginning of the next school year. At the same time, face masks were required during the in-person learning environment until March 2022.[44]

The impact of the COVID-19 pandemic on school-entry vaccination requirements remains underexplored. It is yet clear on how attendance was recorded while students were exclusively engaged in online learning. Nevertheless, schools may have adopted slightly distinct criteria to determine attendance and absenteeism under a remote learning environment. Among the affected years, the 2020–2021 school year may have experienced the most significant disruptions, with most students learning from home through virtual platforms. To address the potential influence of the pandemic on California's chronic absenteeism data, particularly lack of uniformity in taking attendance and absenteeism, I first exclude the pandemic-affected observations from

[44] Retrieved from: https://ballotpedia.org/School_responses_in_California_to_the_coronavirus_(COVID-19)_pandemic

school year 2020–2021 as the major specification and then include them to test for robustness.

California has maintained stringent school-entry vaccination requirements since the 2016 mandate, with no relaxation of standards even during the COVID-19 pandemic. In fact, the COVID-19 pandemic has further strengthened its vaccination requirements. Obtaining a medical exemption has become increasingly difficult in California. In 2021, a new law[45] came into effect requiring all medical exemptions to be filed utilizing a centralized state digital system. To do so, parents are required to first create an account with the California Department of Public Health (CDPH) and apply for exemptions using the California Immunization Registry Medical Exemption website: cair-me.cdph.ca.gov. CDPH will then grant each applicant an exemption application number, which parents must inform doctors and ask doctors to create an account to file exemptions online. Finally, doctors need to provide parents with a printed or electronic exemption and parents are responsible for submitting this copy to schools.[46] Similarly, schools must verify all exemptions, and report exempted cases to California health authorities. Schools are also responsible for notifying families when exemptions expire. This multilayered verification process constitutes one of the most rigorous medical exemption frameworks in the U.S., promoting state vaccination coverage and helps maintain a low prevalence of VPDs. Consequently, California experienced a consistently high vaccination coverage[47] and a comparatively slower increase in chronic absenteeism during the COVID-19 pandemic compared to many other states.

[45] Referred to as the Senate Bill 276 and 714.
[46] Ibid.
[47] Refer to *Essay 1: Pertussis and Measles in California: Trends in Incidence and Vaccination Coverage Before and After the 2016 Vaccine Mandate* of this dissertation.

3.1.5 Mechanisms

While California's vaccine mandate, on the health side, aims to increase vaccination coverage among students upon school-entry, the mandate also generates long-lasting spillover impacts on student attendance and chronic absenteeism through multiple pathways. First, the mandate can protect children from contracting common VPDs, which generally requires a lengthy recovery period, for instance, two to three weeks to recover from pertussis.[48] Therefore, when large scale VPD outbreaks are no longer concentrated at schools, a reduced chronic absenteeism is expected. Second, early childhood VPD infections increase the risk of complications, which can extend the existing absence due to VPD infections (Brenzel et al. 2006). Additionally, the mandate helps transform schools from perceived as disease hotspots to safer learning environments, which further enhances its public image. Consequently, it may influence parental attitude toward school safety, which motivates them to better comply with school attendance requirements.

On the other hand, a vaccine mandate can serve as an effective tool raising public awareness on the importance of vaccination. As a result, the mandate encourages parents to maintain compliance with both mandatory and non-mandatory vaccines for their children. Accordingly, the mandate could display a spillover effect nudging fuller compliance on other vaccines, such as influenza and HPV. In parallel, vaccination-related health education can equip parents with broader disease prevention knowledge, such as hand washing and nutrition supplement, and dispel misconceptions around vaccination,

[48] Retrieved from Centers for Disease Control and Prevention (CDC): https://www.cdc.gov/infection-control/hcp/healthcare-personnel-epidemiology-control/pertussis.html

such as the misconception between vaccination and the development of autism (Holroyd et al. 2020). All these positive spillover effects further enhance children's health.

3.2 Literature

Hypothetically, a high vaccination coverage helps minimize disease incidence, reduce chronic absenteeism, and improve educational attainment and outcomes among students. Therefore, a higher vaccination coverage, as a result of a vaccine mandate, would be negatively associated with chronic absenteeism rates. In other words, vaccine mandates should reduce chronic absenteeism and improve students' presence and performance at schools.

Methodologically, my review of the literature incorporates quantitative and empirical studies published in peer-reviewed journals that combine both health and education journals. PubMed, American Economic Association (EconLit), Journal Storage (JSTOR), and Education Resources Information Center (ERIC) are therefore used as primary source for the literature search. The search term includes and combines "vaccine," "mandate," "school," or "school district," and "illness absenteeism" or "absence".

Evidence from the literature suggests that more stringent school vaccination policies contribute to reduced chronic absenteeism. For instance, Plaspohl et al. (2013) study the impact of flu vaccine program on student absence and find that the average frequency of school absence is much lower among children who receive school-based influenza vaccination. Beyond immediate attendance benefits, such a massive immunization program also promotes students' overall wellness and academic persistence. Lee (2012) quantifies the impact of childhood vaccine mandates in the U.S.

on disease morbidity and mortality and education outcomes. Employing a difference-in-differences approach and measuring years of schooling and high school completion rates, their study finds that childhood vaccine mandates extend the average years of schooling by 0.1 years and improve students' success as the rate graduating from school by 1.8 percentage points. Williams et al. (2013) characterize different types of school-based influenza surveillance indicators and identify school-based absenteeism pattern as the most reliable detector of an influenza pandemic based on laboratory-confirmed total cases of influenza. This in turn highlights the connection between illness, early signals of pandemic, and the value of school-based chronic absenteeism in predicting the pandemic. Collectively, studies substantiate the hypothesis that vaccine mandates may improve school attendance through enhancing vaccination coverage and reducing illness-related absence.

The positive relationship between immunization programs, mandates, and school absenteeism is also evident in studies conducted outside the U.S. For example, Green et al. (2016) assess whether recommending influenza vaccines in U.K. schools have any correlation with illness-based chronic absenteeism. They find a significantly decreased illness absenteeism among program participants. Kawai et al. (2011) conduct a retrospective descriptive analysis on the effect of an influenza program in Japan and find that massive vaccination reduces both the number of class cancellation days and absenteeism in schools. The overall review returns consistent results: vaccine mandates are in general associated with reduced absenteeism, even though the magnitude of the effect could be small. Methodologically, most of the reviewed studies are merely

correlational. Only three studies employ a more rigorous statistical approach, such as using a difference-in-differences (DiD) design.

The literature also confirms several methodological and conceptual limitations. First, in most studies, causal inference and a clear identification strategy are either lacking or weak, making it difficult to conclude that a vaccine mandate directly results in reduced school absenteeism. Second, most studies only employ state-level analyses, and there is a need to further test the heterogeneity issues through more granular data, such as at the county or school level. Third, most studies have disproportionally focused on empirically examining the impact of the non-mandatory influenza vaccination whereas the study on the impact of mandatory vaccines for school-entry is lacking. Influenza-based vaccination programs differentiate from the vaccines required for school-entry, and in most states, influenza vaccine is merely a recommended vaccine, providing parents with different motivations to participate compared with mandatory vaccines. This again confirms that few studies have focused on the relationship between mandatory school-entry vaccines and chronic school absenteeism. This paper fills this gap in literature, by empirically examining the spillover effect of a health-focused vaccine mandate on chronic school absenteeism rate, which is a major outcome that measures students' behavior pattern and success attending schools.

This study demonstrates that health-focused vaccine mandates can also generate meaningful spillover effects, particularly in reducing chronic absenteeism, a critical factor to determine student success. This study makes two meaningful contributions. First, it shows how public health interventions can advance educational settings. Second, the analysis discloses racial disparities in the perceived policy impacts, with White

students benefiting more compared to other groups. On the one hand, the study helps identify subpopulations that may require additional support to achieve more equitable outcomes, such as Black and Hispanic students. On the other hand, it highlights the inequalities rooted in both health and education outcomes. While vaccine mandates represent an effective tool to reduce school absenteeism, complementary strategies should accompany the implementation of mandates to achieve more equal benefits.

3.3 Data

This study utilizes data from the Civil Rights Data Collection (CRDC), a nationwide data collection initiative administered by the U.S. Department of Education. The CRDC is a national data collection initiative collecting a series of metrics of educational setting, including, for example, students' demographics, learning barriers, school conditions, among many other school factors, such as teachers and students' life and success in all public schools, charter schools, alternative schools, and other types of schools. The CRDC database covers students ranging from a wide variety of grades, including from early childhood development to grade 12. Data are publicly available at the U.S. Department of Education website.[49]

The CRDC employs a biennial cycle for data collection, which aligns with the academic school years. For example, the 2020-2021 round of survey captured school characteristics and student performance metrics spanning the entire corresponding academic year between 2020 and 2021. Data collection relies on a mandatory standard survey disseminated to each school, school district, or local education agencies (LEAs). Data are therefore reported at the school level. The CRDC collects comprehensive

[49] CRDC database can be retrieved from: https://civilrightsdata.ed.gov/

indicators across multiple domains, such as school characteristics, teachers and school conditions, students' demographics and learning environment and activities. It also collects students' academic performance and placement, such as their exam taking and passing and classroom retention.

The CRDC first introduced chronic absenteeism as a measured indicator in school year 2013 and 2014. Initially, this metric was operationalized as the number of students in each school who have missed more than 15 instructional days within an academic year. The same definition of the indicator on chronic absenteeism was employed in collecting data for school year 2015 and 2016. Starting school year 2017 and 2018, the CRDC has revised the data collection approach by moving the data collection into the "EDFacts" data collection initiative, which is parallel with the CRDC data collection. Additionally, the CRDC has revised the definition on the metric of chronic absenteeism. Instead of capturing a student missing 15 school days or more, the new definition measures the number of students who miss 10% or more of total instructional days within a school year. This revised definition introduced a more stringent threshold, increasing the measured absenteeism from 15 to approximately 18 school days (based on 180 days of instruction mandated in California). The updated metric has been applied in all subsequent CRDC data collection cycles from school year 2017-2018 onward.

The alignment between California's 2016 implementation of the vaccine mandate and CRDC's revised absenteeism introduced in 2017-2018 school year introduces a measurement challenge. The shift from 15 to 18 days represents a more lenient operationalization of chronic absenteeism. Therefore, any policy effects perceived from this period are in fact conservative measures, with the true effects likely larger than what

the CRDC can provide. This suggests that the empirical analysis of this study will yield a lower-bound approximation of the policy's actual effects in reducing absenteeism.

The CRDC data collection also demonstrates recurring reporting inconsistencies. First, since the CRDC retains unmodified data reported directly from each school, there are cases where the total number of students reported chronically absent from schools surpasses the total number of enrolled students. Second, survey participation varies largely across reporting cycles, with many schools only responding to the survey in merely one or two school years, resulting in an incomplete raw panel dataset. To ensure data quality and strengthen validity, this analysis only considers schools that have regularly and appropriately reported the chronic absenteeism cases. In other words, schools must have reported surveys in each school year, and the reported case of absence cannot exceed total enrollment. This filtering approach yields a balanced panel with reliable data reporting from each school. More details of the raw CRDC database and the data cleaning process are presented in *Appendix B Data and Methodological Notes.*

Given that California's vaccine mandate primarily targets kindergarteners and early elementary students, this study specifically focuses on educational institutions that serve younger age cohorts, specifically, kindergarteners, primary schoolers, elementary schoolers, and daycare and preschool students. One limitation of the CRDC data is that there is no explicit way to identify school types. To overcome this caveat, I employ a name-based filtering protocol to identify schools that are clearly labelled as kindergartens, primary, elementary, or preschool schools and daycares. My final school-level dataset comprises these types of schools from all U.S. states and jurisdictions, covering four school years: 2013-2014, 2015-2015, 2017-2018, and 2020-2021. The final

dataset includes 107,780 "*school-year*" observations,[50] from 50 states spanning four school years. More specifically, this analysis uses a consistent sample of 26,945 schools per year across all 50 states as the final dataset for the main specification. These school-year observations serve as the unit of analysis for this study.

3.4 Methodology

3.4.1 Construction of Measure

The CRDC dataset does not explicitly report chronic absenteeism rate at the school or school district level. It, instead, reports the total count of enrolled students and those who are chronically absent from schools, by school total, male and female in each school, as well as by different racial groups under each gender categorization: Hispanic, Asian, White, and Black.[51] Despite the lack of the explicit chronic absenteeism rate, based on the total count of enrolled and absent students, I can readily calculate the chronic absenteeism rate for each school in each school year by relying on the following formula:

*(# of students who are chronically absent) / (# of total enrolled students) * 100%*

As previously noted, inconsistent data reported directly from schools undermines the validity of data analysis, jeopardizing the trustworthiness and reliability of the study results. For instance, even for the same school during the same school year, total count of

[50] This number includes observations from the four school years. The same school can be counted to four times.

[51] CRDC reported racial groups include Hispanic, Asian, White, Black or African American, American Indians or Alaska Native, and Native Hawaiian or Other Pacific islander, as well as two or more races. Due to the small sample size of certain racial groups, such as Hawaiian or Other Pacific islander, and to ensure analytical robustness, my analysis only incorporates four major racial groups: Hispanic, Asian, White, and Black under each gender.

enrolled students is sometimes reported smaller than students chronically absent from schools, yielding a chronic absenteeism rate higher than 100%.[52]

3.4.2 Descriptive Analysis

Following data cleaning processes, I first conduct a series of descriptive analyses to examine longitudinal patterns in overall chronic absenteeism rates, from before to after the implementation of California's 2016 vaccine mandate. Such analyses provide a quick examination and overview of California's baseline chronic absenteeism rate prior to the mandate and its changes after. *Table 3.1* displays the chronic absenteeism rates of California and other states in school year 2015-2016, the year prior to the implementation of the California's vaccine mandate. Other states which serve as the comparison group of states include all 49 other states, as the CRDC comprehensively collects enrollment and absence data from schools in each state.

In addition to displaying the overall trend of the chronic absenteeism rates, this study also reveals the total count of enrollment and absence from school-reported survey data in California and other states. *Table 3.6, Figure 3.3 and Figure 3.4 in Appendix A* respectively present the total count of enrolled students and students who are reported chronically absent from schools in California. The trend is further broken down by each racial group. Moreover, I showcase California's share of the nation's total enrollment and total absence via *Figure 3.5 (Appendix A)*, which displays the share of California among the nation's total of both enrollment and absence in each school year. Finally, *Figure 3.6 (Appendix)* displays changes in the average chronic absenteeism rates of California and other states that form the comparison group from before to after the 2016 mandate, by

[52] In this analysis, I exclude 3,251 school-year observations with calculated chronic absenteeism rates higher than 100% to reduce data accuracy issues.

each racial group and in each school year. All descriptive analysis results are presented in *Appendix A*.

3.4.3 Statistical Approach

3.4.3.1 Interrupted Time Series (ITS)

In this study, I first employ an interrupted time series analysis to only Californian schools to examine changes in chronic absenteeism rates before and after California's 2016 vaccine mandate implementation. The ITS or single group pre- and post- difference approach is suitable for this research context given the availability of longitudinal absenteeism data spanning both pre- and post- policy periods, allowing for comparison of outcomes across two distinct phases. The objective of conducting the ITS study is to explore whether absenteeism rates declined after the mandate, as this design enables detection of immediate changes and slope alteration following the policy intervention. The analysis is applied exclusively to California schools, which renders estimation of within-state effects. The basic ITS specification for solely California schools takes the following formula:

$$Y_{st} = \beta_0 + \beta_1 Time_{st} + \beta_2 Post_{st} + \beta_3 (Time_{st} * Post_{st}) + \varepsilon_{st}$$

In the above specification, Y_{st} represents the average school-level chronic absenteeism rate of state California ("*s*") and school year "*t*". The coefficient *β0* captures the baseline absenteeism rate of California of school year 2013-2014. The coefficient *β1* on $Time_{st}$ measures the pre-policy trend. In this case, the change in the chronic absenteeism rate from school year 2013-2014 to 2015-2016, given that only two school years' data are available before the mandate. *β2* on $Post_{st}$, which is the most important parameter, captures the immediate post-policy change, which is the percentage point

difference of the chronic absenteeism rates between school year 2015-2016 and 2017-2018. $\beta 3$ on the interaction term ($Time_{st} * Post_{st}$) measures post-policy slope change, which is the percentage point difference in the chronic absenteeism rate from school year 2017-2018 to 2020-2021. The ITS model is performed on all students from kindergartens, primary schools, elementary schools, preschools, and daycares in California. The model first applies to the chronic absenteeism rates of total students reported by schools. It is then also applied to male and female students, as well as each specific race reported at the school-level.

3.4.3.2 Difference-in-Differences (DiD)

To have a more accurate estimator quantifying the impact of the California's 2016 vaccine mandate on chronic school absenteeism rate, by comparing California with a set of comparison states without such a mandate, I also implement a two-way fixed effects difference-in-differences (DiD) model. This approach specifically examines changes in chronic absenteeism rates across different racial profiles among students attending kindergartens, primary schools, elementary schools, preschools, and daycares, by comparing California to comparison states before and after the 2016 policy implementation. The initial model treats California as the treatment group and all 49 other states as one comparison group and includes school year 2017-2018 observations as the only post-mandate year. Additionally, I also conduct two separate specifications to assess model robustness which includes adding school year 2020-2021 observations to consider the potential impact of the COVID-19 pandemic on chronic absenteeism rates. The regression model for the DiD analysis takes the following formula:[53]

[53] 'A' denotes chronic absenteeism rates and 'i' denotes schools

$$A_{ist} = \alpha_i + \lambda_t + \beta Mandate_{st} + \varepsilon_{it}$$

The model includes school and year fixed effects α and λ to account for unobserved heterogeneity. Standard errors are clustering at the state level to account for possible school-level autocorrelation. In this simple DiD regression model, the outcome variable *A* measures the average absenteeism rate for school *i*, in state *s* and in school year *t*. *Mandate* is a dummy variable that equals one to indicate California schools in school year 2016-2016 or later. The key coefficient of interest β on *Mandate* represents the average treatment effect on the treated, which measures the mandate's impact on chronic absenteeism rates in California schools, relative to the other states. The regression outputs from the DiD analysis are presented in *Table 3.4.*

In addition to the primary DiD analysis using all 49 states as comparison, I conduct two additional robustness checks by refining the comparison groups. First, I selected eight states that demographically and economically resemble California: they tend to have comparable economic profiles as California, and most are politically Democratic leaning. The selection is not random, and the goal is to select states that best resemble California. Washington, Massachusetts, Oregon, Colorado, Illinois, New Jersey, Maryland, Connecticut are selected. Notably, New York is excluded from the selection due to its 2019 measles outbreak, resulting in a subsequent adoption of similar vaccine mandate policies. Second, I further adjust the scope of comparison states by selecting eight states that are economically and politically contrasting California. These states tend to have a lower level of economic development, more conservative, and more Republican leaning. These states are Wyoming, Mississippi, Alabama, Idaho, Arkansas, Oklahoma,

Kentucky, and North Dakota. *Table 3.5 (Panel A* and *B)* presents the same regression results for these alternative specifications.

Implementing the DiD model as an unbiased causal estimation requires satisfying the parallel pre-trend assumption, which requires California and the comparison states to demonstrate a similar trend on the average chronic absenteeism rates in the period leading up to the adoption of the intervention. Therefore, the average chronic absenteeism rate should display a similar trend between California and comparison states across years before 2016. To test this assumption, I implement an event study, using leads and lags models to depict the policy's effects visually. The leads and lags model takes the following form:

$$A_{ist} = \alpha_i + \lambda_t + \sum_{\tau=1}^{2} £_{-\tau} Mandates_{t-\tau} + \sum_{\tau=0}^{1} £_{+\tau} Mandates_{t+\tau} + \varepsilon_{it}$$

In the above specification, *Mandates, t-* takes on the value of one τ years before repealing the non-medical exemptions in California. *Mandates, t-*$+\tau$ takes the values of one τ years after the mandate and equals zero otherwise. The model continues to include the school and year fixed effects, with standard errors clustering at the state-level. Pre-trend results of the event studies are presented in *Figure 3.2*.

3.5 Results

Interrupted Time Series analysis (*Table 3.3*) assessing Californian schools reveal that before the mandate, the average change in chronic absenteeism rate slightly increased from 2013-2014 to 2015-2016. Immediate change from 2015-2016 to 2017-2018 school years, following the implementation of the mandate, is a 11.6-percentage points reduction, which is the highest on Black, Hispanic, and White students.[54] From

[54] Reduction on the Black students is 18.66 percentage-point, followed by Hispanic, 14.47 percentage points, and white: 5.75 percentage points.

2017-2018 to 2020-2021 school years, average chronic absenteeism increased by 3.49 percentage points. This increase is most pronounced in Black students followed by Hispanic and White students. On the other hand, I cannot conclude a statistically significant change of chronic absenteeism rates among Asian students post mandate. Looking at the constant, which measures the baseline absenteeism rate in California in 2013-2014 school year, the average chronic absenteeism rate is 9.27 percentage, with Black the highest and Asian the lowest at the baseline estimation. Overall, the interrupted time series analysis demonstrates a statistically significant decline in chronic absenteeism rates immediately following California's 2016 vaccine mandate implementation, consistent with the policy's phased rollout timeline, and is consistent across most racial profiles. These results suggest the mandate improved chronic school absenteeism patterns during the post-intervention period (*Table 3.3*).

Many studies from the education realm reveal an adverse impact of the COVID-19 global pandemic on the chronic school absenteeism (Dee, 2023; Evans et al., 2024), with many schools closed to cope with the pandemic through social distancing. As did California at the onset of the COVID-19 pandemic, school closure brought extra uncertainties and levels of complexities to successfully measure chronic school absenteeism. To mitigate the pandemic's potential impact on chronic absenteeism rate, I first only include school year 2017-2018 observations as the post period in the difference-in-differences design, which serves as the main specification. I then rerun the same set of DiD analysis by adding school year 2020-2021 observations as the secondary specification. The results of both specifications are presented in *Table 3.4.*

The main specification with only 2017-2018 observations as post-period indicates a statistically significant decline in the chronic absenteeism rate from before to after the mandate. Specifically, as shown in *Table 3.4, Panel A*, the mandate reduced California's chronic absenteeism rate by 1.09 percentage points, which is modest in size and is equivalent to a 10.8 percent reduction of the average chronic absenteeism rate before the mandate. In terms of heterogeneous effects by race, the mandate had the greatest impact on White students, with a reduction of 1.98 percentage points among White male students and 1.89 percentage points among White female students, followed by Hispanic male students (0.87 percentage points) and Black female students (1.65 percentage points). On the other hand, the overall magnitude of the effect is smaller compared to the secondary specification where observations from the 2020–2021 school year are included (*Table 3.4 Panel B*). This suggests that the COVID-19 pandemic may have contributed more substantially to the decline in chronic absenteeism than the 2016 mandate alone, consistent with the strict measures California imposed to cope with the pandemic.

When comparing California to all other states before to after the implementation of the mandate considering the impact of the COVID-19 pandemic, as *Table 3.4 Panel B* illustrates, overall, the average chronic absenteeism rate in California decreased because of the mandate. More specifically, the mandate reduced average chronic absenteeism rate by 2.07 percentage points. The effect does not display a strong gender differentiation, although the reduction is slightly greater among female students (2.08 percentage points) than male students (2.05 percentage points). Among both male and female students, Black, White, and Hispanic students experienced the largest declines in chronic absenteeism, followed by Asian students. On average, the 2016 vaccine mandate in

California reduced the chronic absenteeism rate among White and Black male students by 2.71 and 2.37 percentage points, and Hispanic male students by 2.29 percentage points, all coefficients are statistically significant at the 99% confidence level. Among female students, the mandate reduced the chronic absenteeism rate of White students by 2.78 percentage points, Black students by 3.53 percentage points, and Hispanic students by 2.38 percentage points. *Table 3.4, Panel B* presents the difference-in-differences coefficients for all students, disaggregated by gender and racial group.

When comparing California to the eight states resembling California, the 2016 mandate does not exhibit a statistically significant effect in reducing the average chronic absenteeism rate. *Table 3.5, Panel A* presents the results using a comparison group composed only of Washington, Massachusetts, Oregon, Colorado, Illinois, New Jersey, Maryland, and Connecticut, rather than all 49 other states. In contrast, the mandate shows a slight increase in California's chronic absenteeism rate by 0.24 percentage points; however, this coefficient is not statistically significant. It might be that vaccination rates were increasing in these states making small differences hard to detect.

Similarly, *Table 3.5, Panel B* presents the results when the comparison group consists of Wyoming, Mississippi, Alabama, Idaho, Arkansas, Oklahoma, Kentucky, and North Dakota. In this specification, the mandate is associated with a statistically significant reduction in the average chronic absenteeism rate. Specifically, the mandate reduced the average absenteeism rate by 0.53 percentage points, with the largest effects observed among Black students, 2.99 percentage points for males and 3.78 percentage points for females, and White students, 2.13 percentage points for males and 2.46 percentage points for females. In contrast, the mandate is associated with an increase in

average chronic absenteeism among Hispanic students, for both males and females. These additional analyses suggest that in states with socioeconomic and political characteristics similar to California, chronic absenteeism trends may have evolved in parallel with California's, even without the mandate, not creating significant variation following the mandate. Conversely, the mandate appears to have had a stronger effect when compared to states with contrasting profiles. My preferred specification uses all 49 comparison states, mitigating these two different results when adjusting the scope of comparison states.

Testing the parallel-trend assumptions required by the difference-in-differences approach typically necessitates multiple years of observations before and after the event, to adequately capture changes in outcome variables. A key limitation of applying a DiD, in this research context, is the restricted availability of data, which span only four school years, introducing complexities to establish a clear trend around leads and lags. The results of the event study are presented in *Figure 3.2*. The first chart displays results for all students, indicating a general downward trend in the average chronic absenteeism rate, with the most pronounced decline occurring during the 2020 school year. The subsequent charts disaggregate the results by racial group. Similar downward trends in chronic absenteeism are observed among Hispanic, Black, and White students, whereas no significant pattern is evident among Asian students. Additionally, when focusing on the 2017–2018 school year and comparing it to the two pre-mandate years, there is a notable decline in chronic absenteeism among Black and Hispanic students, even though coefficient on school year 2013-2014 is statistically different from zero. To address the limitation of having only four years of data for the event study, a visual representation is

employed to illustrate trends in chronic absenteeism across racial groups. *Figure 3.6* in the Annex provides these visual results. Before mandate, California and the comparison states displayed similar trends in chronic absenteeism. Beginning in the 2017 school year, a decline is observed among White students in California.

3.6 Interpretations, Limitations, and Policy Implications

California's public school system demonstrates both racial diversity and disparity in enrollment and chronic absenteeism patterns. Hispanic students, who constitute the largest enrolled student body, also proportionally representing the largest counts of chronic absent students, a trend that steadily increases over the past decade. Notably, Black students experience the most severe absenteeism rates overall (*Appendix A*). Moreover, empirical test using difference-in-differences model suggests that there is also a decreasing trend in California's chronic absenteeism rate, coinciding the implementation of California's 2016 vaccine mandate, particularly among White students reported by each school. The COVID-19 pandemic exacerbates chronic absenteeism in California and nationwide, and in California and the nation's public school system, the total enrollment is decreasing while the chronic absenteeism is increasing simultaneously.

Several limitations warrant extra consideration when interpreting these descriptive findings. First, the change in CRDC's chronic absenteeism definition beginning in school year 2017-2018 means that all analyses capture conservative lower-bound estimates of the mandate's true effects, with the true effects larger than the observed coefficients. Second, despite introducing measures that have reduced reported data errors, such as omitting schools with abnormal data collection with the reported chronic absenteeism rate above 100%, data quality concerns may still undermine results, introducing

additional measurement errors. On the other hand, the availability of only four years of school-level data limits and undermines the robustness of the DiD and the event study.

Despite these limitations, this study quests into how health-centered policymaking can impact education settings and outcomes. California's example shows how vaccine mandates can contribute to healthier students and lower chronic absenteeism rates, which helps support students' socioemotional and mental development by enabling more consistent participation in both academic and extracurricular activities. The significant spillover effects of the vaccine mandate on education outcomes cannot be overlooked, and these findings highlight further a need for education policymakers to consider root causes of absenteeism and collaborate across sectors to develop coherent policies. It is imperative to consider the complementarity of policymaking across sectors, ensuring that policies are not introducing contradictory directions that counter the effect of one another.

Nationwide and in California, data reveal alarming trends as enrollment declines, and absenteeism rises. Moreover, it is critical to also address disparity issues among racial groups historically been left behind, particularly Black students, who continue to face limited access to educational opportunities. It is also imperative to alter the increasing trend of absenteeism among Hispanic students.

For researchers, there remains an imperative need to investigate the drivers of worsening absenteeism beyond VPDs, and particularly the impact of the COVID-19 pandemic on absent students. While VPD outbreaks contribute to declining enrollment and attendance, they are not the sole factor. Further studies must identify the underlying

causes, whether socioeconomic, institutional, or systemic, and develop targeted solutions to mitigate this growing crisis.

Finally, legal mandates represent a powerful tool for increasing compliance, as demonstrated by California's experiences implementing a major new law, which successfully altered students and parental behavior to achieve its public health and education objectives. Notwithstanding, this policy intervention, coercive in nature, is also high in cost and may carry unintended consequences, including rising homeschooling rates, an important limitation not covered in this study. While enforcement mechanisms may most effectively improve compliance, they risk disproportionately by excluding vulnerable populations from the system of consideration. Alternative strategies rooted in behavioral principles, such as nudge-based incentives to reward vaccination, may offer a complementary advantage. Non-coercive measures might help reduce implementation costs while extending benefits to a wide scope of population.

3.7 Conclusions

In this study, I examine changes in chronic absenteeism as an educational spillover effect of California's 2016 vaccine mandate, which eliminated non-medical exemptions for school-entry vaccinations. Using Civil Rights Data collected by the U.S. Department of Education, I employ a quasi-experimental difference-in-differences methodology to empirically analyze absenteeism trends both within California schools and relative to comparison states without similar mandates. The results reveal two key findings; First the mandate successfully reduced chronic absenteeism among California's school-eligible young children by 1.09 percentage points, with particularly strong effects observed among White students, demonstrating how health policies can positively

influence educational outcomes. Second, persistent racial disparities emerged, with Hispanic students showing increasing absenteeism trends and Black students experiencing both disproportionately highest absenteeism rates and declining enrollment. These mixed results suggest that while vaccine mandates can improve school attendance and reduce absenteeism broadly, additional targeted interventions may still be necessary to address inequities among historically marginalized student populations to achieve better racial equality, on both targeted health and education results and outcomes.

References

Allison, M. A., Attisha, E., Lerner, M., De Pinto, C. D., Beers, N. S., Gibson, E. J., Gorski, P., Kjolhede, C., O'Leary, S. C., Schumacher, H., & Weiss-Harrison, A. (2019). The link between school attendance and good health. *Pediatrics*, *143*(2). https://doi.org/10.1542/peds.2018-3648

Bloom, D. E., Canning, D., & Shenoy, E. S. (2011). The effect of vaccination on children's physical and cognitive development in the Philippines. *Applied Economics*, *44*(21), 2777–2783. https://doi.org/10.1080/00036846.2011.566203

Brenzel L, Wolfson LJ, Fox-Rushby J, et al. Vaccine-preventable Diseases. In: Jamison DT, Breman JG, Measham AR, et al., editors. Disease Control Priorities in Developing Countries. 2nd edition. Washington (DC): https://www.ncbi.nlm.nih.gov/books/NBK11768/

Chang, H., Gee, K., Hennessy, B., Alexandro, D., & Gopalakrishnan, A. (2021). *Chronic absence patterns and prediction during covid-19:* Chronic Absence Patterns and Prediction During Covid-19: Insights from Connecticut. https://www.attendanceworks.org/wp-content/uploads/2019/06/Chronic-Absence-in-CT_011222.pdf

Dee, T. S. (2023). *Higher Chronic Absenteeism Threatens Academic Recovery from the COVID-19 Pandemic*. https://doi.org/10.31219/osf.io/bfg3p

Evans, W. N., Muchnick, K., & Rosenlund, O. (2024). Virtual learning in kindergarten through grade 12 during the COVID-19 pandemic and chronic absenteeism. *JAMA Network Open*, *7*(8). https://doi.org/10.1001/jamanetworkopen.2024.29569

Gee, K. A. (2018). Minding the Gaps in Absenteeism: Disparities in Absenteeism by Race/Ethnicity, Poverty and Disability. *Journal of Education for Students Placed at Risk.* 23(1-2): 204-208. https://doi.org/10.1080/10824669.2018.1428610

Green, H. K., Brousseau, N., Andrews, N., Selby, L., & Pebody, R. (2016). Illness absenteeism rates in primary and secondary schools in 2013–2014 in England: Was there any impact of vaccinating children of primary-school age against influenza? *Epidemiology and Infection*, *144*(16), 3412–3421. https://doi.org/10.1017/s0950268816001680

Holroyd, T. A., Howa, A. C., Delamater, P. L., Klein, N. P., Buttenheim, A. M., Limaye, R. J., Proveaux, T. M., Omer, S. B., & Salmon, D. A. (2020). Parental vaccine attitudes, beliefs, and practices: Initial evidence in California after a vaccine policy change. Human Vaccines & Immunotherapeutics, 17(6), 1675–1680. https://doi.org/10.1080/21645515.2020.1839293

Humm Patnode, A., Gibbons, K., & Edmunds, R. R. (2018). *Attendance and Chronic Absenteeism: Literature Review.* Saint Paul, MN: University of Minnesota, College of Education and Human Development, Center for Applied Research and Educational Improvement.

Kawai, S., Nanri, S., Ban, E., Inokuchi, M., Tanaka, T., Tokumura, M., Kimura, K., & Sugaya, N. (2011). Influenza vaccination of schoolchildren and influenza outbreaks in a school. *Clinical Infectious Diseases*, *53*(2), 130–136. https://doi.org/10.1093/cid/cir336

Jones, M., & Buttenheim, A. (2014). Potential effects of California's new Vaccine Exemption Law on the prevalence and clustering of exemptions. American Journal of Public Health, 104(9). https://doi.org/10.2105/ajph.2014.302065

L. Iachini, A., & Anderson-Butcher, D. (2012). The contribution of extracurricular activities to school priorities and student success. *Mental Health Promotion in Schools: Foundations*, 127–148. https://doi.org/10.2174/978160805466411201010127

Lee, D. N. (2012). The impact of childhood health on adult educational attainment: Evidence from mandatory school vaccination laws. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.1987898

Lissack, K. (2021). School attendance difficulties: An exploration of perceived barriers to attendance and the support offered for non-attendance from the perspectives of parents and school staff (Order No. 31626625). Available from Publicly Available Content Database. (3122677636).

Liu, J., & Lee, M. (2022). Beyond chronic absenteeism: The dynamics and disparities of class absences in Secondary School. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.4268772

Nandi, A., & Shet, A. (2020). Why vaccines matter: Understanding the broader health, economic, and Child Development Benefits of routine vaccination. *Human Vaccines & Immunotherapeutics*, *16*(8), 1900–1904. https://doi.org/10.1080/21645515.2019.1708669

Plaspohl, S. S., Dixon, B. T., Streater, J. A., Hausauer, E. T., Newman, C. P., & Vogel, R. L. (2013). Impact of school flu vaccine program on student absences. *The Journal of School Nursing*, *30*(1), 75–80. https://doi.org/10.1177/1059840513487750

Ricci, J. M., Clevenger, K. A., Sellers, S., Davenport, S., & Pfeiffer, K. A. (2020). Associations between extracurricular activity participation and health-related variables in underrepresented children. *Sports Medicine and Health Science*, *2*(2), 102–108. https://doi.org/10.1016/j.smhs.2020.06.001

Richwine, C., Dor, A., & Moghtaderi, A. (2019). Do Stricter Immunization Laws Improve Coverage? Evidence from the Repeal of Non-Medical Exemptions for School Mandated Vaccines. https://doi.org/10.3386/w25847

Stevens, P. (2017). *Fighting the diseases of poverty*. Taylor and Francis.

Tate, J., Aguado, T., Belie, J. D., Holt, D., Karafillakis, E., Larson, H. J., Nye, S., Salisbury, D., Votta, M., & Wait, S. (2019). The life-course approach to vaccination: Harnessing the benefits of vaccination throughout life. *Vaccine*, *37*(44), 6581–6583. https://doi.org/10.1016/j.vaccine.2019.09.016

Williams, N. J., Ghosh, T. S., Bisgard, K. M., & Vogt, R. L. (2013). Comparison of 3 school-based influenza surveillance indicators. *Journal of Public Health Management and Practice*, *19*(2), 119–125. https://doi.org/10.1097/phh.0b013e318252f005

Table 3.1. Average Chronic Absenteeism Rates in California and All Other States: School Year 2015-2016

Table 1. compares average chronic absenteeism rates between California and other U.S. states in school year 2015–2016, the year before the mandate implementation. Overall absenteeism rate was slightly lower in California compared to average of other 49 states, especially among Hispanic and Asian students. However, it was higher among Black and White students.

	California	All other states	*Difference: California – All other states*
Variables			
Chronic Absenteeism Rate			
Chronic absence rate (%)	10.30	11.18	-0.88
Chronic absence rate - female (%)	10.08	11.02	-0.94
Chronic absence rate - male (%)	10.49	11.35	-0.86
Chronic absence rate -Hispanic (%)	10.37	13.65	-3.28
Chronic absence rate - Asian (%)	8.47	10.33	-1.86
Chronic absence rate - Black (%)	18.79	14.48	4.31
Chronic absence rate - White (%)	13.97	11.47	2.50

Table 3.2. Pre and Post Average Chronic Absenteeism Rates: California and Other States

Pre period contains school years 2013-2014 and 2015-2016. Post period contains school years 2017-2018 and 2020-2021. White students experienced the highest decline on chronic absenteeism post-mandate.

	California			Other States			Diff-Diff
	Pre	Post	Post-Pre	Pre	Post	Post-Pre	
Total	10.81	13.34	2.53	12.25	16.56	4.31	-1.78
Female	10.62	12.94	2.32	12.01	16.22	4.21	-1.89
Male	10.98	13.74	2.76	12.40	16.86	4.46	-1.7
Female							
Hispanic	11.21	14.61	3.4	14.99	19.22	4.23	-0.83
Asian	9.17	7.04	-2.13	11.34	9.00	-2.34	0.21
Black	19.84	23.01	3.17	15.19	21.43	6.24	-3.07
White	14.55	13.92	-0.63	12.47	14.87	2.4	-3.03
Male							
Hispanic	10.80	13.76	2.96	15.09	19.69	4.6	-1.64
Asian	8.38	6.41	-1.97	11.81	9.65	-2.16	0.19
Black	19.10	21.24	2.14	16.27	22.49	6.22	-4.08
White	14.18	13.23	-0.95	12.69	15.50	2.81	-3.76

Pre period contains school years 2013-2014 and 2015-2016. Post period contains 2017-2018.

	California			Other States			Diff-Diff
	Pre	Post	Post-Pre	Pre	Post	Post-Pre	
Total	10.81	11.10	0.29	12.25	13.37	1.12	-0.83
Female	10.62	10.93	0.31	12.10	13.14	1.04	-0.73
Male	10.98	11.29	0.31	12.40	13.60	1.2	-0.89
Female							
Hispanic	10.80	11.38	0.58	14.99	15.35	0.36	0.22
Asian	8.38	6.56	-1.82	11.34	8.61	-2.73	0.91
Black	19.10	18.14	-0.96	15.19	16.37	1.18	-2.14
White	14.18	12.49	-1.69	12.47	13.05	0.58	-2.27
Male							
Hispanic	11.21	11.60	0.39	15.09	15.49	0.4	-0.01
Asian	9.17	6.88	-2.29	11.81	8.89	-2.92	0.63
Black	19.84	19.83	-0.01	16.28	17.32	1.04	-1.05
White	14.55	12.88	-1.67	12.68	13.52	0.84	-2.51

Table 3.3 Interrupted Time Series Parameters – California Schools Only

Interrupted time series outputs of the effect of California's 2016 vaccine mandate on chronic absenteeism. Model includes observations of four school years. Table presents total, male, and female, and each racial group of California. Standard errors are clustered at the state level. *, **, *** indicates statistical significance at the 10%, 5%, and 1% level. Results on "Post" show that chronic absenteeism rate declined after implementation of California's 2016 mandate. The impact is most pronounced on Black and Hispanic students.

Interrupted Time Series – California Schools Only

	Total	Male	Female	Hispanic	Asian	Black	White
Time	1.03***	0.98***	1.07***	1.23***	0.70**	0.82*	0.64**
Post	-11.64***	-12.82***	-10.14***	-14.47***	-0.27	-18.66***	-5.75***
Time_Post	3.46***	3.89***	2.95***	4.40***	-0.70	6.12***	1.21***
Cons	9.27	9.51	9.01	9.14	7.77	17.98	13.34
N	18,007	18,887	18,879	18,817	17,564	17,278	18,706
R-squared	0.06	0.06	0.05	0.07	0.001	0.02	0.002

Table 3.4 Difference-in-Differences Results: California and 49 Other States

Panel A: Post-Mandate Observations Includes School Year 2017-2018 (Main Specification)

Difference-in-differences results of the effect of California's 2016 vaccine mandate on chronic absenteeism rates. Model includes schools of three school years, including only one year post mandate: school year 2017-2018. First table presents total, male, and female, second and third tables present each racial group under male and female, all using school-level data. Models control school and the year fixed effect, with standard errors clustered at the state level, with standard errors clustered at the state level. *, **, *** indicates statistical significance at the 10%, 5%, and 1% level.

School years 2013-2014, 2015-2016, 2017-2018[55]

	All	Male	Female
Mandate	-1.09***	-1.18***	-0.99***
(Std. Err.)	0.14	0.14	0.14
Observations	80,819	80,815	80,782
R-squared	0.54	0.53	0.52

Male

	Hispanic	Asian	Black	White
Mandate	-0.87***	0.35	-0.36	-1.98***
(Std. Err.)	0.30	0.43	0.45	0.23
Observations	76,953	58,232	68,495	79,693
R-squared	0.34	0.34	0.35	0.44

Female

	Hispanic	Asian	Black	White
Mandate	-0.69**	0.74*	-1.65***	-1.90***
(Std. Err.)	0.30	0.42	0.45	0.23
Observations	76,369	58,464	66,883	79,459
R-squared	0.38	0.35	0.36	0.44

[55] A total of 26,945 schools are included in each school year, yielding 80,835 school-year observations across three years. This number may vary slightly depending on the specific racial cohort analyzed.

Panel B: Post-Mandate Observations Include School Year 2017-2018 and 2020-2021

Difference-in-differences results of the effect of California's 2016 vaccine mandate on chronic absenteeism rates. Model includes schools from four school years, including two years post mandate: school year 2017-2018 and 2020-2021. First table presents total, male, and female, second and third tables present each racial group under male and female, all using school-level data. Models control school and year fixed effect, with standard errors clustered at the state level. *, **, *** indicates statistical significance at the 10%, 5%, and 1% level.

School Years 2013-2014, 2015-2016, 2017-2018, and 2020-2021[56]

	All	Male	Female
Mandate	-2.07***	-2.05***	-2.08***
(Std. Err.)	0.13	0.14	0.14
Observations	107,652	107,636	107,613
R-squared	0.50	0.50	0.49

Male

	Hispanic	Asian	Black	White
Mandate	-2.29***	-0.37	-2.37***	-2.71***
(Std. Err.)	0.25	0.33	0.37	0.19
Observations	102,747	77,876	91,274	106,160
R-squared	0.34	0.28	0.32	0.41

Female

	Hispanic	Asian	Black	White
Mandate	-2.38***	0.02	-3.53***	-2.78***
(Std. Err.)	0.25	0.33	0.37	0.19
Observations	102,385	77,765	89,350	105,893
R-squared	0.34	0.29	0.33	0.40

[56] A total of 26,945 schools are included in each school year, yielding 107,780 school-year observations across four years. This number may vary slightly depending on the specific racial cohort analyzed.

Table 3.5 Difference-in-Differences Results: California and 8 Comparison States

Panel A: Comparison State: Washington, Massachusetts, Oregon, Colorado, Illinois, New Jersey, Maryland, Connecticut

Difference-in-differences outputs of the effect of California's 2016 vaccine mandate on chronic absenteeism rates. Model includes observations of three school years, including only one year post mandate: school year 2017-2018. First table presents total, male, and female, second and third tables present each racial group under male and female, all using school-level data. Models control for school and school year fixed effect, with standard errors clustered at the state level. *, **, *** indicates statistical significance at the 10%, 5%, and 1% level.

School years 2013-2014, 2015-2016, 2017-2018

	All	Male	Female
Mandate	0.24	0.14	0.32
(Std. Err.)	0.19	0.20	0.20
Observations	28,252	28,247	28,227
R-squared	0.54	0.54	0.53

Male

	Hispanic	Asian	Black	White
Mandate	-0.14	1.44***	2.32***	-0.23
(Std. Err.)	0.30	0.50	0.67	0.36
Observations	27,760	23,584	21,263	21,106
R-squared	0.44	0.37	0.37	0.44

Female

	Hispanic	Asian	Black	White
Mandate	0.48	1.50***	1.51**	0.07
(Std. Err.)	0.28	0.50	0.68	0.38
Observations	27,671	23,555	20,781	20,596
R-squared	0.44	0.38	0.38	0.44

Panel B: Comparison State: Wyoming, Mississippi, Alabama, Idaho, Arkansas, Oklahoma, Kentucky, North Dakota

Difference-in-differences outputs of the effect of California's 2016 vaccine mandate on chronic absenteeism rates. Model includes observations of three school years, including only one year post mandate: school year 2017-2018. First table presents total, male, and female, second and third tables present each racial group under male and female, all using school-level data. Models control for school and school year fixed effects, with standard errors clustered at the state level. *, **, *** indicates statistical significance at the 10%, 5%, and 1% level.

School years 2013-2014, 2015-2016, 2017-2018

	All	Male	Female
Mandate	-0.53***	-0.69***	-0.38*
(Std. Err.)	0.19	0.20	0.20
Observations	20,186	20,184	20,171
R-squared	0.57	0.56	0.55

Male

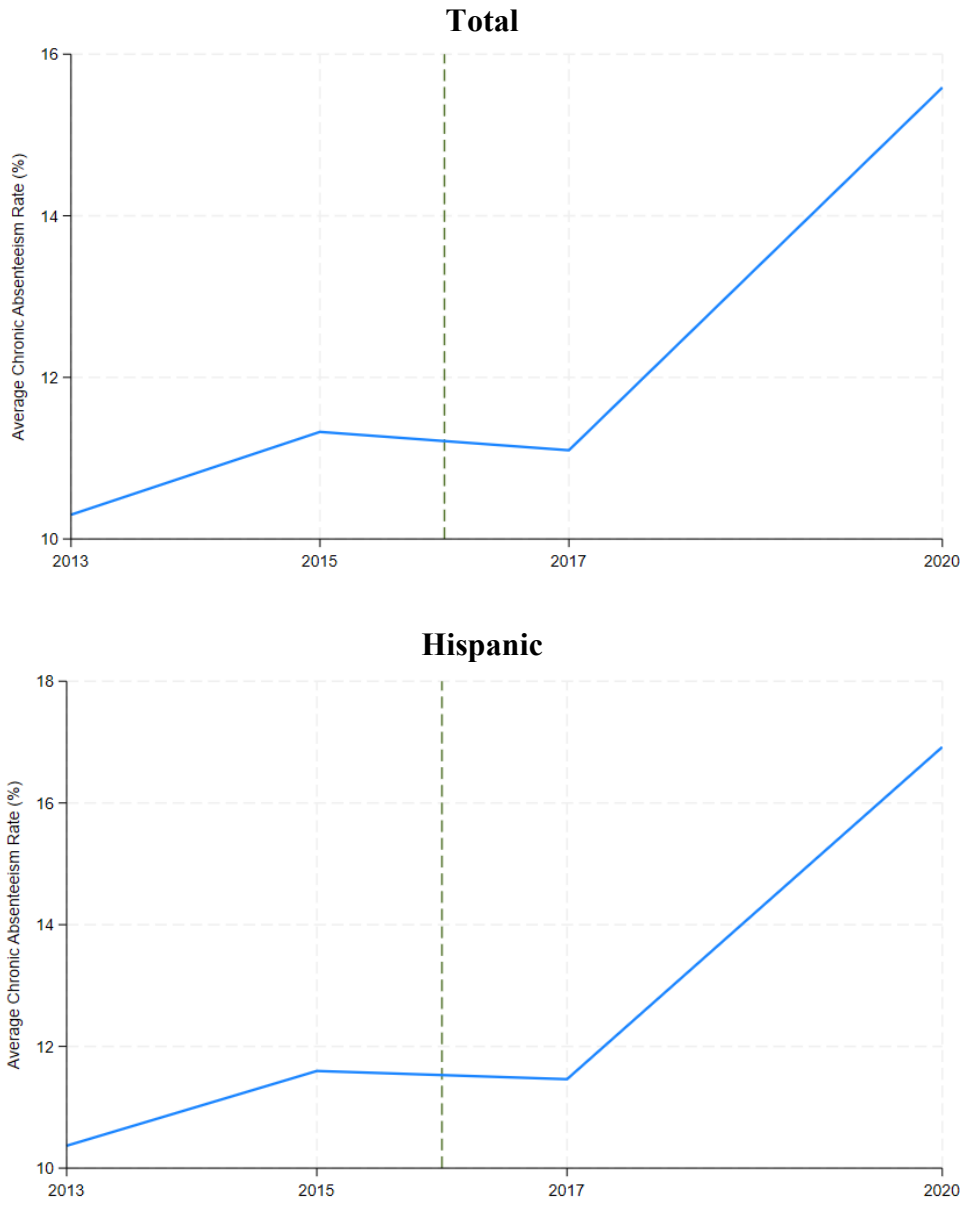
	Hispanic	Asian	Black	White
Mandate	1.65***	0.18	-2.99***	-2.13***
(Std. Err.)	0.39	0.76	1.07	0.60
Observations	19,478	15,498	13,836	13,714
R-squared	0.38	0.36	0.38	0.43

Female

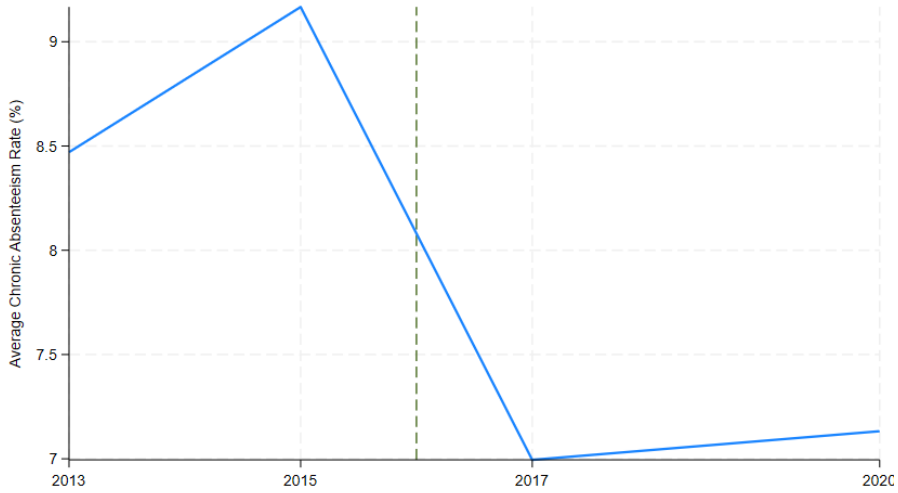
	Hispanic	Asian	Black	White
Mandate	2.58***	0.20	-3.78***	-2.46***
(Std. Err.)	0.39	0.77	1.06	0.61
Observations	19,365	15,467	13,569	13,429
R-squared	0.40	0.34	0.39	0.44

Figure 3.1 Average Chronic Absenteeism Rate in California: 2013-2020

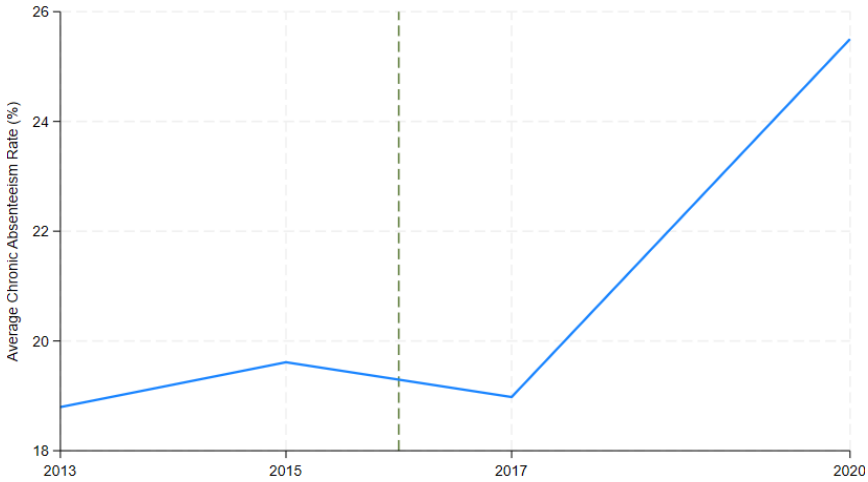
Figure 3.1. shows average chronic absenteeism rates in California covering four school years: school year 2013-2014, 2015-2016, 2017-2018, and 2020-2021. Green dashed vertical line indicates the implementation of California vaccine mandate. Chronic absenteeism rate (total) declines following the mandate and increased considerably during the COVID-19 pandemic.



Asian



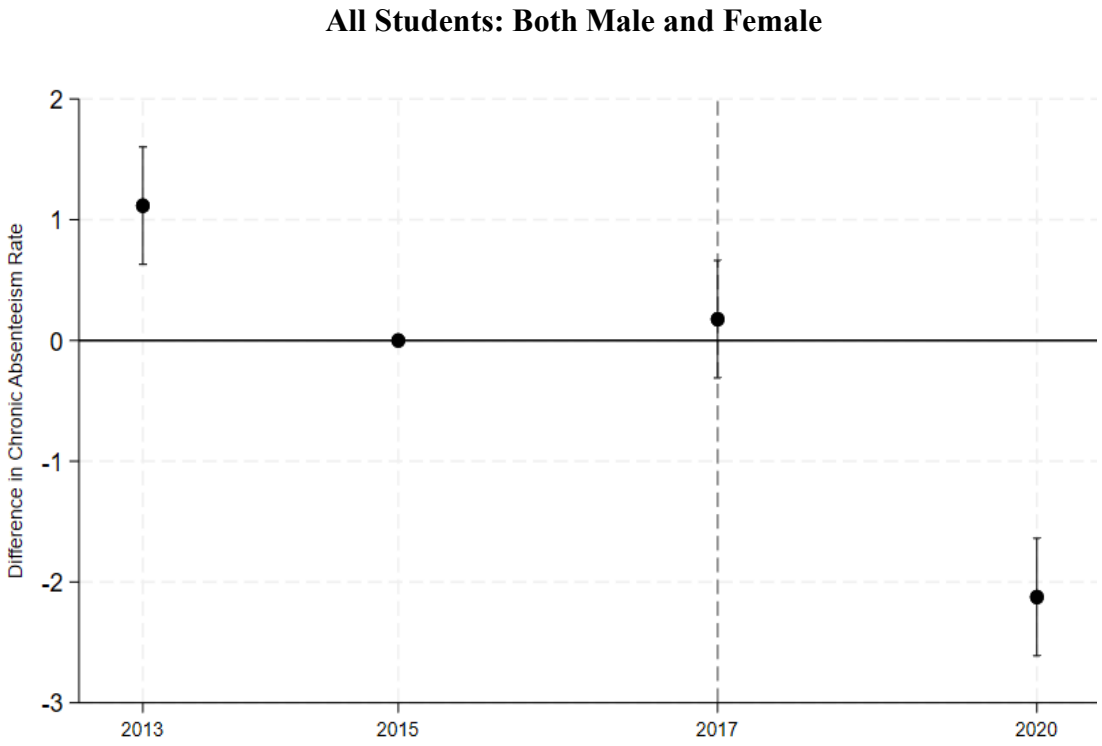
Black



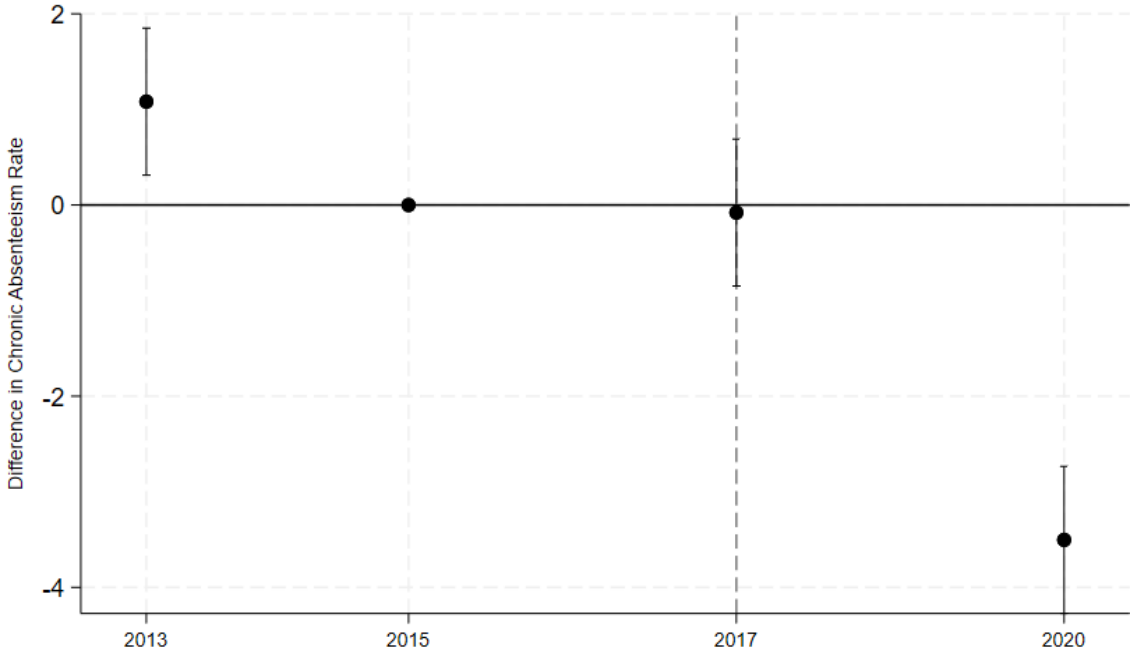
White

Figure 3.2 Event Study Results: Effect of California's 2016 Vaccine Mandate on Chronic Absenteeism Rates

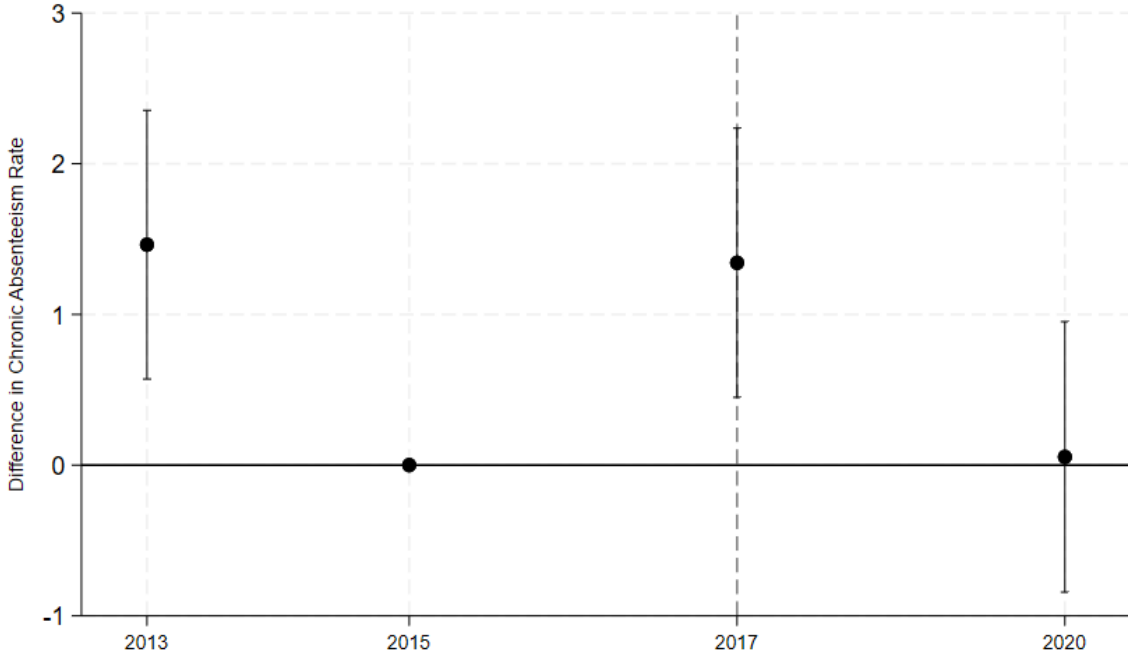
Figure 3.2 presents the event study results covering total students and each racial cohort reported at school level. School year 2015-2016 (presented by -1 year) average absenteeism rate is set as zero. School year 2017-2018 is set as year zero, indicating the enactment of California's 2016 vaccine mandate. School year 2013-2014 is presented as -2 years relative to Mandate. School year 2020-2021 is presented as 1 year relative to Mandate. Grey dashed vertical line indicates the implementation of California vaccine mandate.



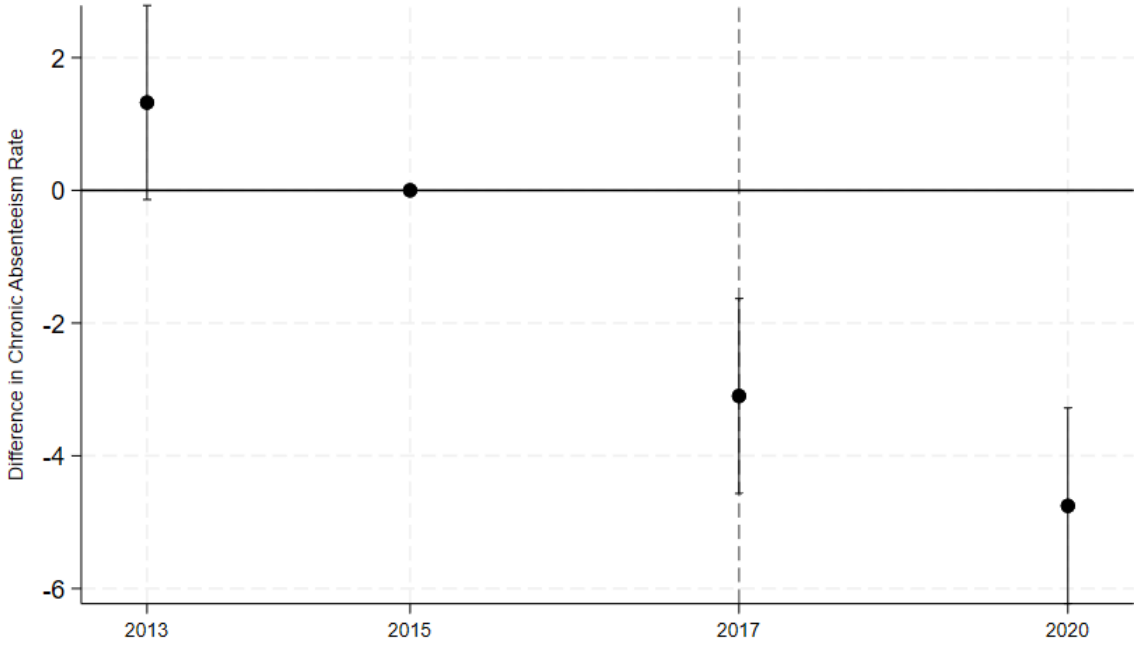
Racial Groups
Hispanic



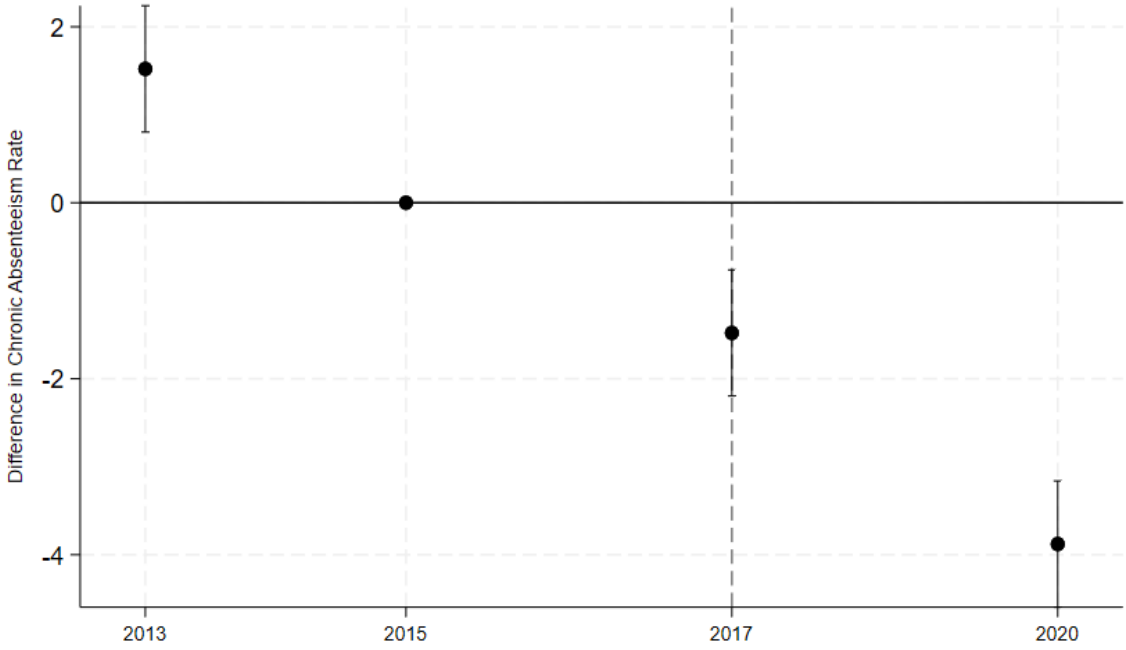
Asian



Black


Difference in Chronic Absenteeism Rate
2
0
-2
-4
-6
2013
2015
2017
2020

White


Difference in Chronic Absenteeism Rate
2
0
-2
-4
2013
2015
2017
2020

Appendix A: Descriptive Analysis Results

During school year 2015-2015, one year before the mandate, California's public-school enrollment exhibits distinct demographic patterns compared to national averages: Hispanic and Asian student representation exceeds national average proportions, while White and Black students' share of total enrollment falls below national averages. California's overall chronic absenteeism rate is lower than the national average. However, this pattern did not hold uniformly across racial groups, and both White and Black students in California experience an absenteeism rate higher than national average. (*Table 3.6*)

The California public school system demonstrates racial and ethical diversity, with Hispanic students representing the predominant demographic and racial group. In each school year, roughly 1-1.5 million students from kindergartens, primary schools, daycares, elementary schools, and preschools, are Hispanic, which constitutes more than 50% of the total enrolled students in California's public-school system for younger age students. White students form the second largest enrolled student population, roughly 25% of the total enrollment. Asian students form the third largest enrolled group, followed by Black students, which has the smallest number of enrolled students compared to other races. (*Table 3.7* and *Figure 3.3*)

Student demographic data also indicate notable enrollment shifts from school year 2013-2014 up to school year 2020-2021. In California, the share of Hispanic and Asian enrolled students, relative to the total enrolled students, has steadily increased from school year 2013-2014 to 2020-2021. On the other hand, share of White students, has decreased considerably. Overall, the total number of enrolled students in California

statewide, has also declined in the past decade. The most pronounced enrollment drop occurred during the 2020-2021 school year, likely attributable to the COVID-19 pandemic disruptions, including widespread school closures and shifts to remote learning modalities across California and the nation. (*Figure 3.3*)

In California, the total number of students who are chronically absent from schools experiences a mild drop in the school year 2017-2018. Starting school year 2015-2016 to school year 2020-2021, comparing to previous school years, there has been a slight increase in the total count of chronic absent children. Hispanic students account for the largest share of student body reported chronically absent, proportional to its enrollment share, followed by White, Black, and Asian students. The share of the Hispanic students among total students chronically missing schools is also increasing. On the other hand, the share of White students among all students in California who miss schools chronically is declining. (*Figure 3.4*)

California's proportion of both enrolled students and chronic absent students relative to the nation's total has demonstrated a slight decline in the past decade. Notably, the state's enrollment share always exceeds its share of chronically absent students, suggesting California may be performing better than the national average in addressing chronic absenteeism. The total number of enrollments in U.S. is also decreasing from 2013-2014 to 2020-2021. On the other hand, the total number of chronically absent students from schools is increasing, with the highest number of absenteeism taking place in school year 2020-2021, possibly due to the impact of the COVID-19 pandemic, including nationwide school closures and transitions to remote learning. (*Figure 3.5*)

Descriptive analyses also reveal racial disparities in chronic absenteeism rates in California and nationwide. In California, Black students demonstrate the highest average chronic absenteeism rate, with more than 20%, equivalent to 1 in every 5 students of the enrolled students being chronically absent. White students demonstrate the second highest average chronic absenteeism rate in the initial school years, until they are surpassed by Hispanic students in school year 2020-2021. Hispanic students display an overall fast increasing trend on chronic absenteeism rate. Asian students, on average, experience the lowest average chronic absenteeism, below 10% of its enrolled population. Nationwide, Black and Hispanic students carry the highest rates of chronic absenteeism, followed by White and Asian. This suggests that Californian White students may have experienced a higher chronic absenteeism rate in the early school years compared to their counterparts from other states. There is also an increasing trend of average chronic absenteeism nationwide across all races, particularly from school year 2017-2018 to school year 2020-2021. (*Figure 3.6*)

Table 3.6 Total Number Enrolled Students and Percentage Share by Gender and Race: California and 49 Comparison States in School Year 2015-2016

	California	All other states		
Variables				
Enrollment			*% of total: CA*	*% of total: other states*
Total enrolled students	1,492,699	6,751,079	100.0%	100.0%
Total enrolled students - female	723,269	3,262,247	48.5%	48.3%
Total enrolled students - male	769,430	3,488,832	51.5%	51.7%
Total enrolled students - Hispanic	877,386	1,290,932	58.8%	19.1%
Total enrolled students - Asian	166,507	259,930	11.2%	3.9%
Total enrolled students - Black	80,032	1,096,541	5.4%	16.2%
Total enrolled students - White	368,744	4,103,676	24.7%	60.8%

Table 3.7 Total Number of Enrolled Students and Distribution by Race in California

Table 3.7. present the racial composition of student enrollment in California public schools from 2013 to 2021.[57] Hispanic students represent the majority group, with a steady increase in their enrollment share. The proportion of White students declined, while Asian students displayed a modest increase. Black student enrollment remained relatively stable but showed a slight decrease in percentage.

School Year	Total Enrollment (million)	Hispanic (million, %)	White (million, %)	Asian (million, %)	Black (million, %)
2013–2014	2.5	1.5 (58.0%)	0.6 (24.8%)	0.3 (11.4%)	0.1 (5.8%)
2015–2016	2.5	1.5 (58.7%)	0.6 (24.1%)	0.3 (11.6%)	0.1 (5.6%)
2017–2018	2.4	1.4 (58.3%)	0.6 (24.5%)	0.3 (11.9%)	0.1 (5.2%)
2020–2021	2.2	1.3 (60.3%)	0.5 (21.8%)	0.3 (12.8%)	0.1 (5.1%)

[57] Only include students from kindergarten, primary school, elementary school, preschool, and daycare students.

Figure 3.3 Total Number of Enrolled Students and Percent Share by Race in California

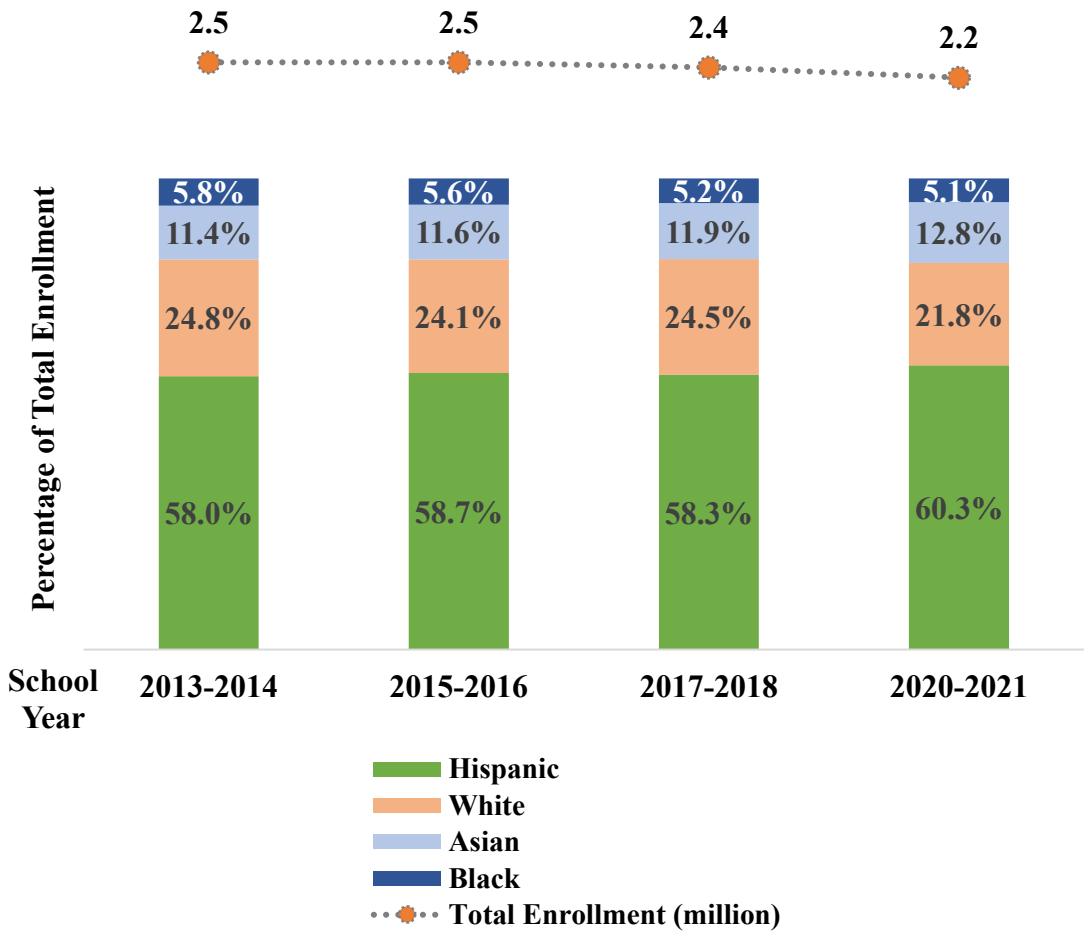
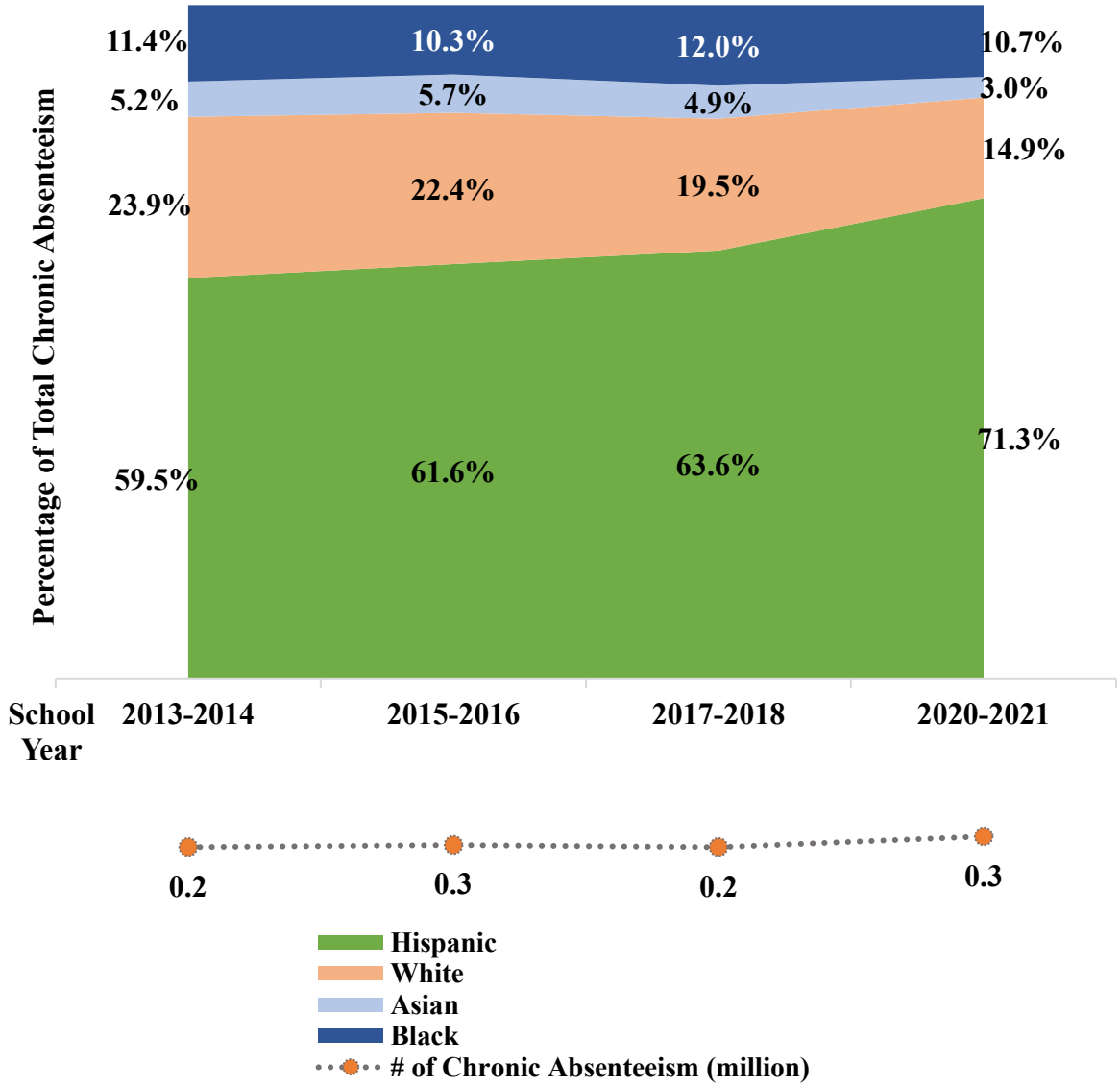


Figure 3.4 Total Number of Students Chronically Absent from Schools in California

Figure 4. displays racial distribution of students chronically absent from California public schools between school year 2013 and 2021.[58] Hispanic students represent the largest share of chronic absences, with their proportion rising to over 70% by 2020–2021. White and Asian student shares declined. The share of Black students showed fluctuations but remained stable.



[58] Only include students from kindergarten, primary school, elementary school, preschool, and daycare students.

Figure 3.5 California Share of Nation's Total Enrollment and Absenteeism

Figure 3.5. presents California's proportion of national student enrollment and chronic absenteeism from school year 2013 to 2020. While California accounts for approximately 20% of national enrollment, its share of chronic absences remains consistently lower, between 15–18%. This suggests that California has a slightly lower relative chronic absenteeism rate compared to the national average.

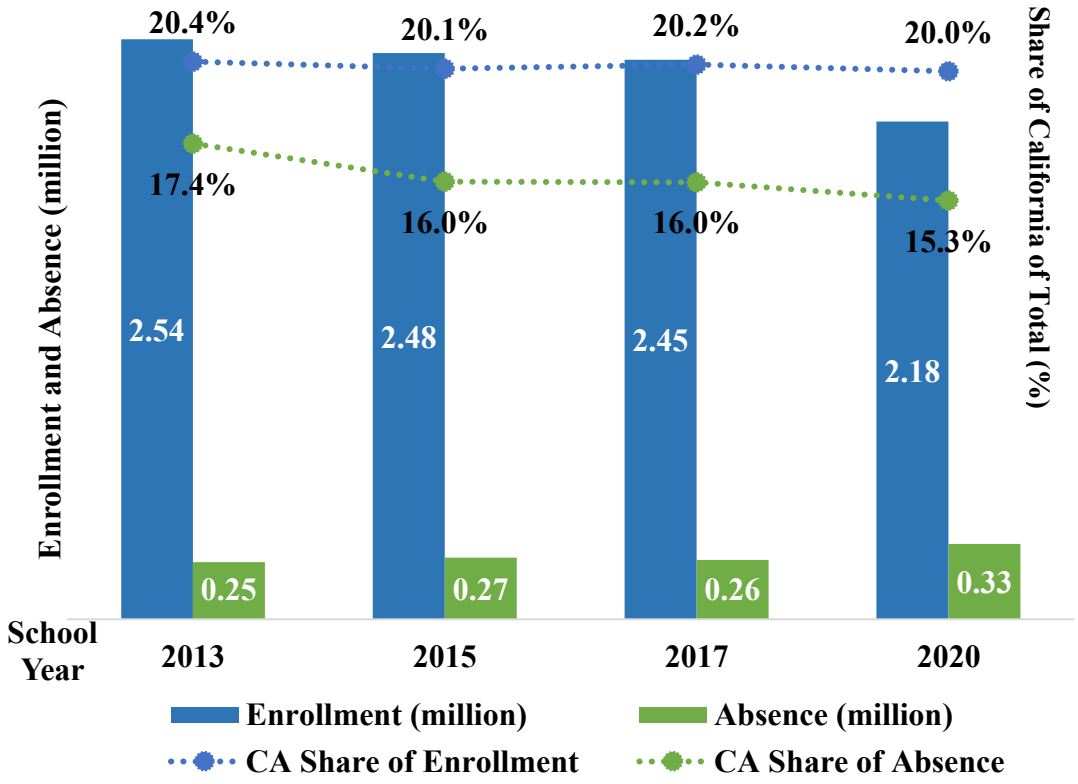
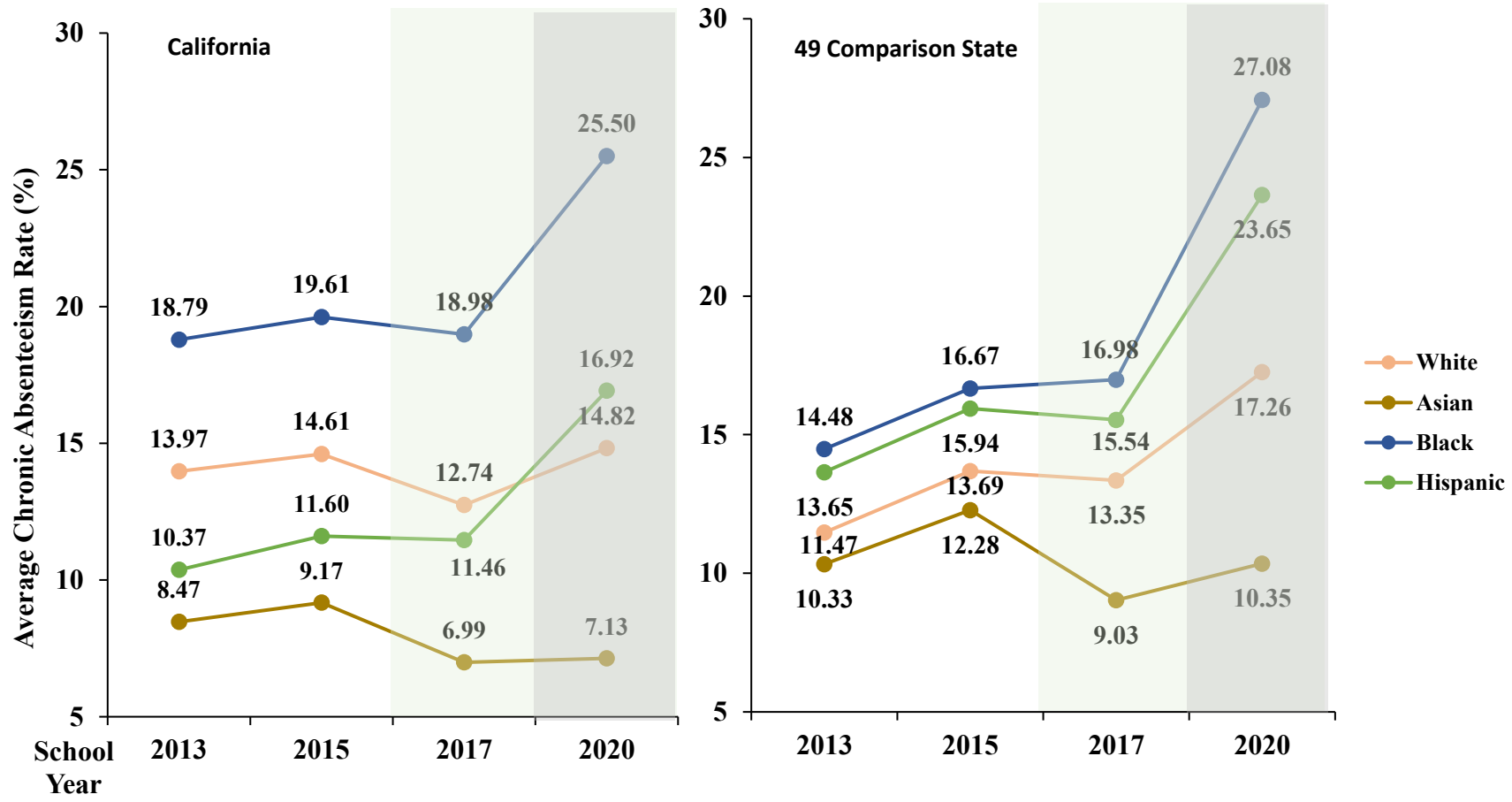


Figure 3.6 Average Chronic Absenteeism Rates in California and 49 Other States

Figure 3.6. presents average chronic absenteeism rates by race in California and other U.S. states from 2013 to 2020. The chart shows higher absenteeism among Black and White students in California, with a marked increase in 2020 following the onset of the COVID-19 pandemic. Shaded areas indicate the California vaccine mandate (2016) and the COVID-19 pandemic (2020).



Appendix B: Data and Methodological Notes

The raw nation-wide CRDC dataset spans four school years: 2013-2014, 2015-2016, 2017-2018, and 2020-2021. It comprises 387,074 school-year observations: 95,507 schools in school year 2013-2014, 96,360 in 2015-2016, 97,632 in 2017-2018, and 97,575 in 2020-2021. Of total number of school-year observations from four years, 314,905 school-year observations, including 79,402 schools in 2013-2014, 79,364 in 2015-2016, 78,203 in 2017-2018, and 77,936 in 2020-2021, provide adequate chronic absenteeism data that do not exceed the total reported enrollment. This data quality filter retained 81% of total school-year observations from the raw data, which are used to build a balanced panel for this analysis. Geographically, California represents the largest share of observations, 31,043 observations from four school years, which accounts for 10% of the total observations, followed by Texas (29,268 observations, 9% of total), Illinois (14,21 observations, 5% total), and Florida (13,220 observations, 4% total).

Given that California's 2016 vaccine mandate impacts young age cohorts the most, I filtered 31,043 school-year observations further by retaining only kindergartens, primary and secondary schools, elementary schools, daycares, and preschools from all U.S. states, covering four school years: 2013-2014, 2015-2015, 2017-2018, and 2020-2021. This filtering process results in the final dataset used for this study, which includes 107,780 school-year observations,[59] from 50 states. More specifically, this analysis uses a consistent sample of 26,945 schools per year across all 50 states as the final dataset. These school-year observations serve as the unit of analysis for this study.

[59] This number includes observations from the four school years. The same school can be counted to four times.