Vaccines, Verdicts, and Vitriol: The Effect of Smallpox Court Decisions on Anti-Vaccine Discourse and Mortality*

Paul Brehm†
Oberlin College

Martin Saavedra‡
Rutgers University

August 25, 2023

Abstract

We estimate the effect of compulsory vaccination court decisions on anti-vaccine discourse and mortality. We measure anti-vaccine discourse using language in American newspapers. Using human-classified training data and machine learning techniques, we predict anti-vaccine discourse for nearly 48,000 newspaper pages. Staggered difference-in-differences estimates show that anti-vaccine discourse increased for a period of two years after pro-vaccine state-level Supreme Court decisions before returning to baseline. Regression-discontinuity-in-time estimates yield similar findings following the *Jacobson v. Massachusetts* US Supreme Court decision. While compulsory vaccinations increase anti-vaccine discourse, mandates remain effective: we estimate that compulsory vaccination reduces smallpox mortality rates by 40 percent.

JEL codes: K32, N3, N4, I18
Keywords: smallpox, vaccine, compulsory vaccination, anti-vaccine sentiment, public discourse, text analysis, sentiment analysis, vaccination law, public health law.

---

*We are grateful for feedback from Brian Beach, Maggie Brehm, Karen Clay, Amanda Griffith, Evan Kresch, John Landon-Lane, Carolyn Moehling, Michael McKelligott, Claire Saavedra, Koleman Strumpf, Eugene White, conference seminar/participants at the University of Connecticut, Virginia Tech, Rutgers, Wake Forest, the SEA annual meetings, the MEA annual meetings, and anonymous referees. Ava Buchanan, Ethan Butler, Chris Dettmer, Hannah Keidan, Carter Lapointe, Hailey Nguyen, Nam Nguyen, Sharanya Rajani, Theo Sharp, and Gillian Sutliff provided excellent research assistance. All errors are our own.

†E-mail: paul.brehm@oberlin.edu.

‡Corresponding author: Department of Economics, Rutgers University, 75 Hamilton St, New Brunswick, NJ 08901. E-mail: martin.saavedra@rutgers.edu.

1 Introduction

When faced with a market failure, potential corrective policies include incentives, nudges, and mandates. One might adjust incentives so that agents internalize their externalities—an approach popular among economists across a range of failures, such as climate change (Baumol, 1972; Nordhaus, 1977). Alternatively, one might employ "libertarian paternalism" (Thaler and Sunstein, 2003), where people are nudged to make socially efficient choices. This paper joins research like Summers (1989), Antwi et al. (2013), and Fullerton and Heutel (2010) in analyzing an important instance of the third option: using the coercive power of the state to try to increase social welfare.

Personal health decisions often result in market failures, including externalities. Consider, for instance, the spread of communicable diseases, which only occur when infected individuals interact with those uninfected. Infection frequently arises when an infected individual benefits from going out into society but simultaneously imposes a negative externality on susceptible individuals. Similarly, other public health issues, such as secondhand smoke and water pollution, are characterized by significant negative externalities.

Governments often intervene in response to these market failures to address the associated externalities. However, the success of their interventions can hinge on the compliance of the governed populace. For instance, during the Covid-19 pandemic, numerous health regulations aimed to promote social distancing. Khataee et al. (2021) demonstrated that locations with greater reductions in mobility saw slower virus spread. However, public compliance with Covid regulations was inconsistent, varying across demographic groups, including those defined by political beliefs (Painter and Qiu, 2020).

In this paper, we test whether the judicial enforcement of vaccine mandates causes backlash in the form of anti-vaccine discourse in the media and whether this backlash causes the mandate to be ineffective. We use one of the most important and controversial mandates in healthcare history—compulsory vaccination against smallpox.

Smallpox was one of the deadliest diseases in human history, with a typical outbreak killing 30% of those infected (CDC, 2021). At the end of the eighteenth century, Edward Jenner invented the first vaccine—a critical step on the long road to eradicating the virus.[1] Although the vaccine became widely available in the United States during the 1800s, smallpox was still endemic in the early 1900s. Vaccine take-up was incomplete, there was an active anti-vaccine movement, and anti-vaccine propaganda frequently appeared in newspapers.

In response to low vaccination rates, local and state authorities passed laws to compel or incentivize people to get vaccinated. These included compulsory vaccination laws (often for school children) or mandatory quarantines of the unvaccinated during outbreaks. Anti-vaccinationists often challenged these laws, seeking judicial relief from what they viewed as infringements on their liberty. Today, opposition to vaccines for diseases like Covid-19 and measles echoes the resistance to smallpox vaccination that occurred over a century ago.

To measure anti-vaccine discourse, we turn to newspaper articles in the *Chronicling America* newspaper archive. The archive, published by the Library of Congress, contains 20 million newspaper pages, nearly 48,000 of which contain the words *smallpox* and *vaccine*, or derivations thereof. Our research team read a 5% sample of those newspaper pages and recorded whether each page contained anti-vaccine discourse. Simultaneously, we use this training data in a machine learning model to predict whether the remaining 95% of the articles contain anti-vaccine sentiment.

First, we estimate the effect of pro-vaccine state-level Supreme Court decisions on vaccine discourse using a staggered difference-in-differences approach. We use empirical approaches from Callaway and Sant'Anna (2021) and Sun and Abraham (2021), as well as two-way fixed-effects estimators. We also estimate how anti-vaccine discourse responded to the 1905 US Supreme Court decision in *Jacobson v. Massachusetts*, which upheld compulsory vaccination. Here, we perform a regression discontinuity in time comparing newspaper articles in the days and weeks surrounding the decision. To better understand our results, research assistants then read all articles within 300 days of the *Jacobson* decision and collected additional

[1] Prior to Jenner's vaccine, inoculation for smallpox typically occurred through deliberate low-level exposure to the virus, resulting in a roughly 2% fatality rate (Riedel, 2005).

information, such as: Was the article anti-vaccine propaganda? Did it contain descriptions of anti-vaccine behavior? Did the article mention the *Jacobson* decision? Did the article mention compulsory vaccination? For the RD-in-time approach, we carefully consider the threats to identification for RD-in-time designs raised in Hausman and Rapson (2018).

Second, we estimate the effect of pro-vaccine state-level Supreme Court decisions on mortality rates, also using staggered difference-in-differences. Because US vital statistics data are not available for much of our study period, we predict smallpox mortality during the pre-vital statistics era. We do this by estimating the relationship between newspaper language and smallpox mortality for years that have both newspaper and vital statistics data. Specifically, for years that have both newspaper and vital statistics data, we calculate the percent of newspaper pages in a state-year cell that have the word *smallpox* co-occurring with words such as *pandemic*, *death*, *burial*, or similar words and we estimate how well this predicts smallpox mortality in the US vital statistics. We then use this relationship to predict smallpox mortality during the pre-vital statistics era.[2]

Using both the difference-in-differences and regression discontinuity approaches, we find an increase in anti-vaccine discourse following pro-compulsory vaccination court decisions. We estimate a short-run increase in anti-vaccination language for approximately two years, after which media sentiment returns to the pre-decision baseline. Despite the rise in anti-vaccine discourse, we find that compulsory vaccination was effective at reducing mortality; states with pro-compulsory vaccinations decisions saw a 40% reduction in smallpox mortality from 1880 levels. That is, smallpox vaccine mandates appear to have reduced mortality, even in the face of a meaningful amount of judicial backlash. That said, more extreme responses could inhibit effectiveness—at a certain point, mandates may become ineffective or overturned.

We make several contributions to the literature. First, we bring empirical evidence to

[2] To demonstrate the efficacy of this method, we perform a test in which we predict 1900 to 1909 smallpox rates using the relationship between newspaper language and mortality in 1910 to 1922. The out-of-sample correlation between smallpox rates and predicted smallpox rates is 0.45.

the literature on judicial backlash, the theory that court decisions have the unintended consequence of increasing polarization and radicalizing groups opposed to the court's ruling. Legal scholars have proposed that *Roe v. Wade* (Greenhouse and Siegel, 2010), *Brown v. Board of Education* (Ball, 2005), and LGBTQ+ rights cases (Keck, 2009) have resulted in judicial backlash. However, the evidence for these hypotheses is mostly qualitative or from opinion surveys and rarely considers whether there are dynamic treatment effects (Fontana and Braman, 2012). Wheaton (2022) shows that there can be legislative backlash in response to (proposed) legislation and extensively analyzes the Equal Rights Amendment.[3] The Harvard Law Review Association (2008) argues that judicial backlash to the *Jacobson v. Massachusetts* decision was a contributing factor to the rise of the anti-vaccine movement in the US, a hypothesis that we are able to empirically test.

Second, we provide causal evidence that compulsory vaccine policies reduced smallpox mortality.[4] A 1943 publication in *Public Health Reports* classified states into six groups based on the stringency of their vaccination requirements and found that states with more stringent vaccination laws had lower smallpox rates (Hampton, 1943). In concurrent work, Chapman (2023) shows that government austerity in Britain increased anti-vaccine sentiment, but the rise in anti-vaccine sentiment did not result in an increase in smallpox mortality.[5] Our view is that Chapman's paper and this paper bolster each other's findings: the papers analyze different interventions that increased anti-vaccine sentiment, with neither intervention increasing smallpox mortality. Holtkamp (2021) uses a difference-in-differences approach to show that smallpox vaccination laws improved human capital development. Of note, the benefits of vaccination mandates were reduced in German-American families that were more likely to oppose vaccination. Holtkamp (2021) also presents a permutation test showing that states

[3]Wheaton (2022) also provides evidence regarding backlash in response to Supreme Court decisions about abortion, the death penalty, and interracial marriage. Unfortunately, data limitations only allow a static difference-in-differences model and prevent the analysis of pre-trends.

[4]As Atwood (2022) shows in the context of measles, the benefits from vaccination may extend beyond lower mortality rates to include higher employment rates, earnings, and productivity.

[5]Additionally, Chapman (2023) finds that anti-vaccine sentiment reduced mortality from other causes, possibly because the anti-vaccine movement often argued that smallpox could be avoided through improved sanitation.

with compulsory vaccination had fewer smallpox cases.[6] By predicting mortality during the pre-vital statistics era, we are able to estimate the effect of compulsory vaccination court decisions within a traditional difference-in-differences framework that includes most states.

Finally, we provide the first causal evidence that vaccine mandates affect anti-vaccine discourse in newspaper language. The literature on vaccine mandates has mostly focused on how mandates affect vaccination rates or disease burden (Acton et al., 2022; Richwine et al., 2019; Carpenter and Lawler, 2019; Abrevaya and Mulligan, 2011; White, 2021; Carrera et al., 2021).[7] However, the literature on how mandates affect sentiment has been limited to either cross-sectional surveys or psychology experiments in which participants consider hypothetical mandates (Betsch and Böhm, 2016; Sprengholz et al., 2021). Similarly, the literature on anti-vaccine sentiment has primarily focused on the role that (social) media plays in the spread of misinformation rather than the direct effects of mandates on sentiment (Chiou and Tucker, 2018; Ortiz-Sánchez et al., 2020; Żuk et al., 2019; Kalichman et al., 2022; Hansen and Schmidtblaicher, 2021; Chang, 2018). In related work, Oster (2018) shows that pertussis outbreaks lead to increased vaccination rates, where local media coverage may be an important source of information.

Understanding the effects of mandates on newspaper discourse is important for two reasons. First, research in other settings has shown that newspaper language affects public opinion and beliefs. For example, media language has been shown to change beliefs regarding illegal immigration (Djourelova, 2020) and police culpability for officer-involved shootings (Moreno-Medina et al., 2022). Media language has also been shown to affect behavior. For example, anti-Semitic rhetoric reduced support for Franklin D. Roosevelt and increased support for the Nazi party (Wang, 2021a), whereas access to Black radio (Wang, 2021b) increased political participation among African Americans. Second, newspaper discourse likely reflects

[6]In the Appendix of that paper, Holtkamp (2021) presents difference-in-differences analysis that finds similar results, although this supporting analysis has limited pre-treatment data; most laws were passed before smallpox incidence data is available.

[7]Likewise, HPV vaccine rates increase if opting out is more administratively burdensome (Churchill, 2021).

an amalgamation of vaccine-related opinions and behaviors including true public opinion, anti-vaccine protests, and letter-writing campaigns.

2 Background

2.1 The Virus and the Vaccine

Smallpox is one of the earliest known diseases, emerging before recorded history. There is evidence that Egyptian mummies had symptoms resembling smallpox (CDC, 2021). It was also one of the most devastating diseases. For example, the 735–737 CE epidemic in Japan is estimated to have killed approximately one-third of the Japanese population (Suzuki, 2011). Prior to vaccines, the case fatality rate varied widely by outbreak, but likely averaged roughly 30% (CDC, 2016b). Starting in 1897 and continuing through the middle of the twentieth century, a much less deadly variant of the virus became dominant (Colgrove, 2006).

Caused by the variola virus, smallpox resulted in fever and progressive rashes. It typically spread via respiratory droplets from coughing and sneezing; patients were contagious as soon as their first rash appeared and remained contagious until the last rash disappeared (CDC, 2016a). In isolated communities without herd immunity, the basic reproductive factor—the average number of secondary infections from an infected individual in a fully susceptible community—was estimated to be approximately 5 (Gani and Leach, 2001), roughly on par with the Delta strain of Covid-19 (Liu and Rocklöv, 2021).

Before the discovery of the smallpox vaccine, it was understood that exposure to smallpox conferred later immunity, and physicians performed inoculations by deliberately spreading the virus. The inoculation process, also known as variolation, involved taking matter from the pustule of a smallpox victim and exposing the individual to be inoculated to the pustule matter subcutaneously with a lancet or needle (Riedel, 2005). The individual would then typically develop a mild case of smallpox, and the appearance of smallpox pustules was used as evidence that the inoculation worked. However, inoculation involved risk: 2% of those inoculated died during a 1721 Boston smallpox epidemic. Notably, this was lower than the 14% fatality rate for those who naturally contracted the disease (Riedel, 2005).

In 1796, Edward Jenner was the first to formally publish experimental results showing that exposure to the milder cowpox virus conferred immunity to smallpox.[8] Jenner removed the lymph from a pustule on a cowpox victim, inoculated a boy, then exposed the boy to smallpox, proving that he had no reaction. Jenner named the process vaccination, after the Latin word for cowpox, *vaccinia*.[9]

2.2 Laws and Court Decisions

While vaccination had high benefits in expectation and was voluntarily sought out by many individuals, it was also the case that some individuals had bad reactions or acquired other diseases in the process. There were also many individuals who chose not to get vaccinated.

Many states passed laws to encourage smallpox vaccination, and a subset passed laws mandating vaccination for certain populations. Compulsory vaccination laws had widely varying scopes from compulsory vaccination for all adults (e.g., Kentucky, Washington, D.C.) to compulsory vaccination for students (e.g., Arkansas) to allowing local jurisdictions to impose compulsory vaccination on students (e.g., Connecticut) to requiring vaccination in order to attend school but only during outbreaks (e.g., Kansas, Louisiana) (Fowler, 1927).[10] At their core, each of these laws had the power to compel individuals to be vaccinated in certain situations.[11]

[8] Jenner was neither the first to suspect cowpox conferred immunity to smallpox nor the first to deliberately spread cowpox as a smallpox prophylaxis. Allegedly, Jenner came upon the idea after hearing a dairymaid say, "I shall never have smallpox for I have had cowpox" (Riedel, 2005).

[9] Cowpox was a geographically isolated disease and shipment was difficult with contemporary technology. Physicians primarily performed arm-to-arm vaccination, obtaining the cowpox virus from a pustule of a recently vaccinated individual.

[10] Even the latter law could be difficult for anti-vaccinationists to avoid; outbreaks could last months and schools served as an important source of childcare so that parents could earn a living.

[11] In *The Pox of Liberty*, Werner Troesken argued that the focus on individual liberty in the Constitution simultaneously set institutional foundations for US economic prosperity *and* made it difficult to control infectious disease. For example, smallpox was eliminated in US-controlled Cuba decades before Massachusetts, as Cubans were not protected under the Constitution and had little recourse to resist the US Army's mass-vaccination efforts (Troesken, 2015).

Colgrove (2006) characterizes vaccination efforts during this period as ranging from persuasion to compulsion; further, public health authorities sometimes exercised powers beyond what the law allowed and other times did not fully enforce the law. For example, "the health commissioners in Brooklyn and New York exercised *de facto* compulsion but portrayed their practices in the language in voluntarism, because they lacked a clear legal mandate." In at least one instance, they would use police powers to forcibly quarantine individuals that refused to be vaccinated *and* prevent delivery of supplies to the quarantined. During an epidemic in Chicago, "teams of vaccinators accompanied by police went house to house, using quarantine as they saw necessary, which also provoked community opposition." In many areas, unvaccinated students were prevented from attending public school, which could be seen as coercive—indeed, working parents may not have had very much of a choice. However, there was considerable heterogeneity across the United States, with many municipalities eschewing approaches that resembled compulsion. Further, the legal status varied greatly across jurisdictions.

Laws were frequently challenged by individuals who did not want themselves or their children to be forced to be vaccinated, most famously in *Jacobson v. Massachusetts*. Massachusetts had a law that local jurisdictions could have compulsory vaccination with the penalty for refusal being a $5 fine. When the city of Cambridge was experiencing the 1902 smallpox outbreak, the Board of Health attempted to vaccinate Henning Jacobson. Jacobson was a pastor originally from Sweden, a country with compulsory vaccination. He claimed that he had an adverse reaction to the smallpox vaccine as a child. Rather than pay the fine, Jacobson, along with Albert Pear who also refused the vaccine, sued the Commonwealth. The case made its way through Massachusetts courts, going through the Massachusetts Supreme Court in 1903, which ruled against Jacobson.

In *Jacobson v. Massachusetts* (1905), the US Supreme Court ruled 7-2 that compulsory vaccination laws were a valid use of the state's police powers. Further, young children may be exempted without violating the equal protection clause of the Fourteenth Amendment, provided that all adults are treated equally (Skelton, 2022).[12]

Beyond Massachusetts, many other states saw cases that challenged whether their laws were compliant with state constitutions. About three quarters of these cases ended with a state Supreme Court upholding the law. These are the cases we focus on in our analysis.

The time from law passage to Supreme Court decision varied from state to state. To end up with a state-level Supreme Court decision, it was generally required that a state try to enforce the law against a party who chose to challenge the law. Then, the case would wind its way through several appeals before finally reaching a state Supreme Court.

Supreme Court decisions could potentially affect vaccine sentiment through several channels. Because Supreme Court decisions are typically "final," they are likely to receive greater scrutiny than appellate-level decisions. People understand that these are the decisions that will apply to them. Beyond this, it is also the case that we might expect enforcement of a law to change. Now that authorities have backing from the judicial and legislative branches, they may be inclined to use compulsion in situations where they might previously have leaned towards persuasion. Increased enforcement of a law would also affect sentiment as, for example, people who previously skirted vaccine requirements without thinking too much about them are now forced to comply against their will.

2.3 The Anti-Vaccine Movement

In the United States, there were at least two national anti-vaccine societies that focused on smallpox, as well as several regional associations. The *Anti-Vaccination Society of America* was founded in 1879 after British anti-vaccinationist William Tebb visited the US, while the *Anti-Vaccination League of America* was founded in 1908, three years after *Jacobson v. Massachusetts* (1905) (The College of Physicians of Philadelphia, 2022; The Harvard Law

[12]For more on the legal framework, see Gostin (2000). The US Supreme Court also used *Jacobson v. Massachusetts* (1905) as a precedent when deciding *Zucht v. King* (1922) (*Zucht v. King, 260 U.S. 174 (1922)*, 2022). This decision upheld the right of municipalities to exclude unvaccinated children from public and private schools. We do not have newspaper data available to examine the anti-vaccine response to this decision.

Review Association, 2008). Those opposed to the vaccine represented a cross-section of the United States, including well-respected members of society—for example, John Pitcairn Jr., co-founder of the *Anti-Vaccination League of America*, was a wealthy industrialist from Pittsburgh and a civic leader in his community (Colgrove, 2005).

Anti-vaccinationist propaganda regularly appeared in some newspapers. One extreme example comes from Zion City, Illinois, a town founded with the intent of building a Utopian evangelical community (Illinois Newspaper Project, 2021). In 1914, the leader of the community founded a newspaper called *The Theocrat*, where he regularly published local news, church sermons, arguments for flat earth theory, and anti-vaccinationist propaganda (Schadewald, 2003). Headlines included "The Foul Vaccination from Hell" and "Vaccine Virus Made from the Rotten Tissue of a Sick Calf."

Some legal scholars hold the view that court decisions motivated the anti-vaccine movement. For example, *The Harvard Law Review Association (2008)* writes:

> Soon after Jacobson's holding came down, the inchoate anti-vaccine movement exploded. As Professor James Keith Colgrove notes, "a diverse assortment of activists would, over the next quarter century, redouble their efforts at combating attempts to force vaccination upon the people."
>
> Most prominently, three years after Jacobson, the Anti-Vaccination League of America was founded in Philadelphia... Hoping to rally widespread public support, the group's co-founder invoked shared constitutional principles, asking, "We have repudiated religious tyranny; we have rejected political tyranny; shall we now submit to medical tyranny?" Pamphlets became the medium of choice for the group. It published titles such as *The Crime Against the School Child* and *Horrors of Vaccination Exposed and Illustrated*, both of which depicted victims disfigured by unsafe vaccines.

This view suggests that the rise of the anti-vaccine movement may be a result of judicial backlash and that the effects may not be limited to the short run. Our goal in this paper is to empirically test these hypotheses.

Alternatively, it is possible that activism increased over several decades "[as] smallpox declined in incidence and receded from the public eye, adverse events arising from vaccination assumed new salience" (Colgrove, 2006). That is to say, the anti-vaccine movement has many contributing factors and likely has more success when the benefits of vaccination are less apparent and the costs are more visible.

The anti-vaccination movement had some legislative success. Of note, Utah (1907) and North Dakota (1919) enacted laws forbidding compulsory vaccination. Washington State (1919) and Wisconsin (1920) repealed their mandatory school vaccination laws. New York's law was modified to strengthen compulsion in urban areas while weakening it in rural ones. Notably, average vaccination rates across the United States appear to have decreased in the decades following *Jacobson* (Colgrove, 2006).

In addition to the anti-vaccine movement, there were other movements related to general mistrust in the medical sciences. There was an active anti-mask movement during the 1918 influenza pandemic, with many arguing masks were ineffective (Dolan, 2020). Distrust in the medical sciences may have been warranted at times. In 1972, it was disclosed that the Tuskegee Study of Untreated Syphilis monitored Black males with syphilis without treating them or informing them of their diagnosis. The disclosure ultimately decreased medical trust and increased mortality rates of Black males (Alsan and Wanamaker, 2018).

3 Data

Section 3.1 describes the newspaper data from the *Chronicling America* newspaper archive. In Section 3.2, we discuss how we obtained data on state-level Supreme Court decisions. Finally, Sections 3.3 and 3.4 describe the construction of the training data and machine learning techniques that are used to generate anti-vaccine discourse predictions and mortality predictions, respectively.

3.1 The Chronicling America Newspaper Archive

To obtain text from American newspaper articles, we use data from the *Chronicling America* newspaper archive, which is published by the Library of Congress. The archive contains data for nearly 20 million newspaper pages dating from 1777 to 1963, although most pages in the archive are from the late nineteenth and early twentieth centuries. Each page includes a digitized image of the page (in the form of both PDF and JPG files) as well as text files generated from an automated Optimal Character Recognition (OCR) program. Each page also contains basic metadata, including the newspaper name, city or town of publication, state of publication, date of publication, and the page number.

While not fully nationally representative, the *Chronicling America* archive is more representative of the United States than one might think. The National Endowment of the Humanities, in partnership with the Library of Congress, awarded state-level grants to organizations like flagship state universities and state historical societies so that they could "select and digitize approximately 100,000 newspaper pages representing that state's regional history, geographic coverage, and events of note."[13] Thus, almost all states are represented in the data set. The exceptions are the only states that had not received grants as of when the data were scraped: Massachusetts and New Hampshire. Relatively rural states, such as Wyoming, Montana, and Idaho are all well-represented in the data set. The data set is also not limited to cities. It includes small towns like Zion City, IL, which had a population of 5,580 in 1920.

Economists increasingly use historical newspapers as a source of data. Examples of papers that use *Chronicling America* include Ferrara and Fishback (2020) on anti-German sentiment, García-Jimeno et al. (2022) on the temperance movement, and Beach et al. (2022) on the 1918 influenza pandemic. See Hanlon and Beach (2022), Ash and Hansen (2023), and

[13]For more on the *Chronicling America* dataset, please see the Library of Congress's website.

Gentzkow et al. (2019) for a review of this literature.

Our primary data come from the OCR text files. Using a web scraper, we collected the text files and metadata for every newspaper page from 1880 to 1922 that contains both the words *smallpox* and *vaccine* (and variants thereof). This resulted in a data set of 47,635 newspaper pages.[14] Note that these pages include everything published in newspapers including, for example, news articles, editorials, and advertisements. The era we study was known for "yellow journalism," where the delineation between news and editorials was not always clean. Of course, this blurring can still happen today.

Ideally, we would be able to extract only the text from articles that contain the words *smallpox* or *vaccination*, as other articles are unlikely to be of interest to us. Unfortunately, the OCR text files make it impossible to know exactly when an article starts and ends. For these reasons, each observation is a newspaper page and we remove text that is far from words that share a root with *vaccine*. Specifically, we start by removing all special and numeric characters, as well as punctuation.[15] We identify words by separating the text string by spaces. We then drop words that do not appear within 10 words of a word containing the root *vaccin*.[16] Thus, an observation (or document) in our context is the collection of words on a newspaper page that appear near a word that has the root *vaccin*, where near is define as within ten words.

We do not include articles that only mention the stems *inocul* (the stem of inoculation and inoculate) or *immun* (the stem of immunization or immune), without mentioning vaccination. Inoculation during this period often referred to practice of variolation in which an individual intentionally exposed themselves to smallpox (not cowpox), a practice that preceded Jenner's

[14] We first collected data from 1850 to 1930, but there are too few newspaper pages per year outside of the 1880 to 1922 period to conduct a rigorous analysis. There are limited pages after 1922 because the archive focuses on newspaper pages that are at least 95 years old and in the public domain. There are likely fewer pages before 1880 because population and literacy rates were lower, the western United States was still being settled, and older newspaper pages were less likely to survive long enough to be scanned.

[15] We replace punctuation with spaces with the exception of dashes, which are commonly used to break up long words that are split between two lines.

[16] Words with this root include: vaccine, vaccines, vaccinated, vaccinates, vaccination, anti-vaccine, anti-vaccination, and unvaccinated.

discovery. Similarly, references to immunity may have been referring to natural immunity rather than immunity via the vaccination process. Adding these words to the data set would require research assistants to read another collection of newspaper pages that contain these words, but not vaccination.

The text files also contain many OCR errors. To minimize these errors, we run the remaining words through an automated spell-checker that replaces any word not in the English dictionary with the first suggestion. Some of these suggestions will be incorrect, but it will replace common OCR errors, such as replacing an incorrectly OCRed *tbe* with the correct *the*. Despite this step, misspellings remain. To limit their impact, we drop every word that does not appear in the entire data set at least 100 times. These words are frequently misspelled but may also contain proper nouns and obscure words. Either way, these words are unlikely to appear in the training data set (introduced in detail in Section 3.3) with sufficient frequency to help the machine learning algorithms predict anti-vaccine discourse. Finally, we truncate every word at twenty characters, as words longer than this are usually multiple words where the OCR did not recognize the space.

Lastly, we create a bag-of-words (BoW) representation of the remaining words. A BoW representation will create a vector in which each element is the count for a specific word. In our case, the length of the BoW representation vector is over 2,000 words.[17] Appendix Section A.1 presents an example of taking a raw OCRed newspaper page through the text cleaning process and then representing the string as a BoW representation.

3.2 Smallpox Court Decision Data

Our state Supreme Court decision data come from "Smallpox Vaccination Laws[,] Regulations, and Court Decisions" published by William Fowler of the United States Public Health Service (Fowler, 1927). This document compiles information on public health laws and reg-

[17] We use the Stata txttools command with the stem option, which strips words of their suffixes using the Porter stemmer (Porter, 1980; Williams and Williams, 2014). Thus, words such as *connect*, *connected*, and *connection* are treated as a single word.

ulations that were on the books as of the time Fowler last examined the state code, as well as major court decisions regarding smallpox public health measures.

We focus on court decisions rather than state laws or health board regulations for several reasons. First, Fowler's data contain the year of court decisions. We were then able to find the exact date by searching law archives for the court decision in question. The laws in Fowler's data do not contain a date that the laws or regulations went into effect, and we were unable to find the dates for most laws or regulations using alternative sources. Additionally, states would sometimes not enforce laws or would repeal laws altogether (Holtkamp, 2021). State Supreme Court decisions were rarely overturned.

We code a state as being treated after the first state Supreme Court decision that upheld a pro-vaccination law. Our intuition is that Court of Appeals decisions would be less influential, as they may only indicate that the case would move on to the state Supreme Court. We focus on the first decisions, as subsequent decisions are likely to get less media attention and may merely uphold the court's previous decision.

A table of the state Supreme Court cases we consider is in Appendix Table A.1. Many of the court cases regard the compulsory vaccination of students. Students were a popular target because schools were one of the main transmission vectors. Some of the ways in which the cases differed related to when compulsory vaccination could be applied (e.g., at all times or during outbreaks only) and who could require compulsory vaccination (e.g., the state health board or local governments).

A caveat of using this source is that the court decisions are to the best of William Fowler's knowledge. While he was an expert on the topic in part due to the fact that he published annual reports tracking state public health laws, he did rely on a variety of sources from different years. We searched online law archives for additional state-level Supreme Court decisions and did not find any.

3.3 Predicting Discourse with Machine Learning

Because it is cost prohibitive to manually classify the sentiment of each newspaper page, we use techniques from supervised machine learning to generate predictions of vaccine sentiment in newspaper language. Research assistants read a random 5% sample of articles. The research assistants then classified each article as containing anti-vaccination discourse, pro-vaccination discourse, neither (if the article was neutral), or both (if the article was presenting multiple sides). This 5% sample forms a training data set that we use to make out-of-sample predictions for articles that were not read by research assistants. Although we focus on the 1880 to 1922 period for our regression analysis, our machine learning model is trained using data from 1850 to 1930. The additional years, even though there are fewer articles per year, are useful for predicting discourse due to the high dimensionality of the language data.

Our measure of anti-vaccine discourse encompasses several possibilities. An article could contain anti-vaccine discourse because the article was making anti-vaccine arguments or because it is describing behaviors or arguments of anti-vaccinationists, even if the article itself is not anti-vaccinationist. Similarly, anti-vaccine discourse in newspapers may be a reflection of consumer preferences (demand), editor/publisher preferences (supply), or events on the ground.[18] We do not attempt to distinguish among these mechanisms and view all of the above as being examples that the anti-vaccine movement was active at that time in that locality. We recognize that our discourse measure may not fully reflect underlying public opinion.

The simplest strategy for predicting vaccine discourse is to run a logistic regression of discourse on our bag-of-words representation vector. The problem with this approach is that the number of words in the word vector is similar to our sample size. Even if the training data set were larger, including every word would result in overfitting the data to noise in the training data set (Athey and Imbens, 2019). To address the high dimensionality

[18] Gentzkow and Shapiro (2010) find that consumer preferences play a larger role in determining political media slant than supply factors.

of the word data, we instead use a LASSO logistic regression. This approach introduces a penalty parameter for including covariates that do not predict discourse and reduces the dimensionality of the covariates included in the regression. We use 5-fold cross-validation and select the penalty parameters that result in the best out-of-sample goodness of fit. This approach is similar to the LASSO approach in Nowak and Smith (2017), who use text from real estate listings to increase the accuracy of price predictions, and to the ridge regression approach Widmer et al. (2022) use to examine the effect cable news on local news slant.[19]

We consider several variations of this approach. Our baseline approach represents the words as vectors that count the frequency that each word appears (the BoW frequency approach). We also consider three alternatives. First, we represent each word as a fraction of all words associated within that article (the BoW proportion approach). Our baseline approach will treat short and long articles differently that use a similar distribution of words, whereas this alternative ignores the length of the article. The second alternative is the same as our baseline approach, but adds year and state indicators (the BoW frequency plus state and year fixed-effects approach). The third alternative is the same as the second, but also adds state-by-year indicator variables (the BoW frequency plus state-by-year FE approach). Lastly, all models include the length of the string and the length squared. It should be noted that many fixed effects are dropped by the LASSO regression. The fitted values from the LASSO regression become our measure of discourse.[20][21]

[19]See Mullainathan and Spiess (2017) for an in-depth review of LASSO regression.

[20]As an alternative to our LASSO-based approach, we used two sentiment dictionaries: the Harvard-IV sentiment dictionary and the Loughran-McDonald sentiment dictionary (Loughran and McDonald, 2011). Both sentiment dictionaries assign lists of words as containing either positive or negative sentiment. We find that there is a negative and statistically significant relation between human classified anti-vaccine sentiment and the dictionary-based sentiment. However, the correlation between the LASSO-based sentiment method and human-classified sentiment is meaningfully higher.

[21]Another alternative to LASSO is to use language models based on neural networks such as Bidirectional Encoder Representations from Transformers (BERT), which is pre-trained using a large corpora of the English language. The primary advantage of BERT is that it takes into account context by considering surrounding words. We examined using BERT in two ways. First, we used the pre-trained sentiment classifier. We then tried to fine-tune the classifier using our human classified data. Both methods returned poor predictions of anti-vaccine sentiment in our context. We suspect that BERT may be confused by the many OCR errors in the surrounding words. It may also be the case that many pro-vaccine statements about smallpox use words with negative connotations (e.g., "There is a terrible smallpox epidemic. Many people died and people who are not yet sick should be vaccinated.") That said, it is possible that a different implementation would yield

Table 1: Correlation matrix of anti-vaccine measures

	(1) Human classified	(2) BoW 1	(3) BoW 2	(4) BoW 3	(5) BoW 4	(6) pseudo-R^2
Human classified	1					
BoW 1	0.613	1				0.351
BoW 2	0.490	0.781	1			0.219
BoW 3	0.622	0.995	0.779	1		0.363
BoW 4	0.631	0.971	0.766	0.976	1	0.374

Notes: Human classified refers to anti-vaccine discourse as classified by research assistants in the training data set. BoW 1 uses the BoW frequency approach; BoW 2 uses the proportion approach; BoW 3 is the same as BoW 1 plus state and year fixed effects; BoW 4 is the same as BoW 3 plus state-by-year fixed effects. Many of the fixed effects are dropped by the LASSO logistic regression. Column (6) presents the pseudo-R^2 between human classified discourse and the automated discourse measure.

The automated discourse measures are significantly correlated with the human-classified data. Table 1 displays a correlation matrix for the discourse measures. The correlation between the human-trained data and the BoW frequency approaches is approximately 61%.[22,23] Adding state and year fixed effects does not meaningfully improve the predictions. The pairwise correlation between the three BoW frequency measures is close to one. The BoW proportion measure performs worse and has a correlation with the human-trained data of 0.49. Because correlations with binary variables can have a less straightforward interpretation, the last column of Table 1 presents the pseudo-R^2 between human-classified discourse and our four discourse measures. Most of our measures have a pseudo-R^2 exceeding 0.3.[24]

Appendix Table A.3 provides the confusion matrix as a final measure of goodness-of-fit.

more promising results.

[22]Our machine learning model predicts human-classified sentiment better than well-accepted historical income proxies predict income (e.g., Bleakley (2010), Abramitzky et al. (2014), and Ward (2020)). Using 1950 census data, we find that the correlation between total income and these income proxies is 0.467, lower than all four of our BoW models. If we use demographic variables along with income proxies to predict income in a regression framework (as in (Saavedra and Twinam, 2020; Inwood et al., 2019)), we find that the correlation between total income and the predicted values of that regression is 0.578, lower than three of our four BoW models.

[23]The out-of-sample deviance ratio, a goodness-of-fit measure similar to R^2, from 5-fold cross-validation is 0.16.

[24]We also present a calibration curve for our measure of anti-vaccine sentiment in Appendix Figure A.2. A calibration curve is a goodness-of-fit measure that is commonly used in the machine learning literature. Each scatter point plots a ventile of predicted anti-vaccine sentiment on the x-axis against the average anti-vaccine sentiment for that ventile on the y-axis. The result suggests that the model is moderately more accurate for pages with minimal anti-vaccine sentiment, likely because such pages are more prevalent in the dataset.

For this table, articles from the training data are divided along two dimensions: (i) whether or not they are human-classified as containing anti-vaccine discourse and (ii) whether or not they are predicted to possess anti-vaccine sentiment (with a predicted value of at least 0.5). A better model fit results in more observations that are true positives (TP; is anti-vaccine and is predicted as such) or true negatives (TN; is not anti-vaccine and is predicted not to be). Conversely, false negatives (FN) occur when an article has anti-vaccine discourse, but is not predicted to and false positives (FP) occur when an article is anti-vaccine, but is not predicted to be. The table also reports accuracy, precision, recall, and the F_1 score, which serves as a comprehensive measure of goodness-of-fit. While the baseline model exhibits high accuracy and precision, its recall is low.[25] This is because only 13% of articles contain anti-vaccine sentiment, thus making the 0.5 threshold difficult to reach.[26] This supports our use of the fitted values of the LASSO model (rather than the binary classification) as the dependent variable in our difference-in-differences model.

The baseline LASSO regression (BoW frequency approach) selected 107 words which predict anti-vaccine discourse. Our primary interest is in the predicted values rather than the coefficients themselves. LASSO regression is known to be biased, as the penalty parameters will force potentially non-zero coefficients to be omitted, a problem similar to omitted variable bias (Mullainathan and Spiess, 2017). With that said, examples of words that increase the probability that a newspaper page contains anti-vaccine discourse are presented in Appendix Table A.2. Intuitive words that predict anti-vaccination discourse include *antivaccinationist*, *resist*, *protest*, *imposs* (stem of impossible), *oppos* (stem of oppose), *refus* (stem of refuse), and *forc* (stem of force). These words are all in the top twenty most anti-vaccine words. There are fewer words that negatively predict anti-vaccine discourse, but examples include many words that focus on the science behind the vaccine, such as *cow*, *method*, and *measur* (stem of measure). The word *typhoid* also negatively predicts anti-vaccine discourse, which

[25] By definition, accuracy is $ACC = \frac{TP+TN}{TP+TN+FP+FN}$, precision is $PRE = \frac{TP}{TP+FP}$, and recall is $REC = \frac{TP}{TP+FN}$. The F_1 combines precision and recall and is $2 \times \frac{PRE \times REC}{PRE+REC}$.

[26] Decreasing to the threshold from 50% to 20% improves F_1 score and recall to 62% and 60%, respectively, with an accuracy of 90% and precision of 66%.

may refer to the less controversial typhoid vaccine that was also available during the same time period.

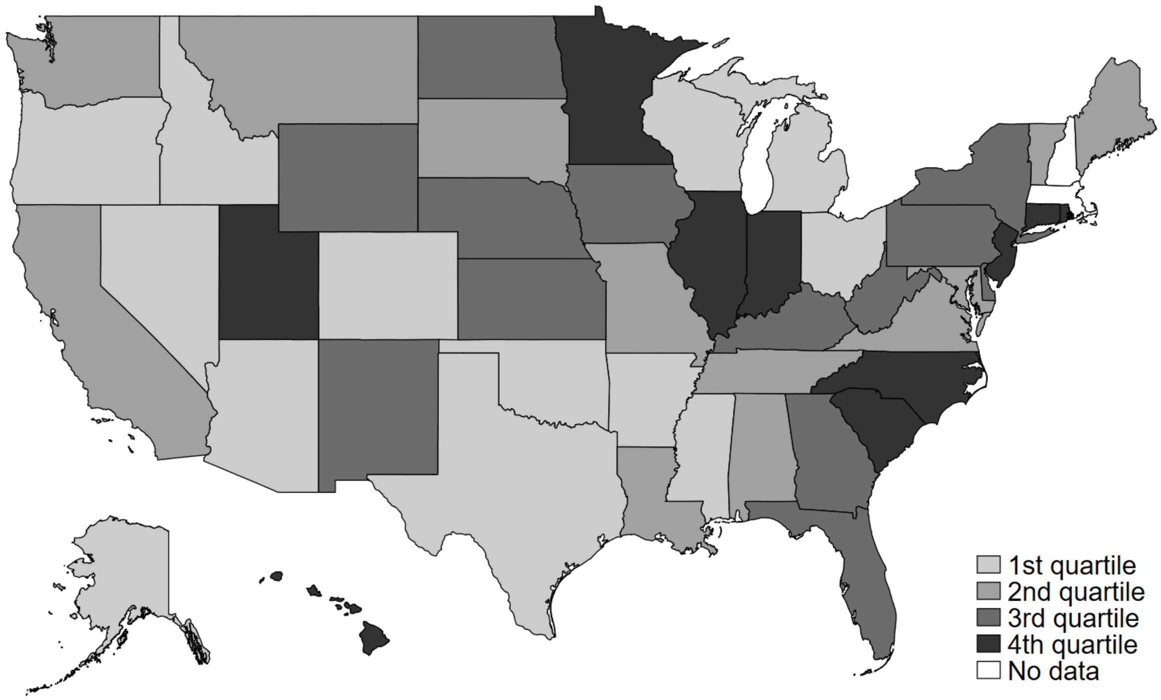
Summary statistics appear in Table 2 below. Among the training data set, 13.4% of pages contain anti-vaccine discourse as coded by hand. The four measures of predicted anti-vaccine discourse for the entire data set have similar anti-vaccine discourse on average, ranging from 13.0% to 13.6%. Notice that there is considerable range in the predicted discourse for each measure—there are newspaper pages with low predicted probability of containing anti-vaccine discourse and newspaper pages that contain anti-vaccine discourse with probability close to one. Each region is well represented, and the average year is 1903. The number of observations by event-time bin appears in Appendix Figure A.5. Approximately half of the sample is never treated. Excluding the bins at the boundary (≤ -10 years and ≥ 10), the sample size peaks from two years before to two years after a smallpox court decision. This highlights that these court decisions were more likely to be handed down when smallpox was a salient issue that was discussed often in newspapers. The minimum bin size is 314, which occurs five years before smallpox court decisions.

Table 2: Summary statistics

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
Anti-vaccine measures					
Human classified	0.134	0.341	0	1	2263
BoW freq.	0.131	0.146	0.023	1	47637
BoW prop.	0.136	0.109	0.075	1	47637
BoW freq. + state and year FE	0.131	0.147	0.026	1	47617
BoW freq. + state-by-year FE	0.130	0.141	0.029	1	47617
Spatial and temporal co-variates					
Year	1902.789	11.453	1880	1922	47637
Northeast	0.149	0.356	0	1	47637
South	0.338	0.473	0	1	47637
Midwest	0.298	0.457	0	1	47637
West	0.215	0.411	0	1	47637

Notes: Data are from the *Chronicling America* newspaper archive, 1880-1922. Sample is restricted to pages that contain the word *smallpox* and the word *vaccine* (and variants thereof).

Figure 1: Map of predicted anti-vaccine discourse



Notes: Data are from the *Chronicling America* newspaper archive, 1880-1920. Data are unavailable for both Massachusetts and New Hampshire. Darker shades represent more anti-vaccine discourse. Anti-vaccine discourse is measured using our baseline frequency bag-of-words representation.

Figure 1 presents a map of average anti-vaccine discourse by state. The darker states have more anti-vaccine discourse than the lighter states (except for Massachusetts and New Hampshire, where we do not have data). Anti-vaccine discourse is highest in Rhode Island, Utah, Connecticut, and New Jersey, whereas the states with the least anti-vaccine discourse are Idaho, Nevada, Oregon, and Alaska.

3.4 Predicting Mortality with Machine Learning

Smallpox death counts start to become available at the beginning of the twentieth century with the annual publication of the Census Bureau's Vital Statistics. States enter the death registration area on a rolling basis, with only 10 states publishing data in 1900, 21 states in 1910, and 34 states by 1920.[27] Thus, the newspaper and mortality data overlap from

[27] We searched for smallpox data from US cities and states before 1900 but were unsuccessful. There does exist data from several European cities, as well as Havana, Cuba. See Troesken (2015).

1900 to 1922, but only for a subset of states. Unfortunately, among the states treated by judicial decisions upholding compulsory vaccination, there are insufficient data during the pre-treatment period to estimate dynamic treatment effects. Vital statistics data often become available shortly after these court decisions.

To generate a proxy for smallpox mortality, we turn back to the newspaper data. We estimate the relationship between newspaper language and mortality during the vital statistics era to generate mortality estimates in the pre-vital statistics era. Specifically, for each state-year cell we measure the percent of newspaper pages in which the word *smallpox* co-occurs within 10 words of a mortality token. The tokens we consider include *outbreak*, *epidemic*, *death*, *died*, *mortality*, *sick*, *kill*, *pandemic*, *endemic*, *plague*, *burial*, *grave*, *obituary*, and *case*. We then use LASSO regression to estimate the relationship between these co-occurrences and the smallpox mortality rate in that state-year cell.

The LASSO regression identifies eight co-occurrences that predict smallpox mortality: *pandemic*, *burial*, *outbreak*, *sick*, *died*, *plague*, *death*, and *epidemic*. All co-occurrences, with the exception of *sick*, predict higher smallpox mortality. The predicted values from this model demonstrate an in-sample correlation of 0.42 with actual smallpox mortality (an R^2 of 0.18). Appendix Figure A.3 shows the relationship between predicted and actual smallpox mortality using a binned scatter plot, also known as a calibration curve in the machine learning literature. Each point represents a decile of predicted mortality.[28] Each decile and the line of best fit are relatively close to the 45-degree line, suggesting accurate predictions within each decile on average. Appendix Figure A.4 plots actual and predicted smallpox mortality for eight sample states: Connecticut, Indiana, Maine, Michigan, New Jersey, New York, Vermont, and Rhode Island. These states were selected as they provide smallpox data dating back to 1900 and also have available newspaper data.[29] While the predictions do not perfectly match the mortality rates, predicted mortality tends to surge during outbreak years.

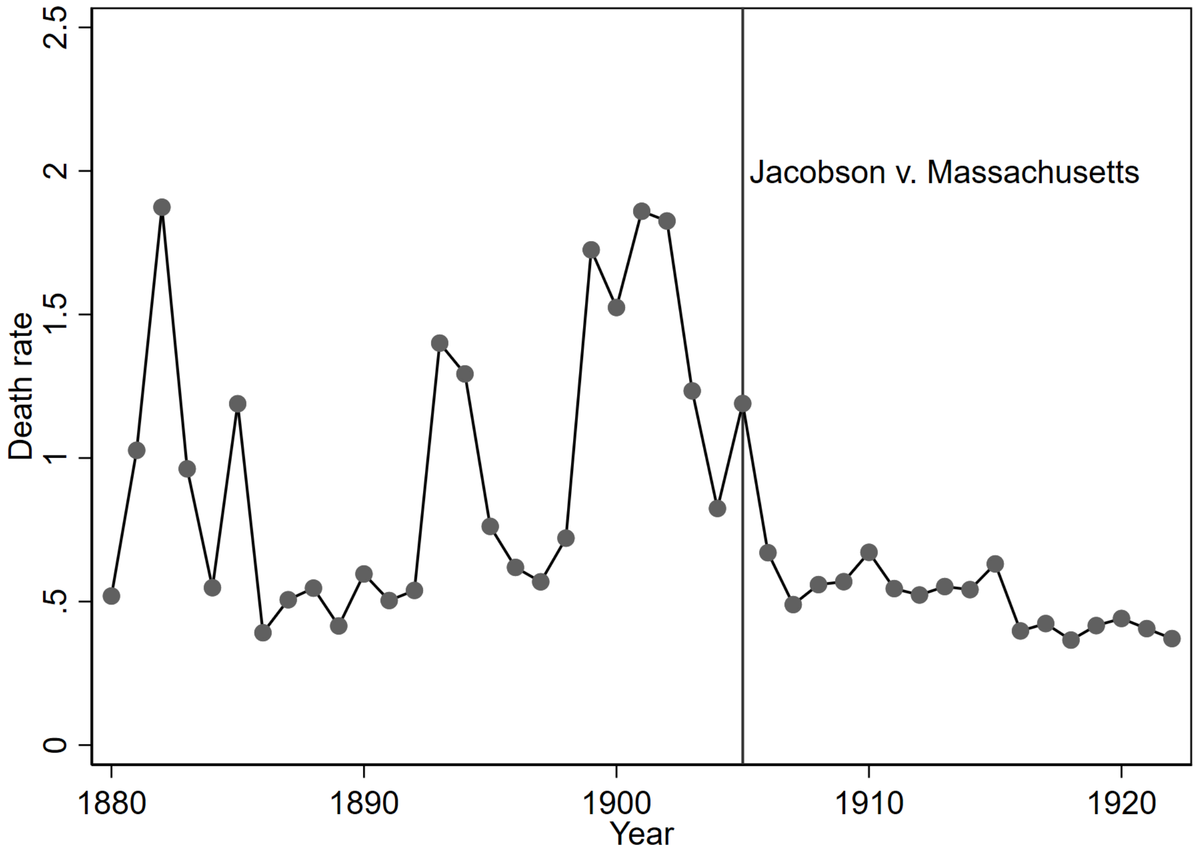
[28] Here, we use deciles instead of ventiles because our sample is smaller.
[29] Massachusetts has smallpox data from 1900 but lacks newspaper data.

Given that the predictions seem to perform well during the vital statistics era, we now provide evidence that the predictions are useful during the the pre-vital statistics era. Given the absence of smallpox mortality data for this period, we cannot directly evaluate the predictions' quality. Indeed, it is conceivable that the relationship between newspaper language and mortality changed over time due to, for example, individual smallpox outbreaks becoming more newsworthy as smallpox rates declined.[30] To address this issue, we undertake an exercise to demonstrate that our method can successfully predict smallpox rates at least a decade into the past. We begin by splitting the post-vital statistics data into two periods: 1900 to 1909 and 1910 to 1922. We then determine the relationship between smallpox mortality and newspaper language during the 1910 to 1922 period (the training sample) and assess how well the LASSO model predicts smallpox rates during the 1900 to 1909 period (the hold-out sample). Here, the out-of-sample correlation between smallpox rates from 1900 to 1909 and predicted smallpox rates (trained on 1910 to 1922 data) is 0.45, indicating no significant decline in prediction quality. This suggests that training the model on 1900 to 1922 data could provide reasonable predictions for the 1880 to 1899 period.

Figure 2 displays trends in predicted smallpox mortality during the study period. The model predicts that there were outbreaks of smallpox in 1882 and 1899-1902, with smaller outbreaks in 1884 and 1894. The data also suggest that high-mortality smallpox outbreaks became less common after the *Jacobson* decision. It is important to remember that this graph is descriptive and not causal. During the late nineteenth and early twentieth centuries, the major strain of smallpox became less common and the minor strain became dominant, which may account for falling smallpox mortality. It is also possible that as the new strain became dominant, smallpox mortality went down while morbidity increased. For these reasons, it is important to account for year effects using our staggered difference-in-differences design.

[30] Costa and Kahn (2017) find that typhoid fever outbreaks became more newsworthy after investments in water infrastructure.

Figure 2: Trends in predicted smallpox mortality



Notes: Smallpox mortality is estimated using language in newspaper data. Actual smallpox mortality comes from the Vital Statistics. *Jacobson v. Massachusetts* was decided in 1905. The death rate is deaths per 100,000.

4 Econometric Methodology

This section describes the two empirical designs we use in this paper. Section 4.1 presents the staggered difference-in-differences estimators using state-level Supreme Court decisions. Section 4.2 presents the regression discontinuity in time approaches using the *Jacobson v. Massachusetts* decision. Section 4.3 discusses the consequences of measurement error in our context.

4.1 Difference-in-Differences

Our first set of analyses follows the staggered difference-in-differences methods presented in Callaway and Sant'Anna (2021). This estimator is robust to arbitrary group- and time-level heterogeneity, alleviating concerns associated with the commonly used two-way fixed effects estimator (Goodman-Bacon, 2021; Callaway and Sant'Anna, 2021). Because each observation is a newspaper page, we use the repeated cross-section approach. Treatment turns on within a state after the first state Supreme Court decision occurs that upholds a pro-vaccination law. We ignore appellate court decisions, which are unlikely to get the same level of newspaper coverage, as well as subsequent Supreme Court decisions, as those often reaffirm the previous decision. We use wild bootstrap standard errors clustered at the state level and display uniform 95% confidence intervals.[31] We present results using both never-treated and not-yet-treated states as control groups, as well as with short and long differences for the pre-treatment periods. When mortality is the dependent variable, an observation is a state-year cell. For discourse, a newspaper page is an observation; we add month of publication as a control to account for seasonality.[32]

We also present results using the Sun and Abraham (2021) estimator (an alternative approach to addressing treatment-effect heterogeneity), as well as the following two-way fixed effects estimator:

$$y_{ist} = \alpha_s + \beta_t + \sum_{k=-10}^{-2} \delta_k \mathbb{1}\left[t - t_c = k\right] + \sum_{k=0}^{10} \tau_k \mathbb{1}\left[t - t_c = k\right] + \epsilon_{ist} \quad (1)$$

where y_{ist} is a measure of anti-vaccine discourse or smallpox mortality, α_s and β_t are state and year fixed effects, respectively, and t_c is the year for which a state Supreme Court first upholds a pro-vaccine law (which can be thought of as infinity for never-treated states). The error term is ϵ_{ist}. We find similar results using all three approaches.

[31] Freyaldenhoven et al. (2019) argue that uniform confidence intervals are more likley to contain the actual event-time relationship compared to point-wise confidence intervals.

[32] To increase computational speed, we collapse newspaper pages to the month-year-state cell and weight by the number of pages in each cell, which is mathematically identical to running the dis-aggregated version.

The primary assumptions necessary to view these estimates as causal are (1) no anticipation of treatment, and (2) parallel trends in potential outcomes. We view no anticipation as being a reasonable assumption in that the general public would be unlikely to know how a court would rule on its first smallpox vaccination case. Because we estimate annual-level treatment effects, the no-anticipation assumption assumes that if the general public could "read the writing on the wall" based on reports during legal arguments, that such insights would have had to occur during the same calendar year the court decision was made. While the parallel-trends assumption is fundamentally untestable, we examine whether pre-trends were approximately parallel before the court decision.

There are several possible threats to our identification strategy. First, trends in potential outcomes might not be parallel, especially over longer periods of time. Slight deviations from parallel trends may cause bias that compounds over time, implying that the bias associated with the short-run effects may be small but become more severe as one moves farther away from the intervention date (Roth, 2022). We consider whether our results are robust to small violations of the pre-trends assumption. Second, we are assuming that states are not influenced by state-level court decisions in neighboring states. Spillovers to neighboring states are possible as, for example, anti-vaccinationists may express outrage at pro-vaccine court decisions even if the rulings do not directly affect them. This is especially true in communities that border two or more states, as many of these newspapers may have been published in multi-state media markets. In our view, spillovers would most likely bias our estimates towards zero.

Lastly, it is possible that our results are biased because state-level court cases are correlated with other smallpox interventions that happen at the same time. The most obvious example of this would be if a state legislature passed a law and the law was immediately challenged in court, we might be confounding the effect of the court case with the legislature's actions. If the court case was filed shortly after the law passed, we would effectively be estimating the joint effect of the legislation and court case combined. In this case, the treatment effect could be considered the effect of smallpox vaccine mandates in general, rather than just judicial enforcement of mandates.[33]

4.2 Regression Discontinuity in Time

All states were affected by *Jacobson v. Massachusetts*, and thus we cannot estimate the effect of that decision using difference-in-differences. For this purpose, we turn to a regression discontinuity in time approach. Let $S(1)_{it}$ be the hypothetical discourse of newspaper article i written in time t in a world in which the Supreme Court holds compulsory vaccination constitutional and $S(0)_{it}$ be the counterfactual world. We view the state of the world as switching from 0 to 1 on February 20, 1905, which we code as $t = 0$.

The treatment effect is:

$$\tau = E\left[S(1)_{it} - S(0)_{it} | t = 0\right]. \tag{2}$$

The identifying assumption is that all unobserved factors that influence vaccine discourse vary continuously from the days and weeks before the announcement of the decision to the days and weeks after. If this assumption holds, τ is the short-run effect of the court's decision on vaccine discourse. Because the estimated effect is local, it identifies only the short-run effects of the court decision and not the medium- or long-run effects.

The regression-discontinuity (RD) in time approach is similar to but distinct from an interrupted time series (ITS). The data we have are not a proper time series—some days have many articles mentioning smallpox while others have none, and gaps are not evenly spaced. There are other data-generating features that are also more similar to a traditional RD than an ITS. Most importantly, a sudden increase of articles in response to the Supreme Court decision can cause heaping or bunching after the threshold. Critically, we rely on conventional asymptotics in N—it is possible for the number of newspaper pages to become

[33] It should be noted that state-level legislation was not a prerequisite for a smallpox court case. Municipal court cases could also be challenged in state Supreme Courts.

arbitrarily large within a narrow bandwidth—as opposed to unconventional asymptotics in T that are sometimes required using a regression discontinuity-in-time framework (Hausman and Rapson, 2018).

We generate non-parametric RD estimates using the methods from Calonico et al. (2017).[34] We limit the RD-in-time approach to newspaper pages that appear within 1,000 days of the *Jacobson* decision, although many of them were not used because they did not fall within the optimal bandwidth. We pick a separate bandwidth for the left and right sides of the discontinuity that minimize the mean-squared error of the estimate.

4.3 Measurement Error in Anti-Vaccine Discourse

Because we use language-based proxies for anti-vaccine discourse and smallpox mortality, there is likely significant measurement error in the dependent variable. While classical measurement error (CME) in the dependent variable does not cause bias, our application is poorly described by CME. It is better described as an optimal prediction error problem (Hyslop and Imbens, 2001).

Let w_i be the bag-of-words vector, which is a noisy signal of discourse Y_{true}. In our case, we can view predicted discourse $Y_{measured}$ as an estimate of $E(Y_{true}|w_i)$. The intuition is that $Y_{measured}$ is our best estimate of discourse given the information contained in the language vector. In this case, $Y_{measured} = Y_{true} + \eta$, but it is more likely that $Cov(Y_{measured}, \eta) = 0$ instead of $Cov(Y_{true}, \eta) = 0$ (as is the case in classical measurement error). To see this, note that $Y_{measured}$ can be thought of as the part of Y_{true} that is explained by language (w_i), and η can be thought of as the part that cannot be explained by the bag-of-words vector. Thus, the two must be uncorrelated with each other. Hyslop and Imbens (2001) show that under these assumptions, a regression of $Y_{measured}$ on X yields estimates that are biased towards zero. An additional result of their paper is that unbiasedness can be restored if we predict Y_{true} using not only the noisy signal w_i, but also the treatment variable X. That is, we get

[34] The choice of bandwidth results in a bias-variance trade off in which small bandwidths result in low bias but high variance and larger bandwidths result in high bias but low variance.

unbiasedness if we set $Y_{measured} = E(Y_{true}|w_i, X)$ (Hyslop and Imbens, 2001).

Our intuition is that since our estimation equations are functions of state and year indicators, measures of sentiment that do not condition on state and year (BoW1 and BoW2) may be biased towards zero. Additionally, measures that condition on state and year (BoW3 and BoW4) are less likely to be biased. In practice, all four measures tend to provide similar estimates of the dynamic treatment effects.

5 Results

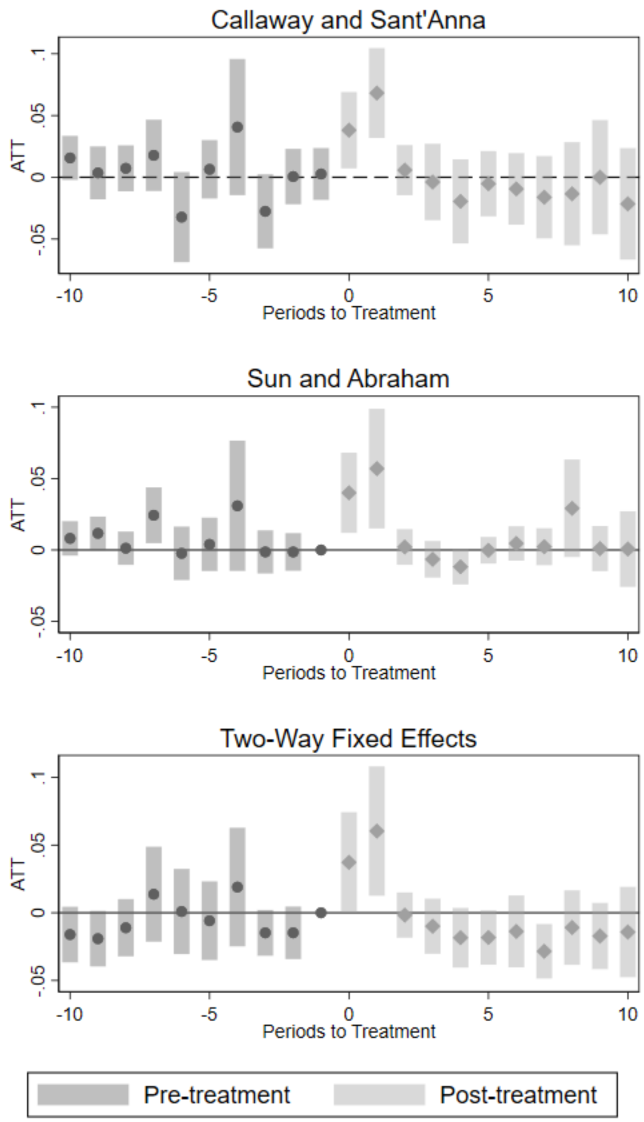
5.1 Discourse and State-Level Supreme Court Decisions

The main anti-vaccine discourse difference-in-differences results appear in Figure 3. The darker bars represent 95% confidence intervals for the pre-treatment period and act as a test of whether parallel trends held in the years before court decisions. The lighter bars represent dynamic treatment effects. Each graph presents results using a different estimation method described in Section 4.1. Panel A presents results from the Callaway and Sant'Anna estimator, Panel B presents the Sun and Abraham estimator, and Panel C presents the two-way fixed effects event-study specification. The dependent variable is the predicted anti-vaccine discourse using the bag-of-words frequency approach.

For all three methods, the estimates suggest that anti-vaccine discourse increased during the calendar year of a pro-vaccine court decision as well as the calendar year after. There is no consistent evidence of pre-trends (only one period is significant in one of the three panels), and no evidence of a long-run effect beyond the second year. Because all estimation strategies provide similar estimates and the Callaway and Sant'Anna estimator allows for arbitrary group- and time-level heterogeneity for repeated cross-sectional data, we focus on the Callaway and Sant'Anna estimator for the remainder of the difference-in-differences analysis.

The estimates suggest that anti-vaccine discourse increased by 4 percentage points during

Figure 3: The effect of court decisions on anti-vaccine discourse



Notes: Bars represent 95% confidence intervals. Standard errors are clustered at the state level. Callaway and Sant'Anna estimates use uniform confidence intervals. Includes data from the *Chronicling America* archive from 1880-1922. Court decision data come from Fowler (1927).

the year of a court decision and 6 percentage points during the year after a court decision. To put the magnitude of these estimates into context, the average newspaper page has a 13% chance of containing anti-vaccine discourse. The predicted discourse measures also have a standard deviation of approximately 0.13, suggesting that anti-vaccine discourse increased by about a third of a standard deviation in the first year, and half of a standard deviation in the second year.

We also estimate a range of alternative specifications. Figure 4 shows similar results for all four measures of anti-vaccine discourse. The estimates suggest that anti-vaccine discourse increased during the first two years following a court decision that upheld a pro-vaccine law. Estimates are statistically significant for both years for all four measures. Appendix Figure A.5 presents an analogous graph using the not-yet-treated states as the comparison groups and finds very similar results to Figure 4.

It is possible that anti-vaccine discourse may have been affected by the initial passage of laws that were later challenged in court. We see some insignificant evidence that it was increasing for a few years preceding the decision. However, these suggestive pre-trends only appear in some of the specifications. Additionally, Appendix Figure A.6 presents results using the Callaway and Sant'Anna estimator with long differences. Here, the pre-period looks less noisy, the pre-trends look closer to parallel, and we similarly see an increase in anti-vaccine discourse in the first two years following a state Supreme Court decision.[35]

It is possible that the reduction in anti-vaccine discourse after the initial two years may be because compulsory vaccination may have no longer been enforced. Many of the court decisions examined applied only during outbreaks, and compulsory vaccination may have no longer been a salient issue after the outbreaks passed. It is also possible that if smallpox vaccination was continually enforced, anti-vaccine sentiment may have persisted for longer.

We next consider whether our results are robust to violations of the parallel trends assumption. Although we do not find statistically significant evidence of pre-trends, it is

[35]It is not clear whether short- or long differences are preferred in our situation. To be conservative, we choose to present short differences as our main specification.

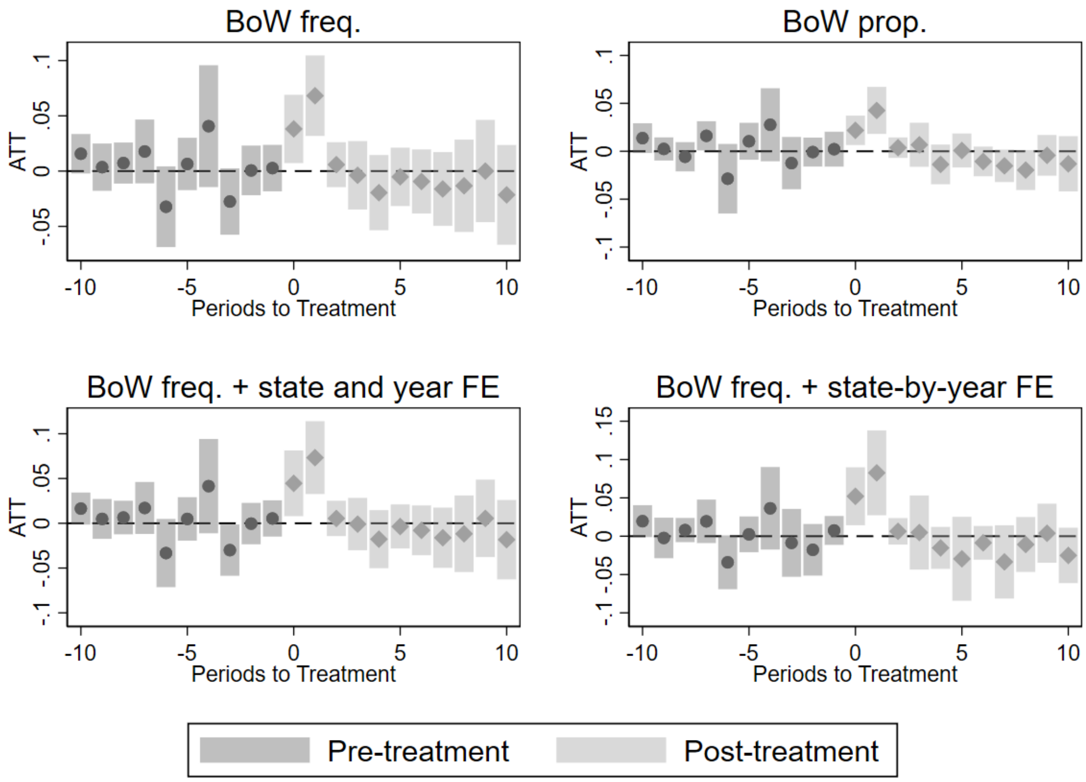
possible that such tests are underpowered. Even small violations of the pre-trends assumptions can cause significant bias (Roth, 2022; Rambachan and Roth, 2023). We explore this issue using the pre-trends test from Roth (2022), which is implemented using the Bravo and Roth (2023) Stata package. Appendix Figure A.7 displays the results of the test. The estimates come from a two-way fixed effects estimator. The red line is the pre-trend line that can be detected with power 50% give our standard errors; the blue dashed line shows the expected event study coefficients if the red line is the true pre-trend. Standard errors are clustered at state level. The year of a court decision, our estimate is on the boundaries of statistical significance. The year after the court decision, we still see a statistically significant increase in anti-vaccine sentiment. Pre-trends of this size are also not consistent with the long-run return to baseline that we see. Taken together, this tests suggests that pre-trends alone cannot account for the rise in anti-vaccine sentiment.

Lastly, Appendix Figure A.8 shows results if we drop states where the anti-vaccine movement achieved legislative success (Utah, North Dakota, Washington, Wisconsin, California, and New York). Here we find that point estimates in the two years following a decision are smaller. Note that the estimates are no longer statistically different from zero (or from the estimates in our main specification). This is consistent with the hypothesis that the states that had the largest anti-vaccine discourse responses were also the ones most likely to, for example, repeal the law in question.

5.2 Mortality and State-Level Supreme Court Decisions

The main event study results for smallpox mortality appear in Figure 5. The treatment is when a state-level Supreme Court upholds its first compulsory smallpox vaccination law. The bars represent 95% confidence intervals. For the mortality analysis, each observation is a state-year cell. The top panel weights each cell by the population (interpolated between census years). The middle panel weights by the number of newspaper pages in that state-year cell. The third panel is unweighted. These estimates use the Callaway and Sant'Anna

Figure 4: Event study estimates of court decisions on anti-vaccine discourse



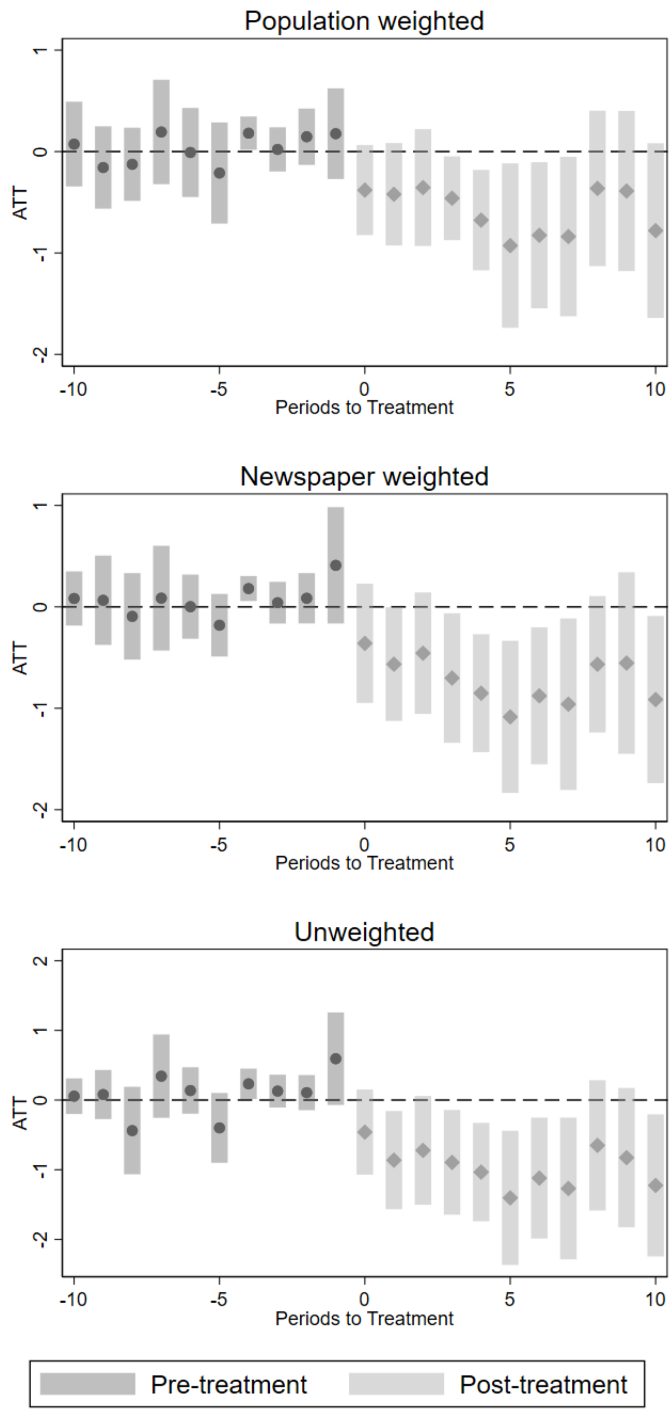
Notes: Estimates use the Callaway and Sant'Anna (2021) estimator. This figure uses never-treated states as the control group. Uniform 95% confidence intervals are based on wild bootstrapped standard errors clustered at the state level.

estimator.

Following treatment, mortality falls for all three specifications. The decline in mortality peaks five years after the court decision, with estimates suggesting that mortality fell between 0.5 and 1 death per 100,000. After 10 years, the treatment effect starts to decline towards zero but remains negative. One possibility is that as smallpox rates declined nationally, the benefits of vaccination declined as well. To put the rates into perspective, Figure 6 presents the results using the inverse hyperbolic sine of smallpox mortality.[36] The results suggest that mortality declined by 30-50% depending on the specification following compulsory vaccination.

[36]These results must be interpreted with caution, as a recent literature has emerged regarding problems with using inverse hyperbolic sine in this way. See Aihounton and Henningsen (2021) for further details.

Figure 5: The effect of compulsory vaccination court decisions on smallpox mortality



Notes: Smallpox mortality is the estimated number of deaths per 100,000 using language in newspaper data. The event study is estimated using Callaway and Sant'Anna (2021). Uniform 95% confidence intervals are based on wild bootstrapped standard errors clustered at the state level.

Almost all of the pre-treatment periods are statistically indistinguishable from zero, and there are points above and below zero. We note that the majority of the points in the years immediately preceding the treatment are above zero. If we take the point estimates literally, this could be because, for example, some of the laws or decisions happened following small outbreaks. If this were the case, we would still view the results as showing large declines in mortality relative to the period between 5 and 10 years prior to treatment.

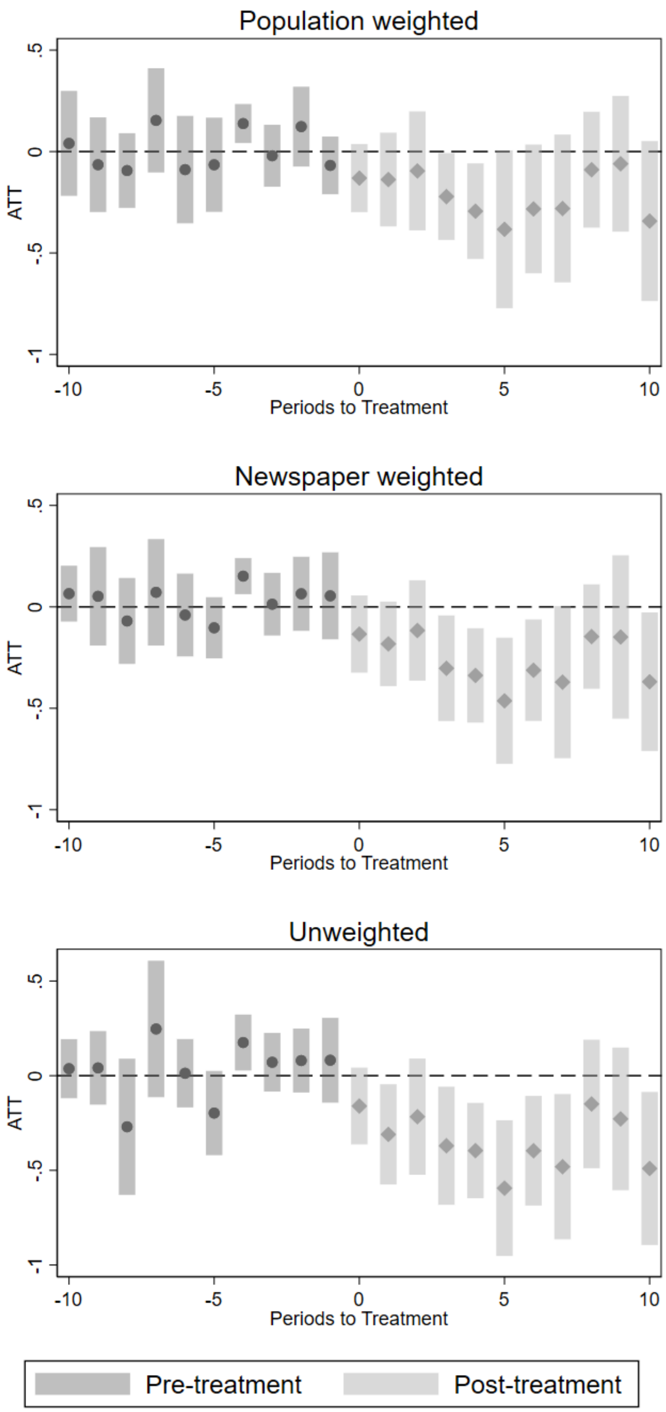
The appendix presents a series of robustness tests. In Figure A.9, we present Callaway and Sant'Anna (2021) estimates using long differences instead of short differences during the pre-period. The pre-trends in this case are still approximately flat, but lie just above zero. We interpret this as evidence that people may have had increased vaccination rates before courts ruled on these cases, possibly when state and local courts passed compulsory vaccination laws.

Figure A.10 presents results in which we drop Utah, North Dakota, Washington, Wisconsin, California, and New York. These states either repealed compulsory vaccination laws, passed laws preventing compulsory vaccination, or did not enforce compulsory vaccination (Colgrove, 2006).[37] As we might expect, point estimates are generally larger when we drop states that, for example, repealed the law subsequent to a pro-vaccine decision. Note, however, that estimates are not generally statistically different from those using the full sample.

Finally, we consider whether the mortality estimates are robustness to violation of parallel pre-trends (Roth, 2022; Rambachan and Roth, 2023). Appendix Figure A.11 presents the results of the Roth (2022) pre-trends test. The largest hypothesize pre-trends that have a power 0.5 are of the opposite sign. For years four, five and six after the court decision, the point estimates are quite different from what the pre-trend line would suggests (and in this two-way fixed effects specification, on the boundaries of statistically different from zero). This alleviates concerns that these results are driven by non-parallel pre-trends.

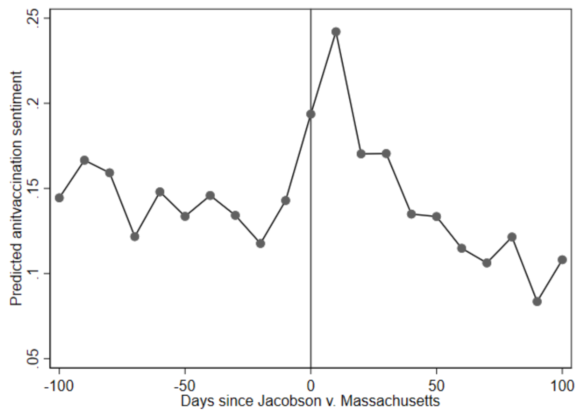
[37] Four of these states are in the treatment group, with North Dakota and Wisconsin in the control.

Figure 6: The effect of compulsory vaccination court decisions on inverse hyperbolic sine of smallpox mortality



Notes: Smallpox mortality is the estimated number of deaths per 100,000 using language in newspaper data. The event study is estimated using Callaway and Sant'Anna (2021). Uniform 95% confidence intervals are based on wild bootstrapped standard errors clustered at the state level.

Figure 7: Trends in anti-vaccine discourse around *Jacobson v. Massachusetts*



Notes: Each dot is a ten-day bin. *Jacobson v. Massachusetts* was decided on February 20, 1905.

5.3 Discourse and *Jacobson v. Massachusetts*

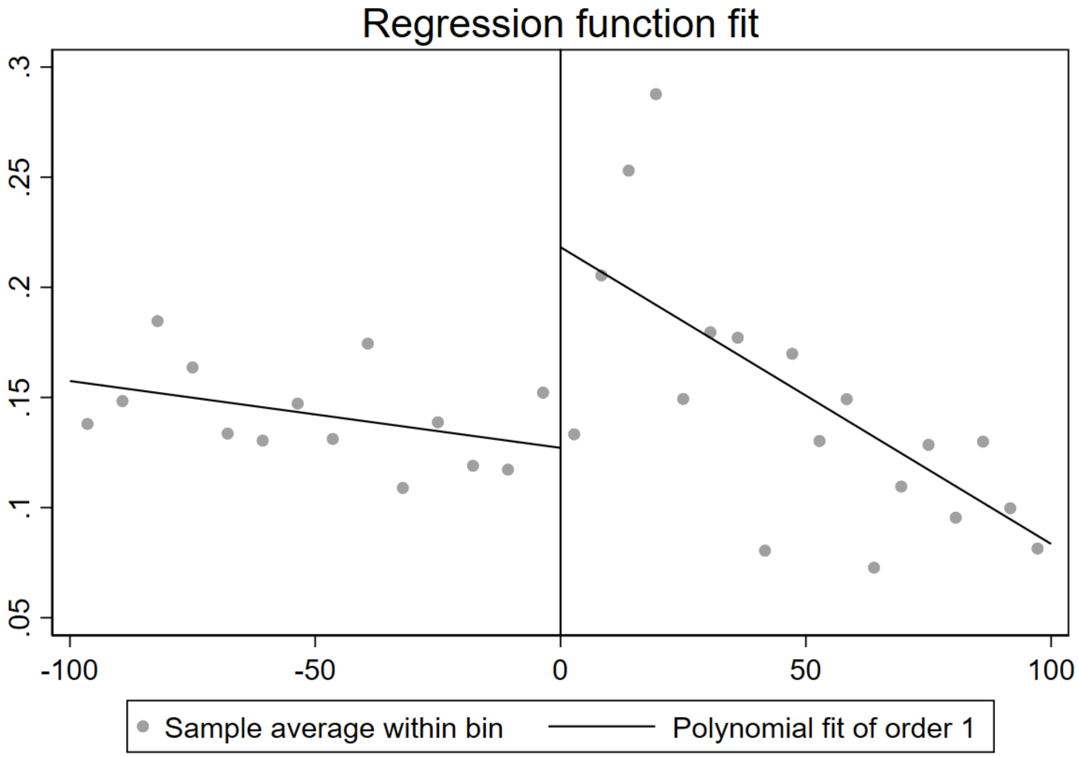
Figure 7 presents trends in anti-vaccine discourse around *Jacobson v. Massachusetts*. Every point is the average of a ten-day bin.[38] Anti-vaccine discourse is roughly constant in the 100 days before the court decision, spikes for the next 40 days, and then roughly returns to trend. Anti-vaccine discourse peaks 10-19 days after the court decision.

Figure 8 shows a standard RD plot with linear trends on each side of the discontinuity. Anti-vaccine discourse is approximately 7 percentage points higher in the days and weeks immediately after *Jacobson v. Massachusetts*.

The formal statistical tests of the discontinuity appear in Table 3 for all four of our discourse measures. The first row presents the conventional RD estimates, while the second row uses the Calonico et al. (2017) bias correction. For all measures, anti-vaccine discourse increases by between 3 and 9 percentage points. All eight estimates are significant at conventional levels (three at the 1% level and five at the 5% level). These estimates correspond to the short-run effect of the decision on anti-vaccine discourse and not the medium- or long-run effect. Note that consistent with the more muted discourse trends for the proportional bag-of-words measure in Figure 1, we find smaller point estimates using the proportional bag-

[38]The first bin contains days 0 to 9, the second bin 10 to 19, and so on.

Figure 8: RD-in-time estimates of the effects of *Jacobson v. Massachusetts* on anti-vaccine sentiment



Notes: Jacobson v. Massachusetts was decided on February 20, 1905. The regression discontinuity plot uses the methods in Calonico et al. (2017). The dependent variable is predicted anti-vaccine sentiment from the LASSO BoW 1 model.

of-words in Table 3. We prefer the frequency measure because it has higher out-of-sample fit.

Figure 9 presents the McCrary (2008) test for bunching on one side of the threshold. This test is often used as a test of strategic manipulation of the running variable. In our context, we would expect bunching when public interest in the vaccine is heightened, such as during outbreaks of smallpox or around court decisions. Bunching to the left side of the threshold would suggest articles about the case were dominated by pre-trial discussions of the arguments, whereas bunching to the right would suggest that reactions to the verdict dominated. In our case, we do not find evidence of bunching on either side of the threshold. The p-value associated with the null hypothesis of no bunching is a statistically insignificant

Table 3: Regression discontinuity estimates of *Jacobson v. Massachusetts* on anti-vaccine sentiment

	(1)	(2)	(3)	(4)
Conventional treatment effect	0.0758***	0.0309**	0.0815***	0.0543**
	(0.0254)	(0.0144)	(0.0244)	(0.0228)
Robust bias-corrected	0.0874***	0.0346**	0.0947***	0.0585**
	(0.0279)	(0.0159)	(0.0261)	(0.0260)
N	5304	5304	5304	5304
N to the left	703	685	708	749
N to the right	385	461	376	446
Left bandwidth	255.3	248.1	257.7	276.9
Right bandwidth	155.9	204.9	149.4	192.4
BoW representation	freq.	prop.	freq.	freq.
Fixed effects	None	None	State and Year	State-by-Year

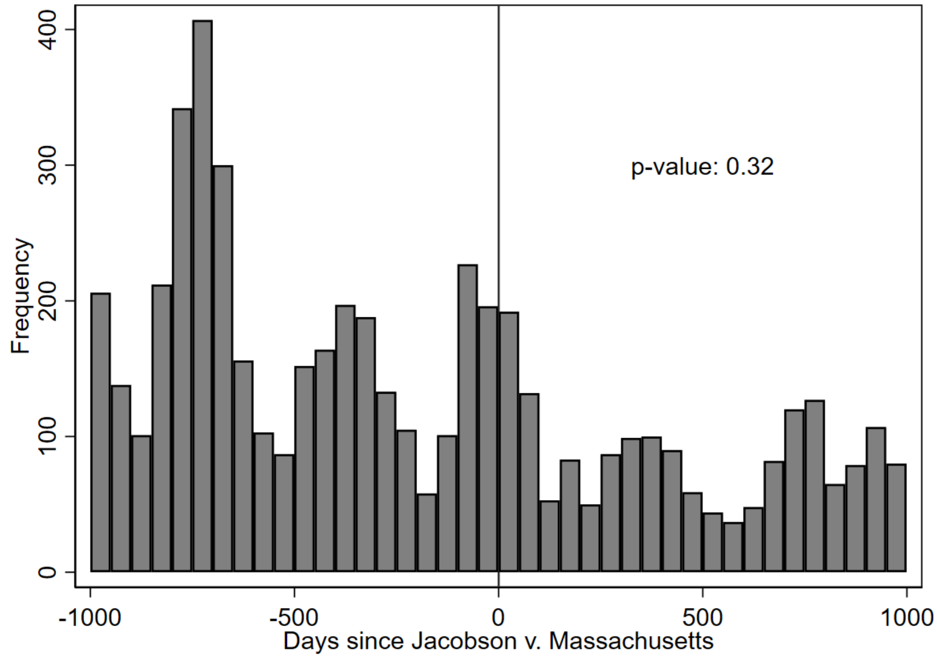
Notes: Treatment effect estimates using the Calonico et al. (2017) estimator. Standard errors are clustered at the state level. A separate bandwidth was chosen to the left and right of the threshold. The dependent variable is predicted anti-vaccine sentiment from the LASSO BoW 1 model.

0.32. The rise in articles approximately two years before *Jacobson v. Massachusetts* likely reflects the smallpox epidemic of 1901–1903 (Albert et al., 2001).

Appendix Table A.4 presents three robustness tests that include newspaper circulation data. A research assistant hand-entered data from the *N.W. Ayer and Son's Newspaper Directory of 1905*, which published circulation data for the majority of US newspapers.[39] Panel A of Table A.4 controls for circulation. For all four discourse measures, the treatment effect is positive and statistically significant. The size of the treatment does not meaningfully change, ranging from approximately 3 to 9 percentage points. Panels B and C present results for newspapers with above- and below-median circulation only. With the smaller sample sizes, these results are generally not statistically significant, but all are positive and range from 1.3 percentage points to 8 percentage points.

[39]We do not use circulation data for our baseline specification as the information becomes less reliable as we move away from 1905. Additionally, many newspapers in our sample did not exist in 1905 (or were renamed or merged). Collecting the data for all newspaper-years was cost prohibitive.

Figure 9: Histogram of newspaper articles around *Jacobson v. Massachusetts*



Notes: McCrary (2008) test for a discontinuity in the density of articles on each side of the *Jacobson v. Massachusetts* date.

5.4 Hand-Collected *Jacobson* Evidence

While it was cost prohibitive to have research assistants read all articles from 1880-1920, research assistants were able to review every article within 300 days of the *Jacobson v. Massachusetts* decision (the approximate optimal bandwidth from the previous section) and answer a richer set of questions. These questions include whether an article contained anti-vaccine discourse, whether the article itself was anti-vaccine, or whether the article described anti-vaccine behavior. Assistants also recorded pro-vaccine analogs of those questions, as well as whether the article mentioned the *Jacobson* decision, court decisions in general, or compulsory vaccination laws.

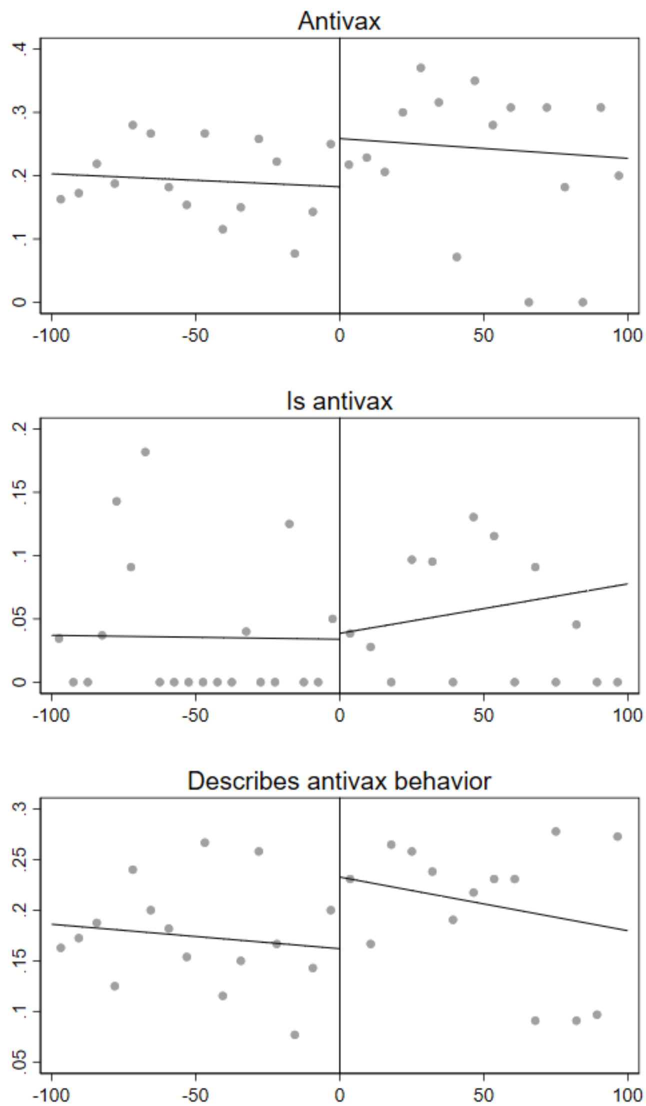
The RD plots are in Figures 10, 11, and 12. It appears that the increase in anti-vaccine discourse following the *Jacobson* decision is more driven by descriptions of anti-vaccine behavior and protests rather than anti-vaccine propaganda. There was also a decline in pro-vaccine articles and articles that describe pro-vaccine behavior. We also observe an increase in articles about *Jacobson*, court decisions, and compulsory vaccine. There was little discussion of the *Jacobson* case before the decision.

Corresponding regression results are in Table 4. Panel A presents results for anti-vaccine related categories, panel B presents results for pro-vaccine related categories, and panel C presents results for judicial categories. Estimates suggests that articles with anti-vaccine discourse increased by between 5 and 12 percentage points, but only the larger estimate is statistically significant. Most of this increase is driven by anti-vaccine behavior, which increased by between 4 and 10 percentage points (again, only the larger point estimate is statistically significant). We also find that pro-vaccine articles decreased by between 11 and 19 percentage points, both of which are statistically significant. This appears to be driven by both a decrease in articles that are pro-vaccination and a decrease in articles that describe pro-vaccine behavior. Articles that mention *Jacobson* increased by between 12 and 17 percentage points, and articles that mentioned courts increased by between 10 and 12 percentage points (all four estimates are significant). Articles that mentioned compulsory vaccination increased by a statistically insignificant 5 to 13 percentage points.

6 Discussion and Conclusion

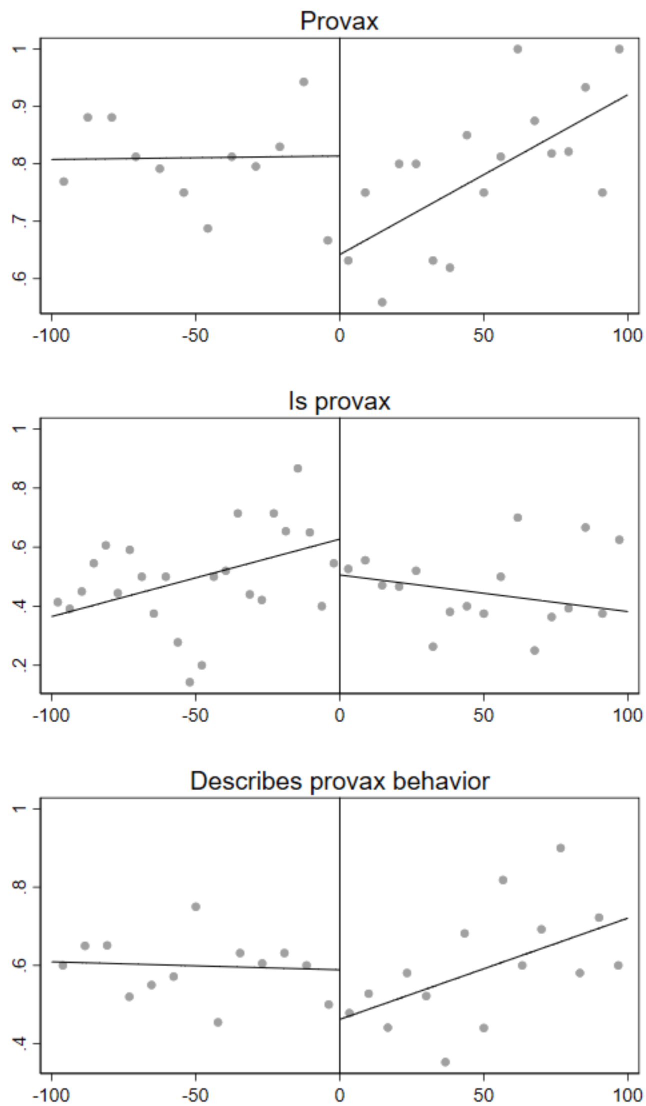
This paper first develops a methodology for predicting the vaccine discourse of historical newspaper articles and then estimates how anti-vaccine discourse changes following major court decisions. We employed research assistants to categorize vaccine discourse in a 5% sample of 48,000 newspaper pages discussing smallpox vaccines. We then use machine-learning techniques to predict the anti-vaccine discourse in the other 95%. Using the predicted data set, we show that court decisions upholding pro-vaccine laws increase anti-vaccine discourse in the short run. We do not find evidence that anti-vaccine discourse increases in the long run. After two years of elevated rates, anti-vaccine discourse returns to baseline.

Figure 10: Hand-collected data near *Jacobson*: Anti-vaccination characteristics



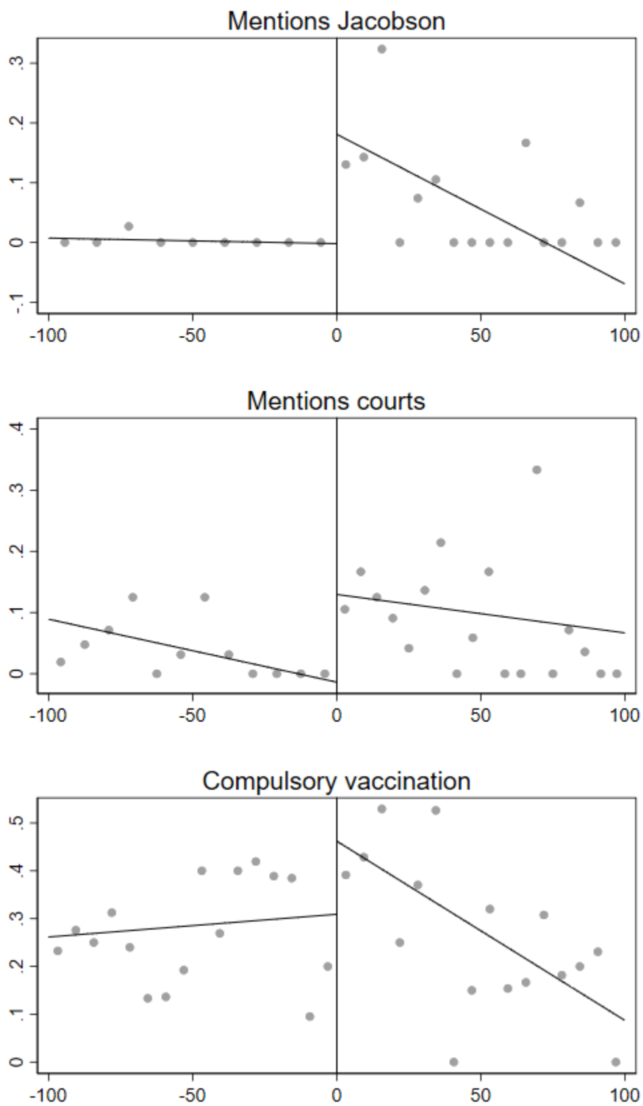
Notes: Data are human classified. Panel A asks RAs whether a page contains any anti-vaccine discourse. Panel B asks whether the article itself is anti-vaccination. Panel C asks whether the article contains descriptions of anti-vaccination behavior or protests.

Figure 11: Hand-collected data near *Jacobson*: Pro-vaccination characteristics



Notes: Data are human classified. Panel A asks RAs whether a page contains any pro-vaccine discourse. Panel B asks whether the article itself is pro-vaccination. Panel C asks whether the article contains descriptions of pro-vaccination behavior or protests.

Figure 12: Hand-collected data near *Jacobson*: Judicial characteristics



Notes: Data are human classified. Panel A asks whether the article mentions *Jacobson v. Massachusetts*. Panel B asks whether the article mentions courts generally speaking. Panel C asks whether the article mentions compulsory vaccination.

Table 4: The effect of *Jacobson* on hand-collected characteristics

	Panel A		
	(1)	(2)	(3)
	Antivax	Is antivax	Describes antivax
Conventional treatment effect	0.0515	0.0135	0.0361
	(0.0433)	(0.0171)	(0.0390)
Robust bias-corrected	0.118**	0.0183	0.102*
	(0.0594)	(0.0239)	(0.0566)
	Panel B		
	(1)	(2)	(3)
	Provax	Is provax	Describes provax
Conventional treatment effect	-0.113**	-0.0890	-0.0750
	(0.0442)	(0.0588)	(0.0569)
Robust bias-corrected	-0.193***	-0.136*	-0.150*
	(0.0643)	(0.0771)	(0.0836)
	Panel C		
	(1)	(2)	(3)
	Jacobson	Court	Compulsory
Conventional treatment effect	0.119***	0.0954**	0.0511
	(0.0303)	(0.0391)	(0.0646)
Robust bias-corrected	0.170***	0.151***	0.128
	(0.0454)	(0.0430)	(0.0865)
N	1409	1409	1409
N to the left	813	813	813
N to the right	592	592	592

Notes: All bandwidths are 300 days. Dependent variables are human classified. Standard errors are clustered at the state level. Significance levels: $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

Similarly, we construct a machine-learning model to estimate smallpox mortality using newspaper language during the vital statistics era. We then use that model to predict mortality in the pre-vital statistics era. This analysis shows that compulsory vaccination was highly effective and that much of the decline in smallpox during this period can be attributed to compulsory vaccination.

Social Welfare

All-together, the meaningful amount of judicial backlash that we see did not ultimately prevent the smallpox vaccine from greatly reducing mortality. However, it is also important to note that some states repealed their compulsory vaccine laws. If we drop those states from our analysis, we find that the point estimates for increases in anti-vaccine discourse drop. This suggests that there may be a tipping point—above a certain level of opposition, we may see governments reverse their mandates and end an intervention. Unfortunately, we do not have enough data to definitively test this hypothesis.

The results suggest that compulsory vaccine court decisions reduced smallpox mortality by approximately 40%. To put that decline into perspective, we conduct a back-of-the-envelope cost-benefit analysis. The 1902 vital statistics contains mortality data from ten states, seven of which did not already have a pro-vaccine court decision. In those seven states, 809 people died of smallpox in 1902. A 40% reduction in smallpox mortality would suggest that 324 lives could have been saved in those seven states in 1902 alone. From 1900 to 1922, 3,328 people died of smallpox in states with both mortality data and no court decision. If 40% of those were saved, that would amount to 1,331 lives. This analysis ignores other benefits from the reduction of smallpox, such as reduced morbidity, lost productivity, and negative non-mortality costs that spillover to family, friends, and community members. It also ignores mortality reductions from states without vital statistics data.

Whether compulsory smallpox vaccination improved social welfare depends on a few additional considerations. First, it is difficult to measure the welfare effects for individuals who have no choice about medical interventions they receive. It is also the case that several states in the post-*Jacobson* era passed laws that, for example, made compulsion explicitly illegal. These states may have ended up with fewer vaccinations. Moreover, to the extent that compulsion invites hostility towards the medical establishment, there are likely additional costs that we are not well-positioned to measure. Finally, the relative magnitudes of the costs and benefits may change as, for example, the prevalence or severity of a disease changes.

Comparison with Covid-19

While our setting has many similarities to the Covid-19 pandemic, smallpox vaccine benefits were much higher than Covid-19 vaccine benefits. The case fatality rate for smallpox far exceeded the case fatality rates for even the highest risk Covid-19 groups, and the smallpox vaccine was more likely to prevent death. Additionally, the smallpox vaccine provided protection for a period of seven to ten years—much longer than the Covid-19 vaccines. As of this writing, the most commonly used Covid-19 vaccines in the United States require two initial shots, followed by one or two boosters.[40]

Additionally, the costs of receiving the smallpox vaccine were much higher than the costs of the Covid-19 vaccine. While the Covid-19 vaccines have been demonstrated to be safe and pose few health risks, the smallpox vaccine did not undergo similar clinical trial testing. Further, arm-to-arm vaccination had the potential to spread other diseases, with syphilis being an especially common concern at the time.

Finally, there are important contextual differences. Today, anti-vaccine propaganda commonly spreads through social media and the Internet. This is fundamentally different than how anti-smallpox vaccine propaganda spread, which was largely through newspapers, pamphlets, books, and local meetings. It is also the case that people may have been more accustomed to living with infectious disease risk during the late nineteenth and early twentieth centuries.[41] Citizens may have thought about smallpox epidemic risk in a different way than modern society thinks about Covid-19. Notably, states have been more likely to respond to Covid-19 with "nudge" programs like Ohio's "Vax-a-Million" lottery than with compulsion. Nudge programs have been less controversial, though they likely have also spurred fewer vaccinations (Brehm et al., 2022).

With these caveats in mind, there are many similarities between the two diseases. Both

[40] It is likely Covid-19 vaccines provide limited protection against infection, but stronger protection against mortality. Therefore, the positive externalities associated with smallpox vaccination may have also been larger.

[41] Tuberculosis, typhoid fever, and pneumonia were common causes of death. Yellow fever and cholera pandemics were not considered "once in a century" shocks.

posed serious health risks, a vaccine was available, and a subset of individuals (for a diverse set of reasons) resisted the vaccine. Anti-vaccine sentiment was often based on misinformation from individuals who had little understanding of the underlying science. When authorities compelled individuals to get vaccinated, there was often backlash, as individuals believed their freedom was being infringed upon, an effect that we document in this study for the case of smallpox.

References

Abramitzky, Ran, Leah Platt Boustan, and Katherine Eriksson, "A nation of immigrants: Assimilation and economic outcomes in the age of mass migration," *Journal of Political Economy*, 2014, *122* (3), 467–506.

Abrevaya, Jason and Karen Mulligan, "Effectiveness of state-level vaccination mandates: evidence from the varicella vaccine," *Journal of health economics*, 2011, *30* (5), 966–976.

Acton, Riley K, Wenjia Cao, Emily E Cook, Scott A Imberman, and Michael F Lovenheim, "The Effect of Vaccine Mandates on Disease Spread: Evidence from College COVID-19 Mandates," Technical Report, National Bureau of Economic Research 2022.

Aihounton, Ghislain BD and Arne Henningsen, "Units of measurement and the inverse hyperbolic sine transformation," *The Econometrics Journal*, 2021, *24* (2), 334–351.

Albert, Michael R, Kristen G Ostheimer, and Joel G Breman, "The last smallpox epidemic in Boston and the vaccination controversy, 1901–1903," 2001.

Alsan, Marcella and Marianne Wanamaker, "Tuskegee and the health of black men," *The quarterly journal of economics*, 2018, *133* (1), 407–455.

Antwi, Yaa Akosa, Asako S Moriya, and Kosali Simon, "Effects of federal policy to insure young adults: evidence from the 2010 Affordable Care Act's dependent-coverage mandate," *American Economic Journal: Economic Policy*, 2013, *5* (4), 1–28.

Ash, Elliott and Stephen Hansen, "Text algorithms in economics," *Unpublished manuscript*, 2023.

Athey, Susan and Guido W Imbens, "Machine learning methods that economists should know about," *Annual Review of Economics*, 2019, *11*, 685–725.

Atwood, Alicia, "The long-term effects of measles vaccination on earnings and Employment," *American Economic Journal: Economic Policy*, 2022, *14* (2), 34–60.

Ball, Carlos A, "The backlash thesis and same-sex marriage: Learning from Brown v. Board of Education and its aftermath," *Wm. & Mary Bill Rts. J.*, 2005, *14*, 1493.

Baumol, William J, "On taxation and the control of externalities," *The American Economic Review*, 1972, *62* (3), 307–322.

Beach, Brian, Karen Clay, and Martin Saavedra, "The 1918 influenza pandemic and its lessons for COVID-19," *Journal of Economic Literature*, 2022, *60* (1), 41–84.

Betsch, Cornelia and Robert Böhm, "Detrimental effects of introducing partial compulsory vaccination: experimental evidence," *The European Journal of Public Health*, 2016, *26* (3), 378–381.

Bleakley, Hoyt, "Malaria eradication in the Americas: A retrospective analysis of childhood exposure," *American Economic Journal: Applied Economics*, 2010, *2* (2), 1–45.

Bravo, Mauricio Caceres and Jonathan Roth, "PRETRENDS: Stata module to produce power calculations for pre-trends tests," 2023.

Brehm, Margaret E, Paul A Brehm, and Martin Saavedra, "The Ohio vaccine lottery and starting vaccination rates," *American Journal of Health Economics*, 2022, *8* (3), 387–411.

Callaway, Brantly and Pedro HC Sant'Anna, "Difference-in-differences with multiple time periods," *Journal of Econometrics*, 2021, *225* (2), 200–230.

Calonico, Sebastian, Matias D Cattaneo, Max H Farrell, and Rocio Titiunik, "rdrobust: Software for regression-discontinuity designs," *The Stata Journal*, 2017, *17* (2), 372–404.

Carpenter, Christopher S and Emily C Lawler, "Direct and spillover effects of middle school vaccination requirements," *American Economic Journal: Economic Policy*, 2019, *11* (1), 95–125.

Carrera, Mariana, Emily C Lawler, and Corey White, "Population mortality and laws encouraging influenza vaccination for hospital workers," *Annals of Internal Medicine*, 2021, *174* (4), 444–452.

CDC, "Transmission," June 2016.

_ , "What is Smallpox?," June 2016.

_ , "History of smallpox," Feb 2021.

Chang, Lenisa V, "Information, education, and health behaviors: Evidence from the MMR vaccine autism controversy," *Health Economics*, 2018, *27* (7), 1043–1062.

Chapman, Jonathan, "The Causes and Consequences of the Anti-Vaccination Movement in Nineteenth-Century Britain," *Working paper*, 2023.

Chiou, Lesley and Catherine Tucker, "Fake news and advertising on social media: A study of the anti-vaccination movement," Technical Report, National Bureau of Economic Research 2018.

Churchill, Brandyn F, "How important is the structure of school vaccine requirement opt-out provisions? Evidence from Washington, DC's HPV vaccine requirement," *Journal of Health Economics*, 2021, *78*, 102480.

Colgrove, James, ""Science in a democracy": the contested status of vaccination in the Progressive Era and the 1920s," *Isis*, 2005, *96* (2), 167–191.

_ , *State of immunity: The politics of vaccination in twentieth-century America*, Vol. 16, Univ of California Press, 2006.

Costa, Dora L and Matthew E Kahn, "Death and the media: infectious disease reporting during the health transition," *Economica*, 2017, *84* (335), 393–416.

Djourelova, Milena, "Media persuasion through slanted language: Evidence from the coverage of immigration," 2020.

Dolan, Brian, "Unmasking history: Who was behind the anti-mask league protests during the 1918 influenza epidemic in San Francisco?," *Perspectives in Medical Humanities*, 2020, *5* (19).

Ferrara, Andreas and Price Fishback, "Discrimination, migration, and economic outcomes: evidence from World War I," *The Review of Economics and Statistics*, 2020, pp. 1–44.

Fontana, David and Donald Braman, "Judicial Backlash or Just Backlash-Evidence from a National Experiment," *Colum. L. Rev.*, 2012, *112*, 731.

Fowler, William, *Smallpox Vaccination Laws Regulations, and Court Decisions*, Washington, D.C.: United States Government Printing Office, 1927.

Freyaldenhoven, Simon, Christian Hansen, and Jesse M Shapiro, "Pre-event trends in the panel event-study design," *American Economic Review*, 2019, *109* (9), 3307–3338.

Fullerton, Don and Garth Heutel, "The general equilibrium incidence of environmental mandates," *American Economic Journal: Economic Policy*, 2010, *2* (3), 64–89.

Gani, Raymond and Steve Leach, "Transmission potential of smallpox in contemporary populations," *Nature*, 2001, *414* (6865), 748–751.

García-Jimeno, Camilo, Angel Iglesias, and Pinar Yildirim, "Information Networks and Collective Action: Evidence from the Women's Temperance Crusade," *American Economic Review*, 2022, *112* (1), 41–80.

Gentzkow, Matthew and Jesse M Shapiro, "What drives media slant? Evidence from US daily newspapers," *Econometrica*, 2010, *78* (1), 35–71.

_ **, Bryan Kelly, and Matt Taddy**, "Text as data," *Journal of Economic Literature*, 2019, *57* (3), 535–74.

Goodman-Bacon, Andrew, "Difference-in-differences with variation in treatment timing," *Journal of Econometrics*, 2021, *225* (2), 254–277.

Gostin, Larry Ogalthorpe, *Public health law: power, duty, restraint*, Univ of California Press, 2000.

Greenhouse, Linda and Reva B Siegel, "Before (and after) Roe v. Wade: New questions about backlash," *Yale LJ*, 2010, *120*, 2028.

Hampton, Brock C, "Smallpox in relation to state vaccination laws and regulations," *Public Health Reports (1896-1970)*, 1943, pp. 1771–1778.

Hanlon, W Walker and Brian Beach, "Historical Newspaper Data: A Researcher's Guide and Toolkit," 2022.

Hansen, Peter Reinhard and Matthias Schmidtblaicher, "A dynamic model of vaccine compliance: how fake news undermined the Danish HPV vaccine program," *Journal of business & economic statistics*, 2021, *39* (1), 259–271.

Hausman, Catherine and David S Rapson, "Regression discontinuity in time: Considerations for empirical applications," *Annual Review of Resource Economics*, 2018, *10*, 533–552.

Holtkamp, Nicholas C., "The Economic and Health Effects of the United States' Earliest School Vaccination Mandates." PhD dissertation 2021.

Hyslop, Dean R and Guido W Imbens, "Bias from classical and other forms of measurement error," *Journal of Business & Economic Statistics*, 2001, *19* (4), 475–481.

Illinois Newspaper Project, "A Twentieth Century Church-State (in Illinois)," 2021.

Inwood, Kris, Chris Minns, and Fraser Summerfield, "Occupational income scores and immigrant assimilation. Evidence from the Canadian census," *Explorations in Economic History*, 2019, *72*, 114–122.

Kalichman, Seth C, Lisa A Eaton, Valerie A Earnshaw, and Natalie Brousseau, "Faster than warp speed: early attention to COVD-19 by anti-vaccine groups on Facebook," *Journal of Public Health*, 2022, *44* (1), e96–e105.

Keck, Thomas M, "Beyond backlash: Assessing the impact of judicial decisions on LGBT rights," *Law & Society Review*, 2009, *43* (1), 151–186.

Khataee, Hamid, Istvan Scheuring, Andras Czirok, and Zoltan Neufeld, "Effects of social distancing on the spreading of COVID-19 inferred from mobile phone data," *Scientific reports*, 2021, *11* (1), 1661.

Liu, Ying and Joacim Rocklöv, "The reproductive number of the Delta variant of SARS-CoV-2 is far higher compared to the ancestral SARS-CoV-2 virus," *Journal of travel medicine*, 2021.

Loughran, Tim and Bill McDonald, "When is a liability not a liability? Textual analysis, dictionaries, and 10-Ks," *The Journal of finance*, 2011, *66* (1), 35–65.

McCrary, Justin, "Manipulation of the running variable in the regression discontinuity design: A density test," *Journal of econometrics*, 2008, *142* (2), 698–714.

Moreno-Medina, Jonathan, Aurelie Ouss, Patrick Bayer, and Bocar A Ba, "Officer-Involved: The Media Language of Police Killings," Technical Report, National Bureau of Economic Research 2022.

Mullainathan, Sendhil and Jann Spiess, "Machine learning: an applied econometric approach," *Journal of Economic Perspectives*, 2017, *31* (2), 87–106.

Nordhaus, William D, "Economic growth and climate: the carbon dioxide problem," *The American Economic Review*, 1977, *67* (1), 341–346.

Nowak, Adam and Patrick Smith, "Textual analysis in real estate," *Journal of Applied Econometrics*, 2017, *32* (4), 896–918.

Ortiz-Sánchez, Elvira, Almudena Velando-Soriano, Laura Pradas-Hernández, Keyla Vargas-Román, Jose L Gómez-Urquiza, Luis Albendín-García et al., "Analysis of the anti-vaccine movement in social networks: a systematic review," *International journal of environmental research and public health*, 2020, *17* (15), 5394.

Oster, Emily, "Does disease cause vaccination? Disease outbreaks and vaccination response," *Journal of health economics*, 2018, *57*, 90–101.

Painter, Marcus and Tian Qiu, "Political beliefs affect compliance with covid-19 social distancing orders," *Covid Economics*, 2020, *4*, 103–123.

Porter, Martin F, "An algorithm for suffix stripping," *Program*, 1980.

Rambachan, Ashesh and Jonathan Roth, "A more credible approach to parallel trends," *Review of Economic Studies*, 2023, p. rdad018.

Richwine, Chelsea J, Avi Dor, and Ali Moghtaderi, "Do stricter immunization laws improve coverage? Evidence from the repeal of non-medical exemptions for school mandated vaccines," Technical Report, National Bureau of Economic Research 2019.

Riedel, Stefan, "Edward Jenner and the history of smallpox and vaccination," in "Baylor University Medical Center Proceedings," Vol. 18 Taylor & Francis 2005, pp. 21–25.

Roth, Jonathan, "Pretest with caution: Event-study estimates after testing for parallel trends," *American Economic Review: Insights*, 2022, *4* (3), 305–322.

Saavedra, Martin and Tate Twinam, "A machine learning approach to improving occupational income scores," *Explorations in Economic History*, 2020, *75*, 101304.

Schadewald, Robert J, "Flat-Earthism," in "The History of Science and Religion in the Western Tradition," Routledge, 2003, pp. 436–439.

Skelton, Chris, "Jacobson v. Massachusetts, 197 U.S. 11 (1905)," *Justia.* Available at `https://supreme.justia.com/cases/federal/us/197/11/`, July 18, 2022 2022.

Sprengholz, Philipp, Cornelia Betsch, and Robert Böhm, "Reactance revisited: Consequences of mandatory and scarce vaccination in the case of COVID-19," *Applied Psychology: Health and Well-Being*, 2021, *13* (4), 986–995.

Summers, Lawrence H, "Some simple economics of mandated benefits," *The American Economic Review*, 1989, *79* (2), 177–183.

Sun, Liyang and Sarah Abraham, "Estimating dynamic treatment effects in event studies with heterogeneous treatment effects," *Journal of Econometrics*, 2021, *225* (2), 175–199.

Suzuki, Akihito, "Smallpox and the epidemiological heritage of modern Japan: towards a total history," *Medical history*, 2011, *55* (3), 313–318.

Thaler, Richard H and Cass R Sunstein, "Libertarian paternalism," *American economic review*, 2003, *93* (2), 175–179.

The College of Physicians of Philadelphia, "History of Anti-Vaccination Movements," 2022. [Online; accessed 19-August-2022].

The Harvard Law Review Association, "TOWARD A TWENTY-FIRST-CENTURY JACOBSON V. MASSACHUSETTS," *Harvard Law Review*, 2008, *121* (7), 1820–1841.

Troesken, Werner, "The pox of liberty," in "The Pox of Liberty," University of Chicago Press, 2015.

Wang, Tianyi, "Media, pulpit, and populist persuasion: Evidence from Father Coughlin," *American Economic Review*, 2021, *111* (9), 3064–3092.

_ , "Waves of empowerment: Black radio and the civil rights movement," Technical Report, Working paper 2021.

Ward, Zachary, "The not-so-hot melting pot: The persistence of outcomes for descendants of the age of mass migration," *American Economic Journal: Applied Economics*, 2020, *12* (4), 73–102.

Wheaton, Brian, "Laws, beliefs, and backlash," *Unpublished Working Paper*, 2022.

White, Corey, "Measuring social and externality benefits of influenza vaccination," *Journal of Human Resources*, 2021, *56* (3), 749–785.

Widmer, Philine, Sergio Galletta, and Elliott Ash, "Media slant is contagious," *arXiv preprint arXiv:2202.07269*, 2022.

Williams, Unislawa and Sean P Williams, "txttool: Utilities for text analysis in Stata," *The Stata Journal*, 2014, *14* (4), 817–829.
Zucht v. King, 260 U.S. 174 (1922)

Zucht v. King, 260 U.S. 174 (1922), *Justia. Available at* `https://supreme.justia.com/cases/federal/us/260/174`*, July 18, 2022 2022.*

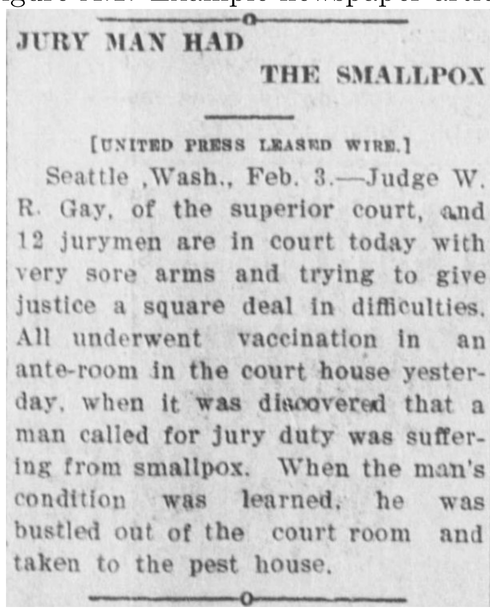
Żuk, Piotr, Paweł Żuk, and Justyna Lisiewicz-Jakubaszko, *"The anti-vaccine movement in Poland: The socio-cultural conditions of the opposition to vaccination and threats to public health," Vaccine, 2019, 37 (11), 1491–1494.*

A Appendix

A.1 OCR Example

Below is an example of the text-to-data process using an article from the February 3, 1911 issue of *The Daily Capital Journal* in Salem, Oregon. Figure A.1 displays a photograph of the article in question.

Figure A.1: Example newspaper article



JURY MAN HAD THE SMALLPOX

[UNITED PRESS LEASED WIRE.]

Seattle ,Wash., Feb. 3.—Judge W. R. Gay, of the superior court, and 12 jurymen are in court today with very sore arms and trying to give justice a square deal in difficulties. All underwent vaccination in an ante-room in the court house yesterday, when it was discovered that a man called for jury duty was suffering from smallpox. When the man's condition was learned, he was bustled out of the court room and taken to the pest house.

Notes: An article from the February 3, 1911 issue of *The Daily Capital Journal* in Salem, Oregon.

Taking the OCRed text, removing punctuation, and considering words that appear within ten words of the word *vaccination* yields the following string:

> *to give justice a square deal in difficulties all underwent vaccination in an ante-room in the court house yester day when*

In this case, the OCR text is relatively error free, aside from not recognizing *yesterday* as a single word. The automated spellchecker replaces the word *yester* with *fester*, a change that does not improve the quality of the string.

After removing uncommon words (words that appear less than 100 times in the total data set), we are left with:

to give a deal in all vaccination in an in the court house day when.

Lastly, after truncating at twenty characters and applying the Porter stemmer, the string is further reduced to:

to give a deal in all vaccin in an in the court hous dai when

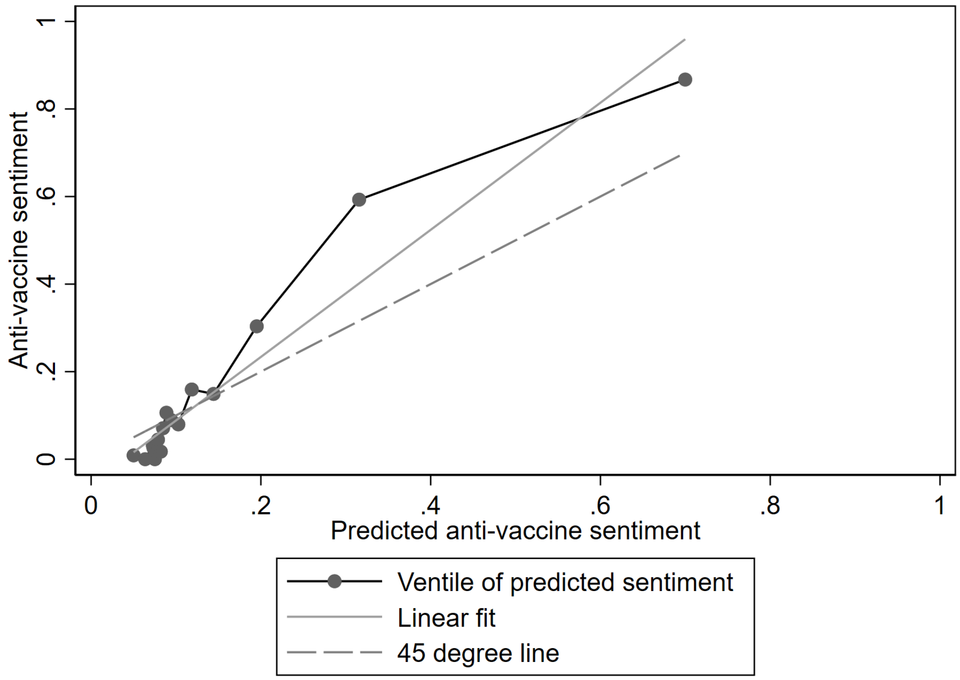
The word *house* is reduced to *hous*, which shares a stem with *houses*, *housing*, and *housed*. The word *day* is represented as *dai*, as is *days*.[42]

The bag-of-words frequency representation of this string would then be three for *in*, and one each for *to*, *give*, *a*, *deal*, *all*, *vaccin*, *an*, *room*, *the*, *court*, *hous*, *dai*, and *when*. All other elements of the vector would be zeros. We do not remove stop words, such as *a*, *in*, and *the*, although they are unlikely to be chosen by the LASSO regression.

[42]The Porter stemmer represents words ending in *y* as an *i* so that words like *ability* and *abilities* will be stemmed to the same word.

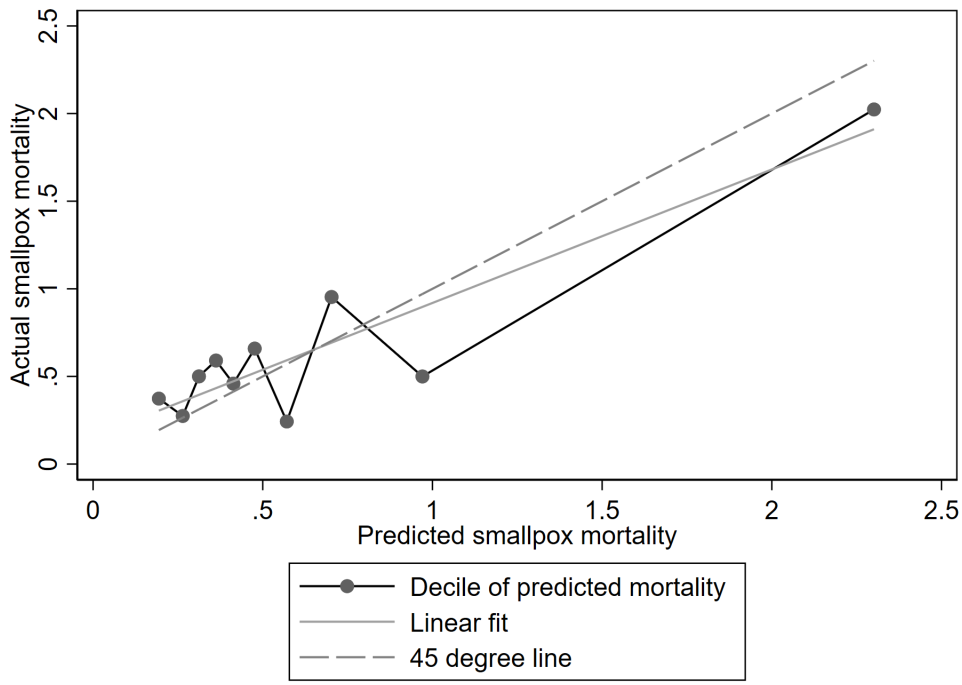
A.2 Additional Tables and Figures

Figure A.2: Calibration curve for anti-vaccine sentiment



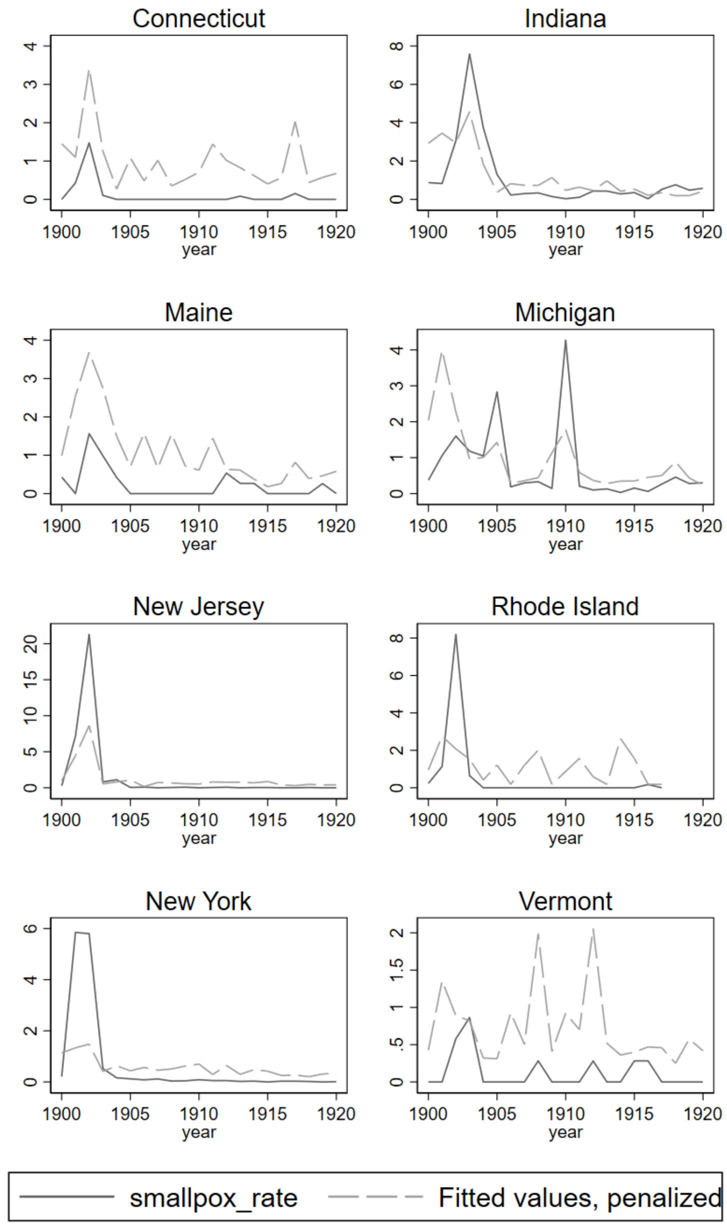
Notes: Data are a 5% sample that were human classified as either containing anti-vaccine sentiment are not. Each dot represents a ventile of predicted sentiment, where predicted sentiment comes from the BoW 1 Lasso model. The y-axis shows the percent of this ventile that is human-classified as having anti-vaccine sentiment. The closer the line of best fit is to the 45 degree line, the better the goodness-of-fit.

Figure A.3: Calibration curve for mortality



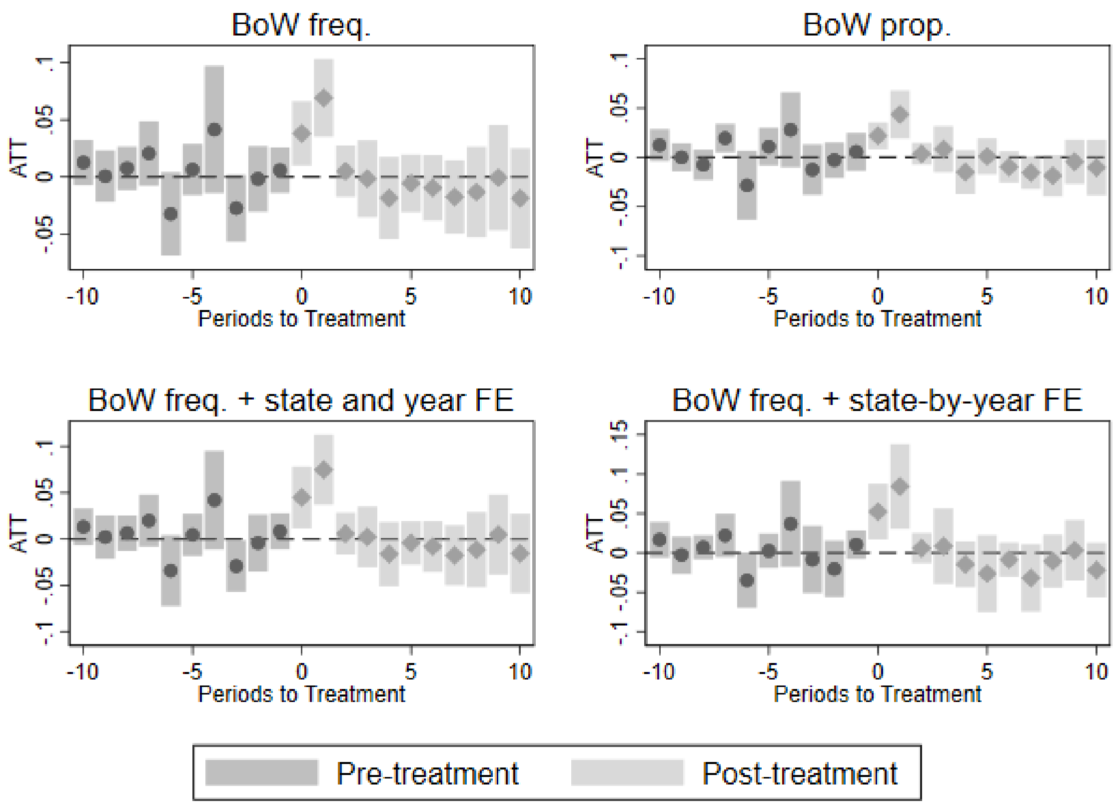
Notes: Each dot represents a decile of predicted smallpox mortality, where smallpox mortality is estimated using language in newspaper data. The y-axis shows actual smallpox mortality for that decile as reported in the US Vital Statistics data. The closer the line of best fit is to the 45 degree line, the better the goodness-of-fit.

Figure A.4: Predicted and actual mortality for selection states



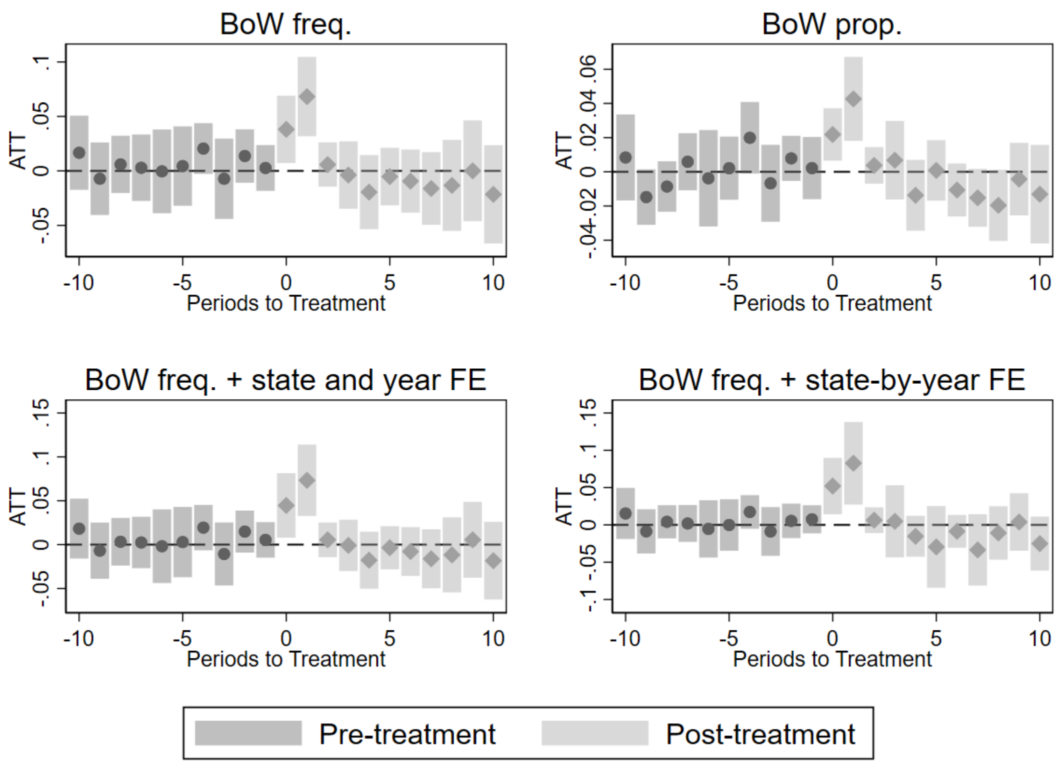
Notes: Smallpox rates are deaths per 100,000.

Figure A.5: Event study estimates of court decisions on anti-vaccine discourse using not-yet-treated states as the control group



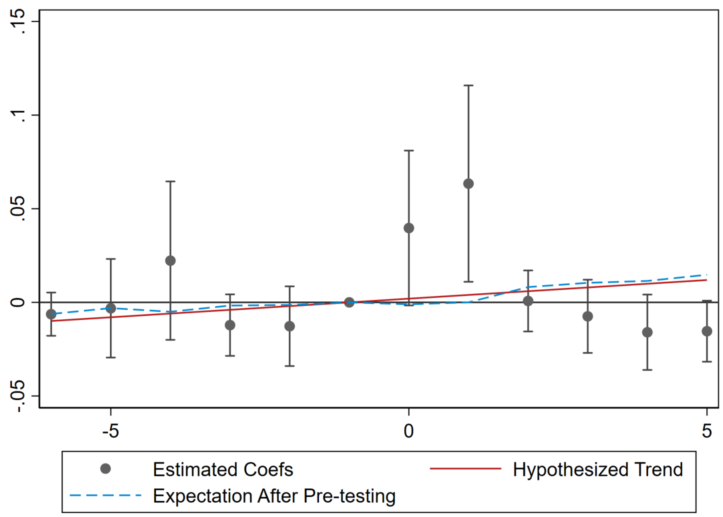
Notes: Estimates use the Callaway and Sant'Anna (2021) estimator. This figure uses not-yet-treated states as the control group. Uniform 95% confidence intervals are based on wild bootstrapped standard errors clustered at the state level.

Figure A.6: Event-study estimates of court decisions on anti-vaccine discourse using long differences



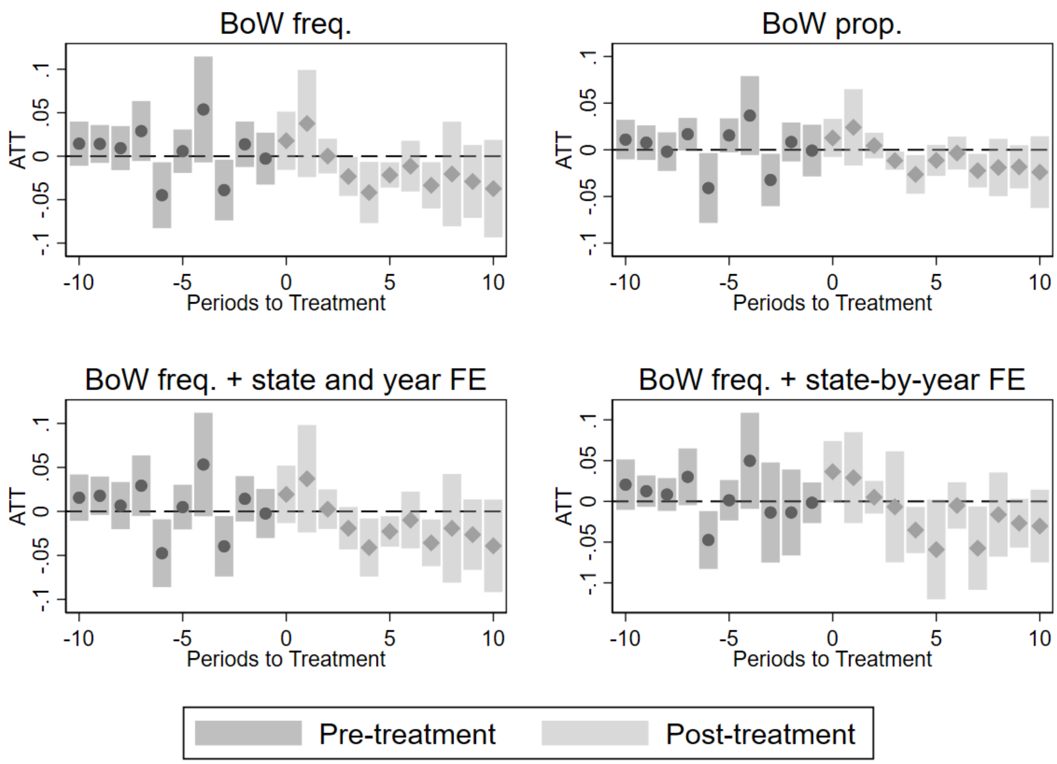
Notes: Estimates use the Callaway and Sant'Anna (2021) estimator. This figure uses not-yet-treated states as the control group. Uniform 95% confidence intervals are based on wild bootstrapped standard errors clustered at the state level. The pre-period estimates are long differences, rather than short differences.

Figure A.7: Robustness of anti-vaccine estimates to non-parallel pre-trends



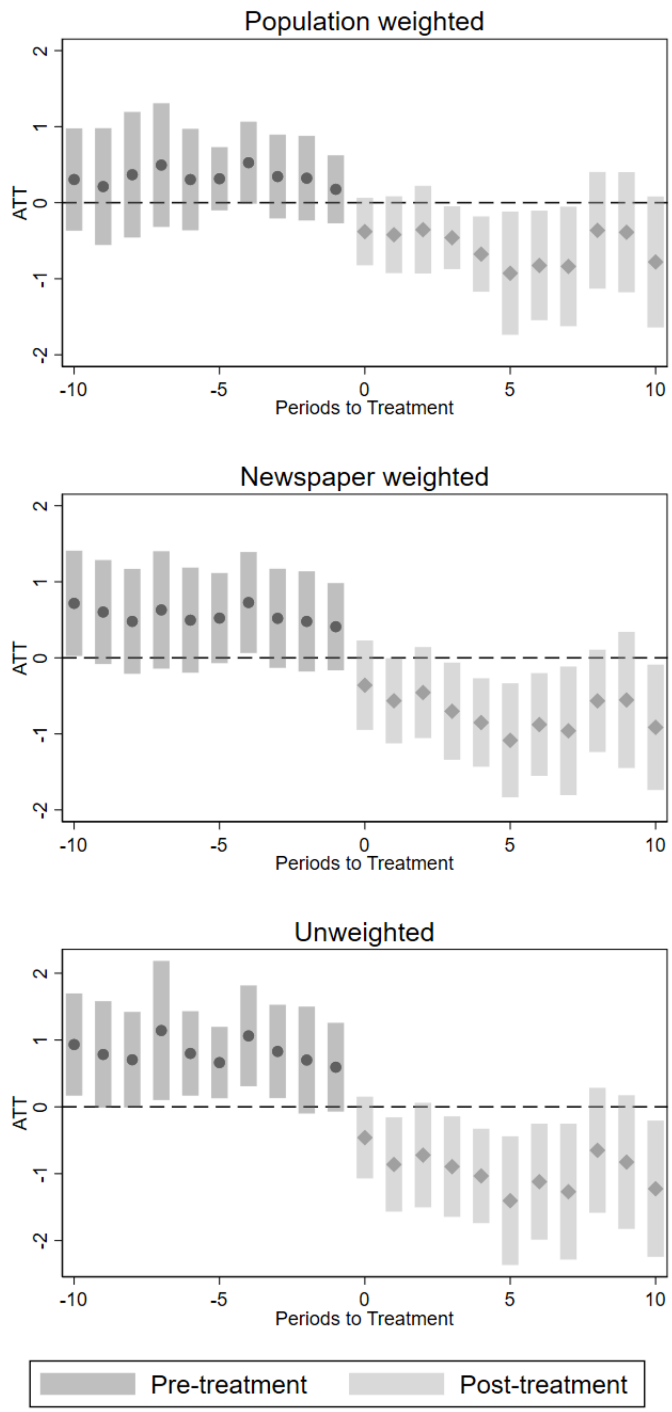
Notes: Two-way fixed effects estimates using the Roth (2022) pre-trends test. The red line is the pre-trend line that can be detected with power 50%. The blue dashed line shows the expected event study coefficients if the red line is the true pre-trend. Standard errors are clustered at state level.

Figure A.8: Event-study estimates of court decisions on anti-vaccine discourse dropping repeal states



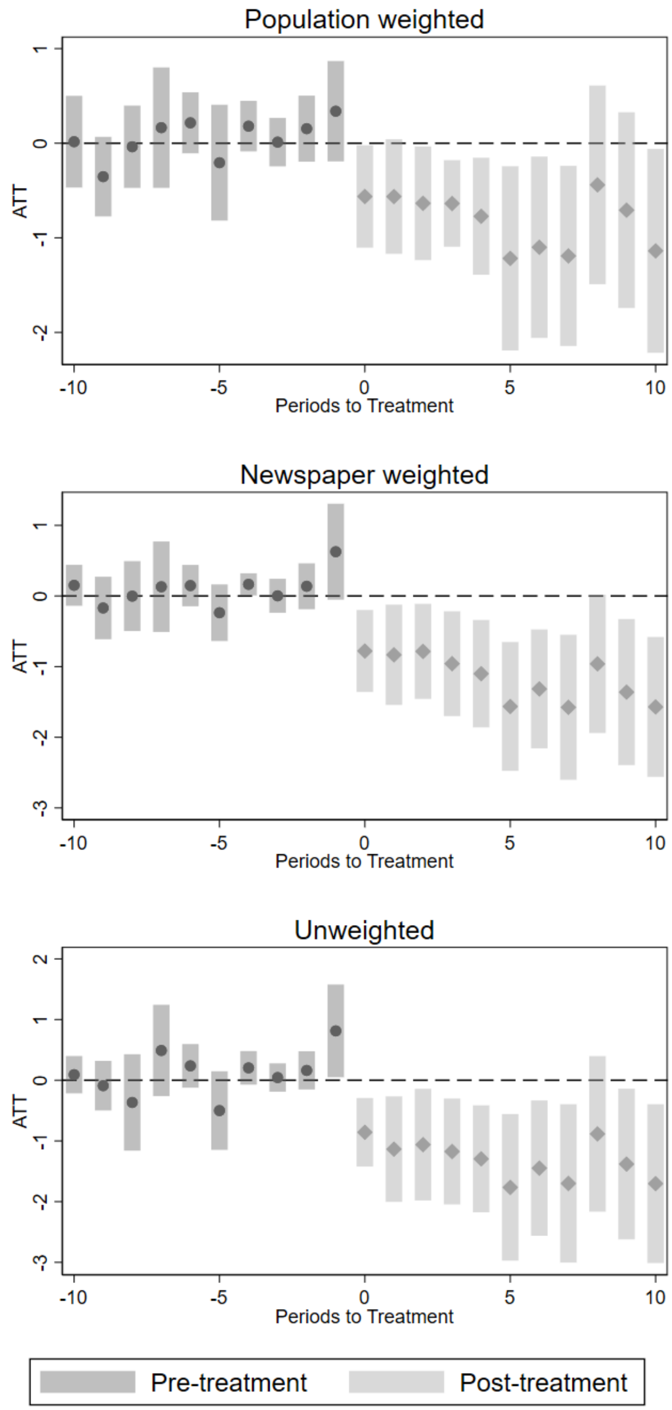
Notes: Estimates use the Callaway and Sant'Anna (2021) estimator. This figure uses never-treated states as the control group. Uniform 95% confidence intervals are based on wild bootstrapped standard errors clustered at the state level. The dropped states include Utah, North Dakota, Washington, Wisconsin, Oregon, California, and New York.

Figure A.9: The effect of compulsory vaccination court decisions on mortality using long differences



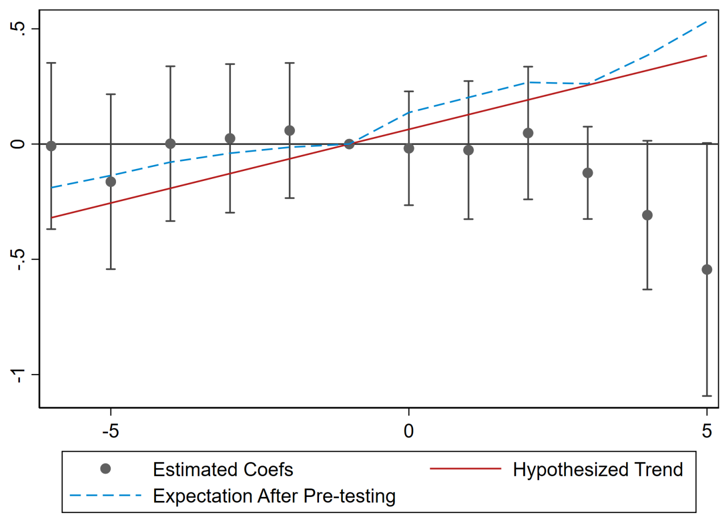
Notes: Smallpox mortality is the estimated number of deaths per 100,000 using language in newspaper data. The event study is estimated using Callaway and Sant'Anna (2021). Uniform 95% confidence intervals are based on wild bootstrapped standard errors clustered at the state level. This graph uses long differences, rather than short differences, during the pre-treatment period.

Figure A.10: The effect of compulsory vaccination court decisions on mortality, dropping repeal states



Notes: Smallpox mortality is the estimated number of deaths per 100,000 using language in newspaper data. The event study is estimated using Callaway and Sant'Anna (2021). Uniform 95% confidence intervals are based on wild bootstrapped standard errors clustered at the state level. The dropped states include Utah, North Dakota, Washington, Wisconsin, California, and New York.

Figure A.11: Robustness of mortality estimates to non-parallel pre-trends



Notes: Two-way fixed effects estimates using the Roth (2022) pre-trends test. The red line is the pre-trend line that can be detected with power 50%. The blue dashed line shows the expected event study coefficients if the red line is the true pre-trend. Standard errors are clustered at state level.

Table A.1: Sample State Supreme Court Cases

Date	State	Case	Law upheld
May 31, 1890	CA	*Abeel v. Clark*	Compulsory vaccination of students
Jul. 11, 1894	PA	*Duffield v. Williamsport School District*	Local jurisdictions may have compulsory vaccination for school attendance during outbreaks
Dec. 1, 1894	CT	*Bissell v. Davison*	Compulsory vaccination of students
Feb. 11, 1895	NY	*In re Walters*	Compulsory vaccination for school attendance
Feb. 28, 1898	GA	*Morris v. City of Columbus*	Compulsory vaccination for all during outbreak
Feb. 1, 1900	IN	*Blue v. Beach*	Compulsory vaccination of students
Mar. 20, 1900	NC	*State v. Hay*	Local jurisdictions may have compulsory vaccination
Apr. 26, 1900	UT	*State ex rel. Cox v. Board of Education of Salt Lake City*	Local jurisdictions may have compulsory vaccination for school attendance during outbreaks
Dec. 31, 1900	SD	*Glover v. Board of Education*	Local jurisdictions may have compulsory vaccination for school attendance during outbreaks
Jun. 6, 1902	MN	*State ex rel. Freeman v. Zimmerman*	Local jurisdictions may have compulsory vaccination for school attendance during outbreaks
May 7, 1907	OH	*The State, Ex Rel. Milhoof, v. The Board Of Education of The Village Of Barberton, Ohio.*	Local jurisdictions may have compulsory vaccination for school attendance
Jul. 8, 1907	AR	*Auten v. School Board*	Compulsory vaccination of students
May 22, 1909	MO	*State ex rel. O'Bannon v. Cole et al.*	Local jurisdictions may have compulsory vaccination for school attendance during outbreaks
Oct. 6, 1909	WA	*State ex rel. McFadden v. Shorrock et al.*	Compulsory vaccination for school attendance
Nov. 16, 1916	AL	*Herbert v. Board of Education*	Compulsory vaccination at municipal level for school
Oct. 21, 1918	IL	*Hagler v. Larner*	Compulsory vaccination of students during outbreak
Dec. 11, 1918	TX	*City of New Braunfels v. Waldschmidt*	Local jurisdictions may have compulsory vaccination for school attendance during outbreaks

Notes: Source is (Fowler, 1927). *Jacobson v. Massachusetts* is not included in the sample as Massachusetts is one of the two states with no newspaper data.

Table A.2: The top 20 words that predict discourse

Positively predicts anti-vaccine discourse	Negatively predicts anti-vaccine discourse
antivaccinationist	cow
resist	typhoid
excel	gener
protest	revaccin
imposs	person
lectur	method
oppos	expos
refus	see
observ	four
antivaccin	emploi
utah	to
major	dai
forc	adult
blood	crime
opposit	read
thou	
caus	
class	
difficulti	
admit	

Notes: Words are stemmed using the Porter stemmer. There are only 15 words that negatively predict anti-vaccine discourse.

Table A.3: Confusion matrix

Category	$Pr(antivax) \geq 0.5$	$Pr(antivax) < 0.5$	Total
Hand-classified anti-vaccination	85	218	303
Hand-classified not anti-vaccination	7	1953	1960
Total	92	2171	2263
Accuracy	0.90		
Precision	0.92		
Recall	0.28		
F_1 Score	0.43		

Notes: The top panel displays the number of true positives (TP), true negatives (TN), false positives (FP), and false negatives (FN), as well as total number of articles. The bottom panel provides some standard measures of confusion. By definition, accuracy is the percent of observations that are correctly predicted ($ACC = \frac{TP+TN}{TP+TN+FP+FN}$), precision is the percent of predicted positives that are true positives ($PRE = \frac{TP}{TP+FP}$), recall is the percent of true positives that are predicted as positive ($REC = \frac{TP}{TP+FN}$). The F_1 score combines precision and recall and is $2 \times \frac{PRE \times REC}{PRE+REC}$. Our metric has high accuracy and precision, as well as lower recall.

Table A.4: RD results using circulation data

	(1)	(2)	(3)	(4)
	Panel A: Controlling for circulation			
Conventional treatment effect	0.0599**	0.0291*	0.0711***	0.0488*
	(0.0266)	(0.0154)	(0.0250)	(0.0252)
Robust bias-corrected	0.0721**	0.0332*	0.0860***	0.0539*
	(0.0299)	(0.0171)	(0.0277)	(0.0290)
N	4825	4825	4825	4825
N to the left	670	622	560	688
N to the right	402	449	402	416
Left bandwidth	256.7	237.3	205.7	264.0
Right bandwidth	183.8	221.5	181.3	189.4
	(1)	(2)	(3)	(4)
	Panel B: Above median circulation only			
Conventional treatment effect	0.0522*	0.0329	0.0621**	0.0391
	(0.0274)	(0.0207)	(0.0302)	(0.0370)
Robust bias-corrected	0.0640**	0.0364	0.0763**	0.0363
	(0.0304)	(0.0228)	(0.0333)	(0.0441)
N	2381	2381	2381	2381
N to the left	261	283	277	296
N to the right	259	308	253	224
Left bandwidth	240.5	256.6	248.5	270.0
Right bandwidth	256.8	328.6	250.2	193.4
	(1)	(2)	(3)	(4)
	Panel C: Below median circulation only			
Conventional treatment effect	0.0433	0.0129	0.0401	0.0398
	(0.0446)	(0.0238)	(0.0383)	(0.0397)
Robust bias-corrected	0.0571	0.0204	0.0549	0.0540
	(0.0501)	(0.0269)	(0.0418)	(0.0444)
N	2444	2444	2444	2444
N to the left	521	406	414	419
N to the right	206	211	204	207
Left bandwidth	359.1	276.6	289.5	294.4
Right bandwidth	206.1	214.3	201.6	209.6

Table A.5: Vaccine sentiment sample size by event time

Event time	Number of pages
Never treated	28,200
≤ -10	4,198
-9	363
-8	389
-7	450
-6	404
-5	314
-4	367
-3	457
-2	698
-1	1,332
0	1,104
1	822
2	700
3	530
4	509
5	445
6	416
7	538
8	614
9	415
≥ 10	4,372

Notes: Displays the sample size (number of newspaper pages) for each event time bin.