Pox, Piety, and Paradox: The Economics of Vaccination in British India*

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Abstract

This paper presents new historical evidence on the cultural roots of vaccine hesitancy and its medium-term effects. Using a newly compiled district-level dataset with religion-specific vaccination rates across colonial India (1868-1878), I examine how Hindu religious beliefs affected smallpox vaccination uptake. An instrumental variables approach using historical Hindu temple desecration sites shows that a one standard deviation increase in Hindu population share leads to a 0.89 to 1.98 percentage points decrease in Hindu vaccination rate at the district level. These effects are specific to Hindu populations and operate through religious and cultural practices. By 1891, a one standard deviation increase in Hindu share is associated with 17.7 and 12.6 percentage point increases in unmarried and widow ratios among young adults aged 10-25. The findings highlight the societal impact of culturally-driven vaccine hesitancy and guide culturally sensitive health policies.

JEL Codes: I18, N35, Z12, C36, J12

Keywords: Vaccine Hesitancy, Religion and Public Health, Colonial India, Smallpox Vaccination, Cultural Resistance, Economics of Religion, Culture and Economics

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1 Introduction

> *"The people... would deny or hide their children, and openly declare that they would not incur the wrath of the goddess...* ***They would rather die of smallpox than accept vaccination.****"*
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> – Sub-Assistant Surgeon Bhoobun Mohun Mitter, First Report of the Eastern Bengal Circle of Vaccination (1873)

"What pygmies we look like!" Edward Jenner exclaimed, reflecting on Governor-General Wellesley's ambitious plans to eradicate smallpox in British-ruled India [Saunders, 1982, pp.162-63]. This remark underscores a stark contrast: while smallpox vaccination saw slow acceptance in Britain, the British administration in India aggressively pursued public health initiatives as part of its imperial agenda. By 1800, India had become a pivotal component of the British Empire in the East, intricately connected through trade and administrative networks [Bennett, 2020, p.266]. However, this expansion created a complex intersection of public health policies and entrenched local cultural practices. Smallpox vaccination campaigns encountered substantial resistance, primarily due to long-standing Hindu religious traditions and societal norms [Arnold et al., 1993, Bhattacharya, 2006, Harrison, 1994]. This historical context not only shaped the implementation of health policies but also provides a foundation for examining how specific Hindu religious practices and cultural norms influenced public health strategies. Understanding these historical dynamics is crucial for contextualizing the broader role of religion in public health, both in the past and present.

Religious beliefs have historically played a pivotal role in shaping public health outcomes, influencing economic development, social behaviors, and political decision-making processes [Iannaccone, 1998, Barro and McCleary, 2003, Herzer, 2022, McCleary and Barro, 2006, Becker and Woessmann, 2009, Iyer, 2016]. The significant influence of religion on public health is particularly evident in the acceptance of medical interventions, such as disease prevention measures and vaccination campaigns. For example, recent global efforts to vaccinate populations against COVID-19 encountered significant resistance rooted in diverse religious beliefs [Wester et al., 2022, Chu et al., 2021, Andrade, 2021, Kibongani Volet et al., 2022, International Vaccine Access Center (IVAC), 2022].

This pattern of religiously influenced hesitancy is not new; similar challenges were faced in colonial India, where British attempts to introduce smallpox vaccination were met with opposition grounded in entrenched Hindu religious traditions and cultural practices [Arnold et al., 1993, Bhattacharya, 2006, Harrison, 1994]. These historical and contemporary examples highlight the persistent influence of religious beliefs on public health outcomes and economic development, prompting economists to investigate the underlying mechanisms driving this relationship.

Economic research has identified several channels through which religion impacts public health outcomes and, by extension, economic development. At the individual and community level, religious practices establish communal norms that influence health-related behaviors, including attitudes toward medical interventions [Iannaccone, 1992, 1998]. This influence is further reinforced by increased religious participation, which can lead to improved health outcomes through enhanced social support networks and higher educational attainment [Hungerman and Gruber, 2006]. Moreover, religious values significantly affect attitudes toward risk and trust, critical factors in the acceptance of new medical interventions such as vaccines [Guiso et al., 2003]. The impact of religion extends beyond immediate health behaviors to shape broader societal attitudes and institutions. For instance, certain religious traditions, particularly Protestantism, have historically fostered education and human capital development, indirectly enhancing health outcomes by promoting more informed health decisions [Becker and Woessmann, 2009]. Additionally, religious tolerance has been shown to encourage innovation, including the adoption of medical technologies, thereby positively impacting health outcomes and economic growth [Chaney, 2016, Cinnirella and Streb, 2017].

However, the relationship between religion and health interventions is complex and not uniformly positive. Religious beliefs can foster resistance to new innovations, including medical interventions, by shaping long-term cultural norms [Bénabou et al., 2015]. This resistance is partly explained by the intergenerational transmission of cultural and religious traits, which reinforces attitudes toward health interventions like vaccination [Bisin and Verdier, 2000]. Historical examples illustrate the persistence of these cultural norms, as evidenced in colonial India, where religious and cultural factors significantly shaped the provision and uptake of public services, such as primary education [Chaudhary and Rubin, 2016]. This historical context parallels the resistance to medical interventions, suggesting that entrenched religious beliefs played a key role in shaping responses to smallpox vaccination efforts. Studies by Iannaccone [1992, 1998] show that religion shapes health behaviors through individual choices, community norms, and institutional structures, with significant short- and long-term economic effects. Recognizing these dynamics is crucial for designing public health policies that not only address immediate health crises but also engage with the deeper cultural and religious frameworks that shape health behaviors. Without such an understanding, even the most well-intentioned interventions risk falling short of their goals, as history has shown both in colonial India and more recently in the global response to COVID-19.

This paper examines smallpox vaccination resistance in colonial India in detail. Specifically, it seeks to answer the following question: How did Hindu religious beliefs and cultural practices contribute to the widespread resistance and lower uptake of smallpox vaccination in colonial India during the late 19th century? To address these questions, the study introduces a newly compiled district-level dataset on smallpox vaccination from 1868 to 1878, providing a unique opportunity to analyze how specific Hindu beliefs—including the veneration of the goddess *Sitala*, caste hierarchies, and gender norms like *purdah*, prevalent in Hindu-majority areas—shaped vaccine hesitancy in Hindu majority areas. By integrating insights from economics, history, and public health, this study quantitatively assesses the impact of these cultural and religious factors on vaccination behavior, filling a critical gap in the literature on historical vaccine hesitancy.

Using an instrumental variables approach that leverages the distance to historical Hindu desecration sites, I establish the causal effect of religious beliefs on vaccination rates. These desecration sites, documented by Eaton [2000], serve as exogenous predictors of Hindu population share, as they represent historical centers of Hindu religious activity that predate colonial vaccination efforts by several centuries. The results show that Hindu-majority districts had notably lower vaccination rates. A one standard deviation (0.241) increase in Hindu population share leads to a 0.70 to 1.33 percentage point decline in overall vaccination rates, a 0.89 to 1.98 percentage point reduction in Hindu vaccination rates, and a decrease of 0.46 to 1.25 percentage points in female vaccination rates. The effects are strongest and most statistically significant for Hindu vaccination rates, while the impact on female vaccination rates is less precisely estimated.

To validate these findings and explore specific mechanisms, I conduct sentiment analysis of historical vaccination reports using natural language processing techniques. The analysis reveals significantly more negative sentiment in reports from districts with higher shares of upper-caste Hindus, supporting the role of caste hierarchy in vaccination resistance. Additionally, a placebo test examining Muslim vaccination rates shows no relationship with Hindu population share, confirming that the observed effects are specific to Hindu religious and cultural factors rather than general district characteristics.

Beyond examining vaccine hesitancy, this paper explores its medium-term demographic consequences. Using 1891 census data, I capture a 13 to 23 year period following the initial vaccination campaign to measure the effects on individuals who were children at the time of the smallpox vaccination efforts. The findings indicate that districts with lower vaccination rates had a higher ratio of widows and unmarried individuals in the 10 to 25-year old age group. This pattern likely reflects the impact of smallpox-related mortality on marriage prospects and family structures. Specifically, a one standard deviation (0.241) increase in Hindu population share increases the ratio of unmarried Hindus aged 10 to 25 by 17.7 percentage points and the widowhood ratio by 12.6 percentage points within this age group, with both effects statistically significant at the 1% level.[1]

This paper makes significant contributions to health economics, the economics of religion and culture, and historical political economy. First, it advances health economics by offering a rigorous empirical analysis of the historical determinants and distributional impacts of vaccine uptake [Lowes and Montero, 2021, Nuwarda et al., 2022, MacDonald et al., 2015]. Second, it contributes to the economics of religion and culture by providing new evidence on the direct influence of religious and cultural norms on public health decisions [Iannaccone, 1998, McCleary and Barro, 2006, Barro and McCleary, 2003, Aldashev and Platteau, 2014]. Third, it introduces a newly compiled district-level dataset on smallpox vaccination in colonial India from 1868 to 1878, offering a unique opportunity to examine how cultural and religious factors shaped public health interventions [Falade, 2014]. Finally, it informs historical political economy by documenting the medium-term effects of colonial health interventions on societal outcomes [Lowes and Montero, 2021].

[1] Existing research (e.g., [Sköld, 2003, Rutten, 1993]) presents mixed findings on smallpox's demographic effects. However, the prevalence of arranged marriages in India and the severity of the *variola major* strain may explain the unique patterns observed in this study.

Together, these contributions underscore the importance of culturally informed health policies, offering insights relevant for both historical and contemporary contexts.

This paper is organized as follows: Section 2 provides a historical overview of smallpox and vaccination efforts in colonial India and it examines religious and cultural barriers to vaccination among Hindu communities. Section 3 introduces the theoretical framework, modeling the relationship between religious beliefs and vaccination decisions. Section 4 describes the dataset and offers descriptive analysis. Section 5 outlines the empirical strategy and presents OLS results. Section 6 presents the instrumental variables approach and IV results. Section 7 includes robustness checks, such as placebo tests and sentiment analysis. Section 8 explores the medium-term demographic consequences of low vaccination rates. Section 9 concludes with a summary of findings and their implications.

2 Smallpox: The Speckled Monster

Smallpox has historically been one of the most devastating diseases, causing widespread suffering and mortality across the globe [Hopkins, 2002, Behbehani, 1983, Oldstone, 2020, Kahn, 1963, Henderson, 2009, Ochmann et al., 2018, Reynolds and Damon, 2008]. This highly contagious disease, caused by the *variola* virus and transmitted through respiratory droplets, exists in two primary forms: *variola major* and *variola minor* (alastrim), with mortality rates of 15%-45% and 1%-2% respectively [Ochmann et al., 2018, Berche, 2022]. Individuals who survive typically develop lifelong immunity [Ochmann et al., 2018, Minsky, 2009]. *Variola major* infections lead to severe symptoms, including high fever, chills, and a distinctive rash that progresses to pustules [Arnold et al., 1993, Bhattacharya et al., 2005, Jame, 1909, Anderson et al., 1885], with death often occurring between days 8 and 10 due to complications like hemorrhaging. Survivors face prolonged recovery, with risks such as blindness,[2] limb deformities, and scarring. Additionally, pregnant women infected with smallpox are particularly vulnerable, facing increased risks of premature delivery and abortion [Berche, 2022, Banthia and Dyson, 1999, Woody, 1922]. Beyond these immediate health impacts, smallpox had significant long-term effects on physical growth and population demographics, influencing economic development. Voth

[2] Fatal in a third of cases, smallpox was also a major cause of blindness, accounting for an estimated three-quarters of blindness in India, as noted by Arnold [1988], citing Jame [1909].

and Leunig [1996] found that survivors were, on average, one inch shorter, reflecting reduced labor productivity. As smallpox incidence declined, average heights increased, underscoring the economic benefits of public health interventions (pp. 541–42).

The historical impact of smallpox on human populations has been catastrophic, shaping demographic and economic trajectories across different regions and eras. The earliest suspected case dates back to Pharaoh Ramesses V in 1157 BC, while the first recorded pandemic, known as the Antonine Plague, claimed an estimated 7-8 million lives in the Roman Empire during Marcus Aurelius's reign [Berche, 2022, Rockwell, 2017]. In the 15th century, smallpox played a pivotal role in the decimation of native populations in the Americas following European contact [Patterson and Runge, 2002, Bollet, 2004, Rockwell, 2017]. For instance, Mexico's population declined from an estimated 17.2 million to about 1 million by the late 16th century, and further to 600,000 by 1800. In 18th-century Europe, smallpox was responsible for 200,000 to 600,000 deaths annually, accounting for approximately 10% of all deaths. The last major epidemic in Europe began in France around 1870, resulting in 125,000 to 200,000 deaths within the French army during the Franco-Prussian War [Berche, 2022, Kotar and Gessler, 2013]. Globally, before its eradication in 1980, smallpox caused an estimated 300-500 million deaths, significantly impacting populations in Asia, Africa, and other regions [Alcamí, 2020, Berche, 2022]. This extensive mortality underscores the World Health Organization's successful vaccination campaign, which ultimately led to the eradication of smallpox [Strassburg, 1982].

In colonial India, smallpox mirrored its global devastation, exerting significant demographic and economic pressures. In the late 19th century, smallpox claimed several million lives, with an average of over 100,000 deaths annually [Banthia and Dyson, 1999, Arnold et al., 1993]. Densely populated cities experienced particularly severe tolls. For example, Calcutta recorded 11,000 smallpox deaths in 1849-50 among a population of just over 350,000, including 6,100 deaths in a single epidemic season. Similarly, Lahore experienced 7,000 deaths in two months in 1865, a rate that would have eliminated one-third of the city's inhabitants within a year [Arnold et al., 1993, Jame, 1909]. Children were especially vulnerable, with case-fatality rates reaching 80% in very young children and 60% in older ones [Minsky, 2009]. In the *Doab* region of northern India,[3] an estimated 95%

[3] *Doab* refers to the area between the Ganges and Yamuna rivers, primarily in the states of Uttar Pradesh and Uttarakhand.

of the population had been afflicted by smallpox by 1869, and nearly 75% of blindness cases were attributed to the disease. In 1869 alone, recorded deaths in India approached 200,000, with actual numbers likely double due to incomplete registration [Jame, 1909]. One estimate suggests that smallpox killed 1.44 million people during the decade of 1868-77, increasing to 1.46 million in the following decade [Arnold, 1988, p.47], citing [Jame, 1909]. The high susceptibility of the Indian population to smallpox was exacerbated by the lack of effective preventive measures, which impeded economic stability and growth.

The introduction of vaccination in colonial India offered a crucial intervention to mitigate the disease's devastating impact.[4] The number of vaccination operations in British India increased significantly from 350,000 annually in 1850 to 8 million by the end of the century. Key developments facilitating this rise included the introduction of animal vaccination in 1869, the use of glycerinated vaccine post-1905, and the adoption of chloroformed vaccine, which enhanced the efficiency and safety of vaccination efforts [Sarkar, 2003]. Despite these advancements, the widespread acceptance of vaccination faced resistance, particularly due to religious beliefs and practices among Hindus, as will be explored in the next section.

2.1 History of Smallpox Vaccination in India

2.1.1 Introduction of Western Medicine and Early Cultural Resistance

The British administration introduced Western medicine in colonial India to safeguard colonial officials and troops, boost economic productivity, and consolidate control [MacLeod and Lewis, 2022, Sarkar, 2003, p. 1180]. By establishing hospitals, dispensaries, and medical schools, the British embedded Western medical practices into Indian society, reinforcing their governance [Bennett, 2020, p. 251]. However, these efforts clashed with local traditions, which were often dismissed as inferior by colonial authorities [Kumar, 2017]. Despite considerable resistance to vaccination, British officials framed these health interventions as moral acts that compensated for the negative effects of colonialism [Arnold,

[4] Banthia and Dyson [1999, p.664] report that in major presidencies of India, smallpox accounted for approximately 5 to 10 percent of all deaths in Calcutta during 1832-69 (excluding 1851-55), 4 to 6 percent in Bombay from 1848-79, and 3 to 11 percent in Madras from 1855-84. These figures highlight smallpox's consistent contribution to mortality before significant declines following vaccination efforts.

2016, Chakrabarti, 2013, p. 36]. Governor Duncan, for example, argued in 1802 that vaccination was a 'kindness' that could offset the 'evils' brought by British rule, a sentiment echoed by Dr. Whitelaw Ainslie 25 years later, who emphasized vaccination's role in demonstrating the British 'sympathizing heart and healing hand' [Harrison, 1994, Bennett, 2020, p. 82].

Vaccination was increasingly seen as an extension of colonial power, with rumors during the 1896 plague epidemic suggesting that vaccination campaigns were spreading the disease [Harrison, 1994, p. 87]. Such perceptions entrenched skepticism toward public health initiatives, particularly among *Brahmins*—the highest caste in the traditional Hindu caste system, who served as priests and scholars—and *zamindars*—landowners and tax collectors who held significant economic and social power over tenant farmers in colonial India [Ramanna, 2000, Arnold, 1988, Bennett, 2007, p. 62]. These groups not only shared these views but also actively propagated them, amplifying opposition to British medical interventions. Having previously controlled traditional variolation practices, they saw government-provided free vaccinations as a threat to their socioeconomic and religious authority. The shift disrupted established economic arrangements reliant on variolation fees, leading *zamindars* to oppose vaccination programs [Greenough, 1980, p. 347]. This resistance was not just a rejection of medical technology but was driven by religious and cultural beliefs, which *Brahmins* and *zamindars* amplified to protect their authority and interests. It reflected a broader protest against colonial policies that threatened local power structures [Paturalski, 2021, pp. 119, 147].

Misinterpretations and mishandling of cultural practices by British vaccinators further impeded vaccination efforts. Although vaccination shared similarities with traditional variolation, British methods fueled fears and myths among the Indian populace. For example, rumors circulated that vaccination scabs were offerings to the 'Railway God,' symbolized by local chants warning of children being sacrificed [Paturalski, 2021, p. 178]. These fears reflected broader anxieties about colonial influence and modernity, positioning vaccination campaigns as symbols of resistance against British authority. The conflict between Western medicine and traditional practices also involved deeper cultural and religious dimensions. Figures like Mahatma Gandhi opposed vaccination, viewing it as unnatural and conflicting with beliefs about bodily purity [Brimnes, 2017, pp. 58-61]. Vaccination thus became a focal point for cultural and religious conflict, as communities sought to preserve indigenous identities and spiritual practices against the imposition of colonial modernity. While the introduction of Western medicine faced immediate cultural resistance, it was the technical implementation, particularly the arm-to-arm vaccination method, that further complicated the British administration's efforts. Essential due to vaccine scarcity, this method sparked concerns over disease transmission, caste purity, and religious beliefs, deepening the socio-economic resistance to public health interventions. I discuss the technique of arm-to-arm vaccination next.

2.1.2 Arm-to-Arm Vaccination: Techniques, Challenges, and Socio-Economic Implications

Before the introduction of animal-derived lymph and advancements in vaccine storage, the predominant vaccination method in colonial India was the arm-to-arm technique [Bennett, 2007, Brimnes, 2004]. This approach involved transferring lymph from a vaccinated individual, referred to as a *vaccinifer*, directly to an unvaccinated person. While efficient in spreading the vaccine, the method was deeply entangled with caste and religious opposition, especially among upper-caste Hindus.

A critical source of resistance stemmed from the use of lower-caste children as *vaccinifers*, which violated the strict norms of caste purity. In Hindu society, any direct physical contact, especially involving the exchange of bodily substances, was considered a serious breach of purity laws. Upper-caste Hindus, particularly *Brahmins*, saw the introduction of lymph from lower-caste children as ritually polluting, further intensifying their mistrust of colonial medical practices [Minsky, 2009, Bennett, 2007]. This violation of caste boundaries was not merely a social inconvenience but a religious offense that reinforced their resistance to vaccination. Additionally, Hindu religious beliefs surrounding the sanctity of the body played a pivotal role. Extracting lymph from human bodies, even from fellow caste members, conflicted with the spiritual and ritual purity that many Hindus sought to preserve. The use of the human body as a conduit for vaccination directly challenged these beliefs, making the arm-to-arm method deeply problematic from both a religious and caste perspective [Sarkar, 2003].

Furthermore, the colonial administration often incentivized lower-caste families, whose economic vulnerability made them more likely to participate in the program as *vaccinifers*. This institutionalized the exploitation of caste hierarchies, whereby lower-caste children were disproportionately used in vaccination drives, perpetuating caste-based inequalities and further alienating upper-caste communities from engaging with the procedure [Minsky, 2009, Bennett, 2007]. The arm-to-arm technique, though efficient in disseminating the smallpox vaccine, thus faced profound opposition due to its infringement on both caste and religious norms. Resistance to the method persisted until the widespread use of cow-derived lymph reduced the need for human *vaccinifers*, alleviating some of the caste-based concerns [Sarkar, 2003].

2.2 Religious and Cultural Barriers to Smallpox Vaccination in Colonial India

Religious and cultural resistance was the central obstacle to the adoption of smallpox vaccination in colonial India, overshadowing technical and logistical challenges. Hindu beliefs, particularly the veneration of the goddess *Sitala*, shaped societal attitudes toward vaccination. Smallpox was often viewed not as a disease but as a divine test, and attempts to prevent it through vaccination were seen as defying divine authority. Traditional practices, such as variolation, were embedded within religious rituals aimed at appeasing *Sitala*, making vaccination appear as a disruption to this sacred order [Arnold et al., 1993, Harrison, 1994]. The direct challenge to spiritual beliefs caused widespread reluctance to embrace the new medical intervention [Bennett, 2020, Brimnes, 2017].

Caste-based concerns amplified this resistance. The caste system, with *Brahmins* at the top as religious leaders and practitioners of variolation, played a significant role in shaping opposition. *Brahmins*, in particular, used their authority to resist vaccination, viewing it as an intrusion into their religious domain. Furthermore, the use of lower-caste children as *vaccinifers* in the arm-to-arm method exacerbated concerns over caste purity. For upper-caste Hindus, the idea of receiving a vaccine derived from a lower-caste individual was seen as ritually polluting, deepening mistrust of the vaccination process [Minsky, 2009, Arnold et al., 1993]. Colonial efforts to assuage these fears, such as Hindu declarations that vaccination would not affect caste status, had limited impact [Bennett, 2007].

Complicating matters further was the sacred status of cows in Hinduism. Although colonial authorities introduced cow-derived lymph to address purity concerns, this backfired. The extraction of lymph from calves was perceived as sacrilege, as cows held a revered position in Hindu society. Attempts by British officials to frame cowpox as a *divine gift* through Sanskrit and Tamil texts did little to overcome the opposition, which saw the process as spiritually contaminating [Bennett, 2007, Arnold et al., 1993].

Gender norms also posed barriers to vaccination. The practice of *Purdah*, which restricted women's interaction with men, prevented access to many women in upper-caste households. Reports of potential abuse by male vaccinators further entrenched resistance among women practicing *Purdah*. While the colonial administration employed female vaccinators to mitigate this, the limited number of female vaccinators left many women unreached, highlighting the persistent gender divide in vaccination efforts [Paturalski, 2021].

Religious and cultural resistance to vaccination was a significant barrier among the Hindu community, despite the proven efficacy of the vaccine. While vaccination efforts notably reduced smallpox prevalence, particularly in urban areas like Bombay [Banthia and Dyson, 1999], the persistence of these beliefs highlights the powerful role of socio-cultural dynamics in shaping public health outcomes. This resistance affected both individual health decisions and broader vaccination efforts across colonial India. In the next section, I develop a microeconomic model to formalize how religious and cultural resistance influenced vaccination behavior and impacted public health across regions.

3 Conceptual Framework

This section develops a conceptual framework to examine how religious beliefs influenced vaccination uptake in colonial India. Building on the health production function from health economics [Grossman, 1972], the framework incorporates religious and cultural resistance as a key factor affecting attitudes towards smallpox vaccination. The model draws on the economics of religion [Iannaccone, 1998] and behavioral economics [Kahneman and Tversky, 1979] to explain how these religious beliefs created barriers to vaccination through their impact on individual decision-making. This integrated approach sheds light on how religious and cultural beliefs shaped health behaviors, leading to vaccine hesitancy.

3.1 Microeconomic Modeling of Vaccination Decisions and Religious Influences

This section presents a microeconomic model analyzing the influence of religious beliefs on vaccination decisions and subsequent health outcomes in colonial India. The model aims to capture how the share of a particular religious group (Hindus), holding beliefs against vaccination, influences individual vaccination choices.

3.1.1 Model Assumptions

I develop the model with the following key assumptions:

i) **Cobb-Douglas Utility Function**: The utility function is assumed to follow a Cobb-Douglas form, implying constant returns to scale between health and consumption.

ii) **No Cost for Vaccination**:[5] Vaccination is provided free of charge by the British colonial administration, so individuals face no financial barrier to receiving the vaccine.

iii) **Uniform Income**: All individuals are assumed to have the same income (Y), which is fully allocated to consumption (C). This removes any income effects on vaccination decisions.

iv) **Perceived Health Benefit Reduction**: The perceived health benefit from vaccination (β) is reduced by two factors: a general opposition to vaccination, represented by γ, and an additional reduction due to religious beliefs, captured by $R(s, I_H)$. The total reduction in perceived benefit is influenced by both general and religious opposition, with religious opposition varying based on the share of Hindus (s) and the strength of these beliefs (I_H).

[5] Vaccination was free and voluntary during the period under study.

v) **Homogeneity of Belief Strength**: All Hindus in a district share the same intensity of religious opposition to vaccination, represented by the parameter I_H. This assumption simplifies the model by assuming uniformity in belief strength within each community.

vi) **No Externalities Considered**: Individuals do not consider positive externalities such as herd immunity when making vaccination decisions. They base their decisions solely on their own utility.

3.1.2 Utility Function

Individuals derive utility from both health (H) and consumption of other goods (C). The utility function follows a Cobb-Douglas form, implying constant returns to scale between health and consumption.[6] The general form of the utility function is:

$$U = C^{\alpha} H^{1-\alpha}$$

Health (H) is influenced by an individual's decision to vaccinate and the perceived benefits of vaccination. The perceived health benefit from vaccination is reduced by two factors: a general opposition to vaccination, represented by γ, and an additional reduction due to religious beliefs, captured by $R(s, I_H)$. This reflects the influence of religious opposition to vaccination in districts with a higher share of Hindus, where social pressure to conform to religious beliefs intensifies.

The health function in the presence of religious opposition to vaccination is given by:

$$H = H_0 + V \cdot (\beta - \gamma - R(s, I_H))$$

where:

[6] Using an alternative utility function, such as the Constant Elasticity of Substitution (CES) function, the threshold condition remains unchanged. With the CES utility function:

$$U = [\delta C^{\rho} + (1-\delta) H^{\rho}]^{1/\rho},$$

the threshold condition is given as $\beta > \gamma + s^{\theta} I_H$, which is the same as in equation (3.1.6).

i) H_0 denotes the baseline level of health in the absence of vaccination.

ii) V is a binary variable representing the individual's vaccination decision, where $V = 1$ indicates the individual is vaccinated, and $V = 0$ indicates they are not.

iii) β represents the intrinsic health benefit derived from receiving the vaccination.

iv) γ captures the general reduction in the perceived benefit of vaccination, arising from opposition not tied to specific religious beliefs, such as general mistrust in the government or skepticism toward public health interventions.

v) s denotes the proportion of the Hindu population in a given district, where $s \in [0,1]$.

vi) I_H is an indicator of the intensity of religious beliefs against vaccination within the Hindu community, where $I_H \in [0,1]$. It is assumed that all Hindus in a district share the same level of opposition, making I_H uniform across the community. $I_H = 0$ implies no religious opposition, while $I_H = 1$ indicates the strongest possible opposition.

vii) $R(s, I_H)$ is a function representing the additional reduction in perceived vaccination benefits due to religious opposition, influenced by both the share of Hindus (s) and the intensity of religious beliefs (I_H).

The function $R(s, I_H)$ is specified as:

$$R(s, I_H) = s^{\theta} \cdot I_H$$

where:

a) $\theta > 1$ represents the nonlinear effect of the share of Hindus (s) on the reduction in perceived vaccination benefits. As s increases, the influence on vaccination hesitancy grows stronger due to social conformity and peer pressure. In larger Hindu populations, religious beliefs against vaccination are more strictly enforced, increasing the cost of deviating from collective norms. This amplifies the impact of religious beliefs on health decisions, leading to a progressively stronger reduction in perceived vaccination benefits.

b) $I_H \in [0,1]$ is the intensity of religious beliefs against vaccination, determining the baseline level of opposition.

These constraints ensure that both the share of Hindus and the strength of religious beliefs contribute to the reduction in perceived vaccination benefits. As the share of Hindus increases (s), its influence on vaccination hesitancy rises nonlinearly, while I_H determines the baseline level of opposition, ranging from no opposition ($I_H = 0$) to maximum opposition ($I_H = 1$).

Substituting this specific form of health into the utility function, I use a Cobb-Douglas utility function with constant returns to scale:

$$U = C^{\alpha}\left(H_0 + V \cdot \left(\beta - \gamma - s^{\theta} I_H\right)\right)^{1-\alpha}$$

where:

a) α denotes the elasticity of utility with respect to consumption.

b) $1-\alpha$ denotes the elasticity of utility with respect to health.

3.1.3 Budget Constraint

Since the price of the vaccine is zero (vaccination conducted by the British was voluntary and free of charge), individuals allocate their entire income (Y) to consumption (C).

$$Y = C$$

3.1.4 Utility Maximization

To determine when individuals will choose to vaccinate, I consider their utility maximization problem. Individuals derive utility from consumption and health, which is influenced by their vaccination status and the share of Hindus in the population.

First, the budget constraint is represented as follows:

$$C = Y$$

Substituting C into the utility function, I get:

$$U = Y^{\alpha}\left(H_0 + \beta V - \gamma V - s^{\theta} I_H V\right)^{1-\alpha}$$

Since V is a binary choice (0 or 1), I evaluate the utility for both $V = 0$ and $V = 1$:

a) **Case 1:** $V = 0$

$$U_0 = Y^{\alpha} H_0^{1-\alpha}$$

b) **Case 2:** $V = 1$

$$U_1 = Y^{\alpha}\left(H_0 + \beta - \gamma - s^{\theta} I_H\right)^{1-\alpha}$$

3.1.5 Derivation of the Vaccination Threshold

To show the main result, I compare the utilities for vaccination (U_1) and non-vaccination (U_0):

$$U_1 > U_0 \implies Y^{\alpha}\left(H_0 + \beta - \gamma - s^{\theta} I_H\right)^{1-\alpha} > Y^{\alpha} H_0^{1-\alpha}$$

Taking logarithms on both sides to simplify, I get:

$$\alpha \ln Y + (1-\alpha)\ln(H_0 + \beta - \gamma - s^{\theta} I_H) > \alpha \ln Y + (1-\alpha)\ln H_0$$

Rearranging terms, I find:

$$(1-\alpha)\ln\left(\frac{H_0 + \beta - \gamma - s^{\theta} I_H}{H_0}\right) > 0$$

Simplifying further:

$$\ln\left(\frac{H_0 + \beta - \gamma - s^{\theta} I_H}{H_0}\right) > 0 \implies \frac{H_0 + \beta - \gamma - s^{\theta} I_H}{H_0} > 1$$

Which gives us the threshold condition:

$$\beta > \gamma + s^{\theta} I_H \tag{1}$$

The threshold condition $\beta > \gamma + s^{\theta} I_H$ suggests that an individual will choose to vaccinate if the health benefit from vaccination (β) exceeds the combined negative influence of non-religious opposition (γ) and religious resistance. The religious resistance depends on both the share of the Hindu population (s) and the intensity of their anti-vaccination beliefs (I_H) in the district. In simpler terms, individuals are more likely to vaccinate when the perceived health benefits outweigh both general skepticism and religious pressures within their community.

3.1.6 Comparative Statics

To analyze how changes in model parameters affect the individual's vaccination decision, I examine the threshold condition:

$$\beta > \gamma + s^{\theta} I_H$$

This inequality determines when the perceived health benefits of vaccination outweigh the combined general and religious opposition. I perform comparative statics on each parameter to understand its impact on the vaccination threshold.

i) **Effect of Hindu Population Share (s)**

   Differentiating with respect to s:

$$\frac{\partial}{\partial s}\left(\beta - \gamma - s^{\theta} I_H\right) = -\theta s^{\theta-1} I_H$$

   Since $\theta > 1$ and $I_H \geq 0$, the derivative is negative. This indicates that as the proportion of Hindus in a district increases, the negative impact of religious opposition on the net perceived benefit becomes stronger. The nonlinear term s^{θ} captures the intensifying effect of social conformity and peer pressure in larger Hindu populations, leading to lower vaccination likelihood.

ii) **Effect of Intensity of Religious Beliefs (I_H)**

Differentiating with respect to I_H:

$$\frac{\partial}{\partial I_H}\left(\beta - \gamma - s^{\theta} I_H\right) = -s^{\theta} \leq 0$$

The negative derivative shows that stronger religious opposition decreases the net perceived benefit of vaccination. As I_H increases, individuals perceive less benefit from vaccinating due to heightened religious resistance, reducing vaccination rates. This underscores the need for culturally sensitive interventions that address specific religious concerns.

iii) **Effect of the Social Conformity Parameter (θ)**

Differentiating with respect to θ:

$$\frac{\partial}{\partial \theta}\left(\beta - \gamma - s^{\theta} I_H\right) = -I_H s^{\theta} \ln s$$

Since $0 < s \leq 1$, $\ln s \leq 0$, making $-\ln s \geq 0$. Therefore, the derivative is non-negative:

$$\frac{\partial}{\partial \theta}\left(\beta - \gamma - s^{\theta} I_H\right) \geq 0$$

An increase in θ amplifies the effect of social conformity. When $s < 1$, a higher θ intensifies the negative impact of religious opposition on vaccination decisions. This reflects that stronger social enforcement of norms exacerbates the reluctance to vaccinate in communities with significant but not overwhelming Hindu populations.

iv) **Interaction Effects Between s and I_H**

The combined effect of s and I_H is multiplicative, magnifying their influence on the vaccination threshold. The cross-partial derivative is:

$$\frac{\partial^2}{\partial s \partial I_H}\left(\beta - \gamma - s^{\theta} I_H\right) = -\theta s^{\theta - 1} \leq 0$$

This negative cross-partial derivative indicates that the adverse effect of increasing I_H on the net perceived benefit is more pronounced when s is larger, and vice versa.

In districts with both a high Hindu population share and strong religious opposition, vaccination rates are likely to be significantly lower.

Building on the conceptual framework that shows how religious beliefs and community composition shape vaccination decisions, I now move to the empirical analysis. This section examines the impact of the Hindu population share on vaccination rates and the medium-term social consequences of lower vaccination rates in colonial India.

4 Data

4.1 Smallpox Vaccination Reports

Starting in 1868, the British began publishing annual smallpox vaccination reports for all provinces, with the first decade (1868–1878) providing district-level, religion-specific data. For my analysis, I use a dataset constructed from 15 of these reports. To analyze this unique dataset, I collapse the year-wise panel data into a cross-sectional format, addressing potential selection bias from missing district-year observations and reducing noise from short-term fluctuations. This allows me to focus on cross-district variation, which is central to understanding the relationship between religious composition and vaccination rates. This approach ensures that my estimates are robust and interpretable, making the findings more reliable despite the limited temporal scope.

These reports highlight the complex challenges encountered in implementing public health interventions during this period. In Punjab, the effectiveness of vaccination campaigns varied significantly, with districts like Rawalpindi demonstrating substantial progress, while others, such as Ludhiana and Delhi, faced considerable cultural and logistical resistance. Public skepticism was particularly pronounced in remote regions where supervision was challenging, and local officials played a pivotal role in either promoting or obstructing vaccination efforts based on their individual perspectives. Notably, there was strong opposition to the use of cow-derived lymph among Hindu communities, illustrating how religious beliefs directly impacted vaccine acceptance. These reports underscore the ongoing tension between colonial public health initiatives and local customs, emphasizing the significant influence of religious norms in shaping public health outcomes.

In Oudh, the reports document a shift from compulsory to voluntary vaccination in 1872-73, reflecting a move toward public education over enforcement. This change, while initially reducing vaccination rates, eventually contributed to a more sustainable approach by gradually reshaping public perception. Success remained uneven across districts, influenced by factors like vaccine quality and entrenched beliefs. Engagement with local leaders, such as Deputy Commissioners, was critical in fostering acceptance, indicating that local cooperation was as important as policy in driving public health efforts. The Bombay Presidency and Sind present a different set of challenges, particularly the refusal of Brahmin communities to use lymph derived from the lower caste children, reflecting the profound impact of caste dynamics on public health practices. Financial constraints also played a key role, with the cost per successful vaccination fluctuating based on the scale of operations and regional cooperation.

4.2 Descriptive Analysis of Vaccination Data [7]

Figure 1 maps the average share of the Hindu population across districts where the British conducted vaccinations between 1868 and 1878. Districts are categorized as high, medium, or low in Hindu population share, indicated by different colors. Hindu populations are primarily concentrated along the western coast of the Bombay province and along the Ganges River, shown in blue. Figure 2 displays the average vaccination rates for the same districts and period. Districts are shaded to represent high, medium, and low vaccination coverage. The maps reveal regional disparities, with Hindu-majority districts generally having lower vaccination rates.

Districts near the Ganges River, particularly within the North-Western Province, exhibit significantly lower vaccination uptake compared to other regions. This suggests that proximity to the Ganges, a site of profound religious importance, corresponds to stronger religious devotion, which played a critical role in resisting colonial vaccination efforts.[8] In these areas, the worship of *Sitala* was particularly prominent, reinforcing the

[7] Summary statistics are provided in the appendix section, Table 8.

[8] Vaccination campaigns in Varanasi, a holy city on the Ganges River, faced significant challenges due to the river's deep religious significance in Hinduism. The Ganges, personified as the goddess Ganga, is central to Hindu rituals, and the introduction of Western medicine, including vaccination, was perceived as a threat to these traditions. This cultural context contributed to local resistance to colonial medical interventions [Bennett, 2007, p. 210], [Sen, 2019].

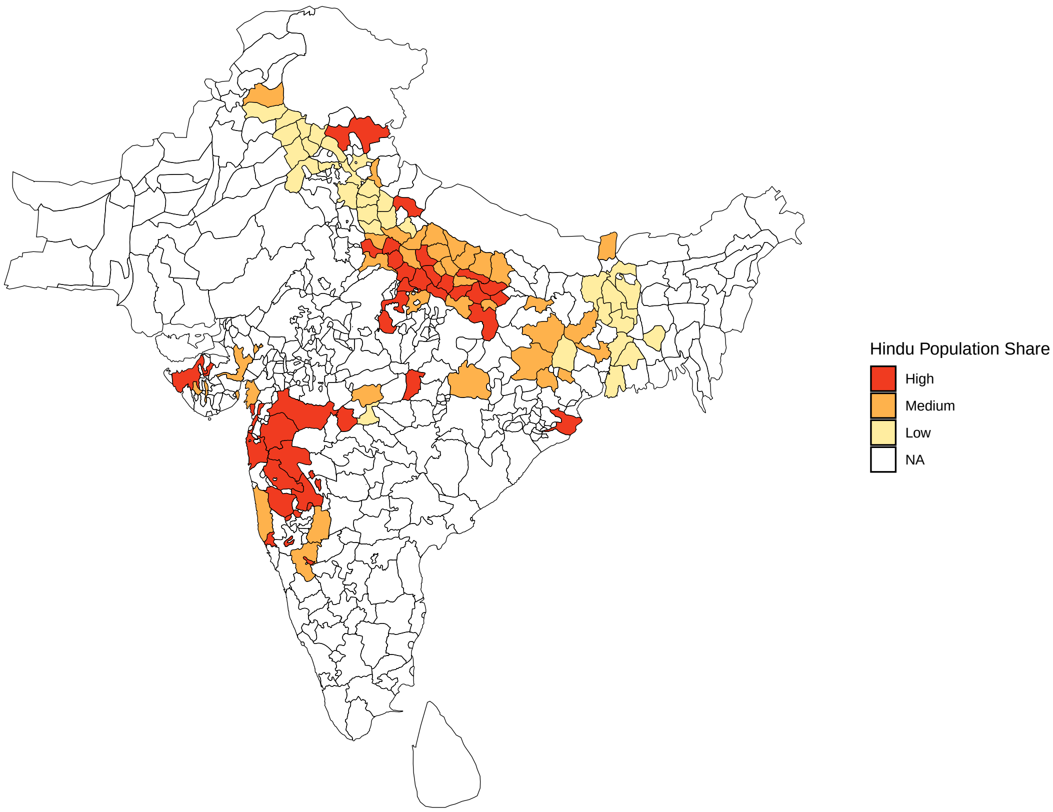

Figure 1: Average Hindu Population Share by District

belief that smallpox was a divine affliction to be managed through religious devotion rather than medical intervention. The closer a district was to the Ganges, the stronger the adherence to this belief system, resulting in greater resistance to vaccination, which was perceived as incompatible with these entrenched religious practices.

Higher vaccination rates in India's coastal districts, particularly along the Arabian Sea, can be attributed to the reduced Hindu orthodoxy shaped by prolonged maritime trade. These regions, historically centers of interethnic cooperation, experienced a blending of cultures due to the involvement of Muslim navigators and merchants, fostering a more inclusive environment. This openness weakened religious rigidity and encouraged the acceptance of innovations like vaccination [Jha, 2013]. The institutional legacy of ethnic tolerance and exposure to Western influences during the colonial period further diminished religious and cultural biases, facilitating the adoption of public health measures in these coastal regions.

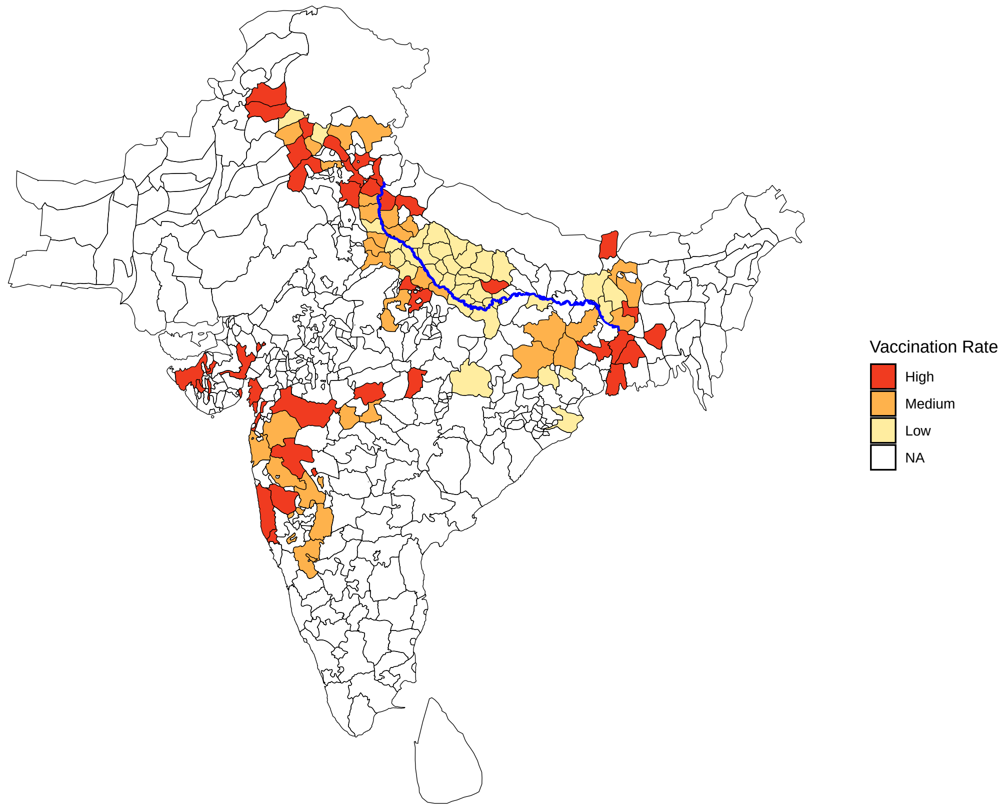

Figure 2: Average Vaccination Rates by District with the Course of the River Ganges Highlighted in Blue

Figure 3 presents a box plot showing the relationship between the share of the Hindu population in a district and its vaccination rates, categorized into Low, Medium, and High Hindu population shares. The plot reveals a clear downward trend: districts with higher Hindu population shares consistently exhibit lower vaccination rates. This inverse relationship is further supported by Figure **??**, which shows a fitted line illustrating the negative correlation between Hindu population share and Hindu vaccination rates across districts. Both figures indicate that as the proportion of Hindus in a district increases, vaccine hesitancy becomes more pronounced, a pattern that aligns with historical smallpox reports identifying religious and cultural factors as key drivers of resistance to vaccination among Hindus.

As previously discussed, the caste system significantly influenced vaccine hesitancy, particularly among upper-caste Hindus. Figure 4 demonstrates that vaccination rates

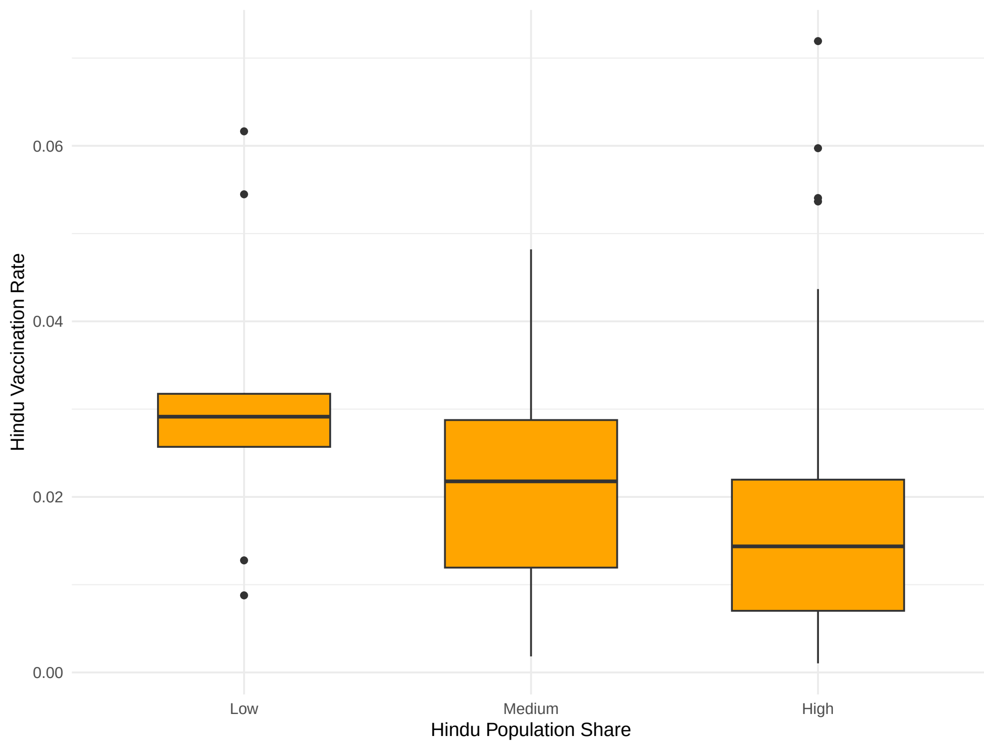

Figure 3: Boxplot showing vaccination rate distribution across varying Hindu population shares

among upper-caste Hindus are consistently lower compared to their lower-caste counterparts across different population share categories. This trend is notable, as lower-caste Hindus, despite facing greater financial and social disadvantages, exhibit higher vaccination rates. The data indicate that among upper-caste Hindus, the social and religious imperative to avoid vaccination outweighed both medical advice and the potential benefits of inoculation. In this context, caste identity appears to have reinforced resistance to vaccination, with upper-caste Hindus leveraging their status to reject colonial interventions that were perceived as threats to traditional societal norms and religious practices.

These findings provide robust empirical support for my hypothesis that religious affiliations significantly influenced vaccination behaviors in colonial India. The consistent pattern of lower Hindu vaccination rates across different demographic compositions strengthens the case for a systematic relationship between religious beliefs and smallpox vaccination campaign by the British. This granular, religion-specific data at the district level provides crucial variation for the forthcoming econometric analysis, allowing us to more precisely isolate and quantify the effect of religious affiliation on vaccination rates.

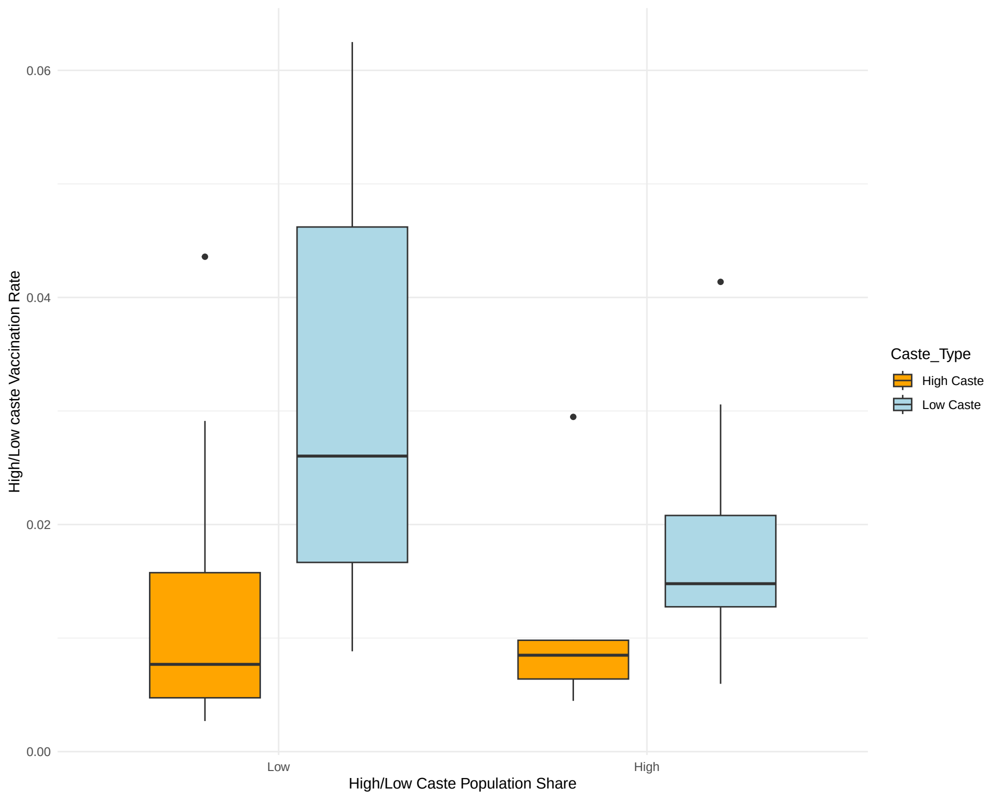

Figure 4: Comparison of vaccination rates between high and low caste Hindu groups

5 Analysis

The descriptive statistics and data visualizations reveal significant spatial variation in vaccination rates across districts in colonial India, suggesting a potential link to religious composition. To rigorously investigate these patterns and quantify the influence of religious and cultural factors on vaccination and social outcomes, I conduct a comprehensive econometric analysis.

Initially, I employ Ordinary Least Squares (OLS) regressions to examine the relationship between the proportion of Hindus in a district and various vaccination rates—overall, religion-specific, and gender-specific—while controlling for an array of demographic, geographic, colonial, and socioeconomic variables. Recognizing the possibility of endogeneity in the relationship between religious composition and vaccination uptake, I implement an Instrumental Variable (IV) approach. Specifically, I use the weighted density of Hindu desecration sites surrounding a district as an instrument for the Hindu population share. This IV strategy aims to provide a more accurate estimation of the causal impact of religious demographics on vaccination rates by mitigating the influence of unobserved confounding factors.

Building upon these initial findings, I explore the medium-term social consequences of differential vaccination uptake across religious groups. Specifically, I assess whether districts with higher proportions of Hindus, which are associated with lower vaccination rates, experienced adverse social outcomes two decades after the vaccination campaign. Utilizing data from the 1891 census, I analyze age-specific widowhood rates and the proportion of unmarried individuals in districts where vaccination campaigns were conducted between 1868 and 1878. While acknowledging limitations such as potential selection bias and unobserved confounders, I discuss the implications of these factors for the robustness of the study's findings.

5.1 Model Specification

The primary objective is to estimate the effect of the Hindu population share on vaccination rates, accounting for a comprehensive set of covariates. The baseline Ordinary Least Squares (OLS) regression model is specified as follows:

$$y_d = \beta_0 + \beta_1 HinduPopulationShare_d + \mathbf{X}_d \boldsymbol{\gamma} + \lambda_p + \varepsilon_d \tag{2}$$

In this equation, y_d represents the vaccination rate in district d, and $HinduPopulationShare_d$ denotes the proportion of Hindus in that district. $\mathbf{X}_d$ is a vector of control variables that includes the proportions of other religious groups, the logarithm of the total population, the gender ratio (number of females per male), the logarithm of ruggedness, the logarithm of maximum caloric availability, the minimum distance to a river, standardized years of British rule, and population density. The term λ_p represents province fixed effects, which control for unobserved heterogeneity at the provincial level that could influence vaccination rates. Finally, ε_d is the error term.

The coefficient β_1 captures the association between the Hindu population share and vaccination rates. A negative and statistically significant β_1 would indicate that a higher proportion of Hindus within a district is associated with lower vaccination uptake. To ensure the robustness of the estimates and address potential confounders, the model incrementally incorporates the aforementioned control variables and province fixed effects, thereby isolating the effect of religious composition on vaccination rates and minimizing the risk of omitted variable bias.

The analysis focuses on three primary dependent variables: the overall vaccination rate, the Hindu-specific vaccination rate, and the female-specific vaccination rate within each district. By first establishing the general association between Hindu population share and overall vaccination uptake, the study sets a baseline for understanding the broader impact of religious composition. Subsequently, by isolating Hindu-specific vaccination rates, the analysis delves deeper into how religious affiliation influences health behaviors within the Hindu population. Finally, by examining female-specific vaccination rates, the study explores potential gender-based disparities in vaccination uptake. This comprehensive approach allows for the identification of both aggregate effects and specific mechanisms through which religious composition shapes public health outcomes.

5.2 Results

Tables 1, 2, and 3 present the main results, examining the relationship between Hindu population share and vaccination rates in colonial India. These results provide empirical evidence for the hypothesis that deeply-rooted Hindu religious beliefs and practices significantly influenced smallpox vaccination uptake during the British colonial period.

5.2.1 Overall Vaccination Rates

Table 1 presents the Ordinary Least Squares (OLS) estimates assessing the impact of Hindu population share on vaccination rates across districts in colonial India. In all six specifications, the coefficient for Hindu population share is consistently negative and statistically significant. In Specification 1, the baseline model without any controls, a one standard deviation (0.241) increase in Hindu population share reduces the average vaccination rate in the district by 0.29 percentage points. The negative effect of Hindu population share on vaccination rates persists and becomes even stronger as demographic, geographic, colonial, and population distribution controls are added. The effect is largest in Specification 5, where a one standard deviation increase in Hindu share reduces vaccination rates by 0.55

percentage points, before slightly decreasing to 0.41 percentage points when province fixed effects are included in Specification 6. Overall, these results suggest a robust negative relationship between the Hindu population share and the overall vaccination rate in a district.

Table 1: OLS Estimates – Hindu Share of Population and Overall Vaccination Rate

	Vaccination Rate					
	(1)	(2)	(3)	(4)	(5)	(6)
Hindu Population Share	-0.012**	-0.014*	-0.021***	-0.017**	-0.023***	-0.017**
	(0.005)	(0.007)	(0.008)	(0.007)	(0.007)	(0.008)
Demographic Controls	No	Yes	Yes	Yes	Yes	Yes
Geographic Controls	No	No	Yes	Yes	Yes	Yes
Colonial Controls	No	No	No	Yes	Yes	Yes
Population Distribution Controls	No	No	No	No	Yes	Yes
Lasso-selected Controls	No	No	No	No	Yes	Yes
Province FE	No	No	No	No	No	Yes
Adjusted R-squared	0.033	0.174	0.281	0.406	0.466	0.462
Observations	110	110	109	109	90	90

Notes: Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are clustered at the district level. Control variables are categorized as follows: *Demographic Controls* include proportions of other religious groups except Muslims which is the comparison group and logarithm of total population; *Geographic Controls* include logarithm of ruggedness, logarithm of maximum caloric availability and logarithm of minimum distance to river; *Colonial Controls* include standardized years of British rule; *Population Distribution Controls* include population density and gender ratio (number of females per male); *Province Fixed Effects* account for unobserved heterogeneity at the provincial level.

5.2.2 Hindu-Specific Vaccination Rates

Next, I focus specifically on the vaccination rate among Hindus in a district and examine how it varies with the Hindu share of the population. The OLS estimates are reported in Table 2. The coefficients are consistently negative and statistically significant across all models, ranging from −0.029 to −0.040. These coefficients, which are larger than those in the corresponding specifications in Table 1, indicate a strong negative effect of the Hindu population share specifically on the Hindu vaccination rate. In the baseline model (Specification 1) without any controls, a one standard deviation (0.241) increase in the Hindu share of the population lowers the average Hindu vaccination rate by 0.70 percentage points. This effect is largest in Specification 5, where a one standard deviation increase in Hindu share reduces Hindu vaccination rates by 0.96 percentage points, and decreases slightly to 0.75 percentage points after province fixed effects are introduced in Specification 6. Furthermore, the larger coefficients in Table 2 compared to Table 1 suggest that the negative relationship between vaccination rates and Hindu population share observed earlier is primarily driven by lower vaccination uptake among Hindus.

Table 2: OLS Estimates – Hindu share of Population and Hindu Vaccination Rate

	Hindu Vaccination Rate					
	(1)	(2)	(3)	(4)	(5)	(6)
Hindu Population Share	-0.029**	-0.030**	-0.037***	-0.037***	-0.040***	-0.031***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.011)	(0.011)
Demographic Controls	No	Yes	Yes	Yes	Yes	Yes
Geographic Controls	No	No	Yes	Yes	Yes	Yes
Colonial Controls	No	No	No	Yes	Yes	Yes
Population Distribution Controls	No	No	No	No	Yes	Yes
Lasso-selected Controls	No	No	No	No	Yes	Yes
Province FE	No	No	No	No	No	Yes
Adjusted R-squared	0.139	0.258	0.344	0.338	0.460	0.461
Observations	110	110	109	109	90	90

Note: Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are clustered at the district level. Control variables are categorized as follows: *Demographic Controls* include logarithm of total population; *Geographic Controls* include logarithm of ruggedness, logarithm of maximum caloric availability and logarithm of minimum distance to river; *Colonial Controls* include standardized years of British rule; *Population Distribution Controls* include population density and gender ratio (number of females per male); *Province Fixed Effects* account for unobserved heterogeneity at the provincial level.

5.2.3 Female-Specific Vaccination Rates

Next, I examine whether women in Hindu-majority districts faced greater barriers to vaccination compared to those in Muslim-majority districts. To investigate this, I perform an OLS regression of the female vaccination rate on the Hindu population share. The results, as shown in Table 3 show a consistently negative and statistically significant association between Hindu population share and female vaccination rates across all six models, with coefficients ranging from −0.016 to −0.027. Specification 1 provides the baseline result, showing that a one standard deviation (0.241) increase in Hindu share of population in a district is associated with a 0.39 percentage point decrease in the female vaccination rate ($p < 0.01$). As additional controls are included across the models, the magnitude of the negative relationship increases slightly, peaking at 0.65 percentage points in specification 5, which incorporates demographic, geographic, colonial, and population distribution controls, as well as Lasso-selected covariates. Specification 6, which adds province fixed effects to account for unobserved regional heterogeneity, shows that a one standard deviation increase in Hindu share reduces female vaccination rates by 0.51 percentage points ($p < 0.01$).

Table 3: OLS Estimates – Hindu Share of Population and Female Vaccination Rate

	Female Vaccination Rate					
	(1)	(2)	(3)	(4)	(5)	(6)
Hindu Population Share	-0.016***	-0.019***	-0.026***	-0.022***	-0.027***	-0.021***
	(0.005)	(0.007)	(0.007)	(0.007)	(0.006)	(0.007)
Demographic Controls	No	Yes	Yes	Yes	Yes	Yes
Geographic Controls	No	No	Yes	Yes	Yes	Yes
Colonial Controls	No	No	No	Yes	Yes	Yes
Population Distribution Controls	No	No	No	No	Yes	Yes
Lasso-selected Controls	No	No	No	No	Yes	Yes
Province FE	No	No	No	No	No	Yes
Adjusted R-squared	0.071	0.225	0.369	0.412	0.515	0.539
Observations	101	101	100	100	87	87

Note: Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are clustered at the district level. Control variables are categorized as follows: *Demographic Controls* include proportions of other religious groups except Muslims which is the comparison group and logarithm of total population; *Geographic Controls* include logarithm of ruggedness, logarithm of maximum caloric availability and logarithm of minimum distance to river; *Colonial Controls* include standardized years of British rule; *Population Distribution Controls* include population density and gender ratio (number of females per male); *Province Fixed Effects* account for unobserved heterogeneity at the provincial level.

These findings support the argument that Hindu households, particularly those of upper castes and classes, were resistant to allowing male vaccinators to interact with women due to the *purdah* system. This cultural practice, which restricted women's interactions with men outside their families, created a significant barrier to female vaccination in

Hindu-majority areas.

6 Instrumental Variable Analysis

To address potential endogeneity and establish a causal link between vaccination rates and the Hindu population share in a district, I construct an instrumental variable (IV) based on proximity to Hindu desecration sites. These desecration sites were more than just religious buildings; they served as pivotal cultural and political symbols for both the rulers and their respective Hindu communities, making them prime targets during periods of conflict. As Eaton [2000] points out, temples were deeply embedded in the social fabric of Hindu life, serving not only as places of worship but also as centers of regional authority and expressions of political legitimacy. By desecrating these temples, conquerors aimed to undermine both the religious identity of the Hindu populace and the political structures that were often intertwined with religious institutions. This strategic destruction was intended to signal the dominance of the ruling powers over the local Hindu communities and to weaken their socio-political cohesion.[9]

However, Eaton [2000] notes that once their dominance was established, many Muslim rulers allowed Hindu communities to continue practicing their religion at these desecrated sites. Rather than completely dismantling the significance of these temples, they often preserved or repaired them, recognizing that maintaining these religious institutions could promote social stability and economic continuity in their newly conquered territories. This pragmatic approach allowed Hindu populations to remain near these sites and continue their religious activities, reinforcing the cultural and religious importance of these locations.[10] As a result, these desecration sites continued to serve as focal points for Hindu communities, making districts in close proximity to these sites more likely to have retained or attracted larger Hindu populations. This enduring cultural and religious significance makes proximity to desecration sites a strong predictor of Hindu population share.

[9] Due to their cultural and religious importance, some temples were desecrated multiple times, highlighting their symbolic role in undermining Hindu socio-political structures (see fig. 5).

[10] Eaton [2000] notes that during the 1661 Mughal campaign in Kuch Bihar, for instance, while the image of the local state deity was destroyed, Mughal authorities issued prohibitory orders to protect the local Hindu population from harm, allowing them to remain in the area despite the temple's desecration.

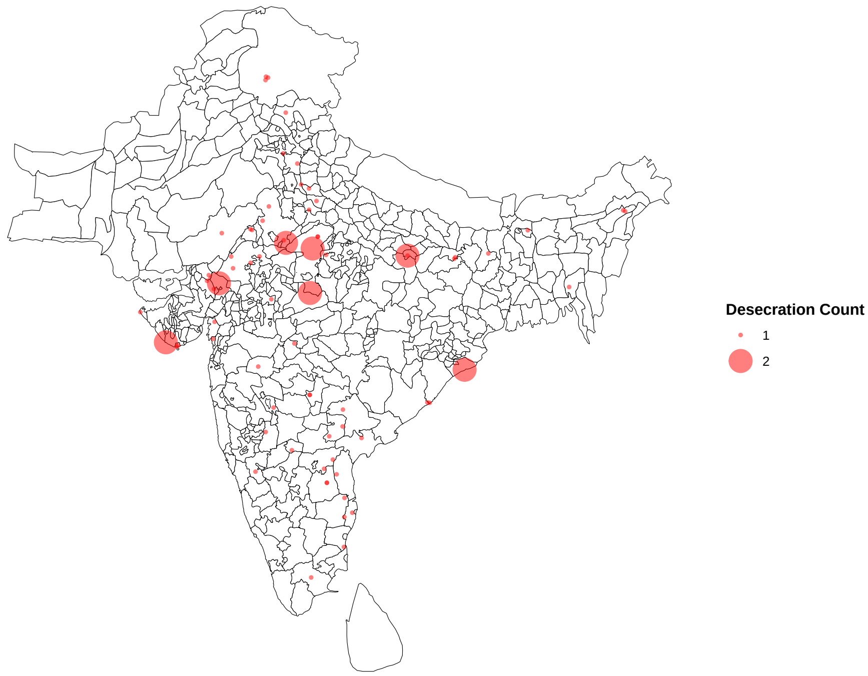

Figure 5: Frequency of Temple Desecrations at Individual Sites. Data sourced from Eaton [2000]; map generated by the author

The list of desecration sites used in this analysis, as compiled by Eaton [2000], is both conservative and highly reliable. Eaton [2000]'s documentation of temple desecrations is based on rigorous historical analysis, including epigraphic and literary sources, ensuring that only well-substantiated cases of temple desecration are included. He identifies 80 desecration sites across five centuries, from 1192 to 1729, each chosen for its verified historical significance (see fig. 7).[11] As shown in Figure 6, these desecration sites are geographically dispersed across India, providing substantial spatial variation for the IV analysis. By focusing on this carefully vetted list, I mitigate concerns about the accuracy or exaggeration of desecration events, ensuring that the instrument is based on genuine and meaningful historical episodes.

I construct the instrumental variable (IV) by calculating the weighted density of temple desecration sites for each district. Sites closer to the district's centroid receive greater weight due to their stronger influence on the local Hindu population. These

[11] Eaton [2000] critiques inflated claims like [Goel, 1998], who reports Mahmud of Ghazni destroying 10,000 temples in Kanauj and similar exaggerated figures for other rulers, noting the lack of credible historical evidence.

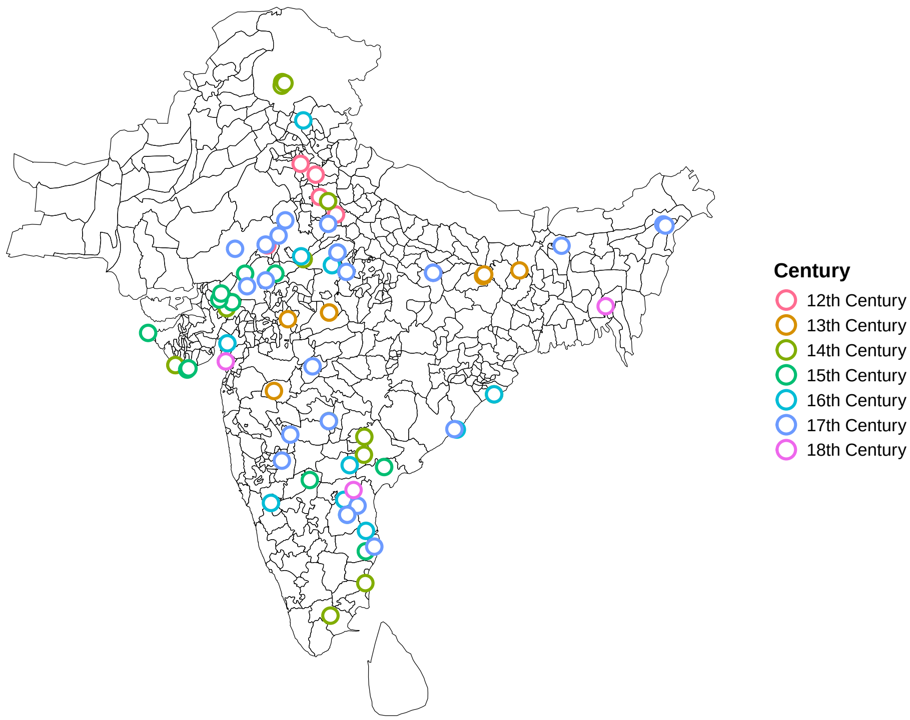

Figure 6: Temple Desecration Locations by Century. Data sourced from Eaton [2000]; map generated by the author

desecration events occurred centuries before colonial vaccination policies, making the location of the sites exogenous to any modern health interventions. This satisfies the exclusion restriction, as the placement of these sites is unrelated to later vaccination rates or public health policies. Their historical and cultural significance also ensures their lasting influence on Hindu population share over time.

To account for the diminishing influence of distant desecration sites, I construct buffers around each district in 50-kilometer increments, extending up to a total distance of 750 kilometers. Desecration sites located within each additional buffer are counted only if they fall outside the previous buffer, thereby avoiding double-counting. A graphical representation of the buffer construction process and the calculation of weighted density is provided in Figure 11, included in the appendix.

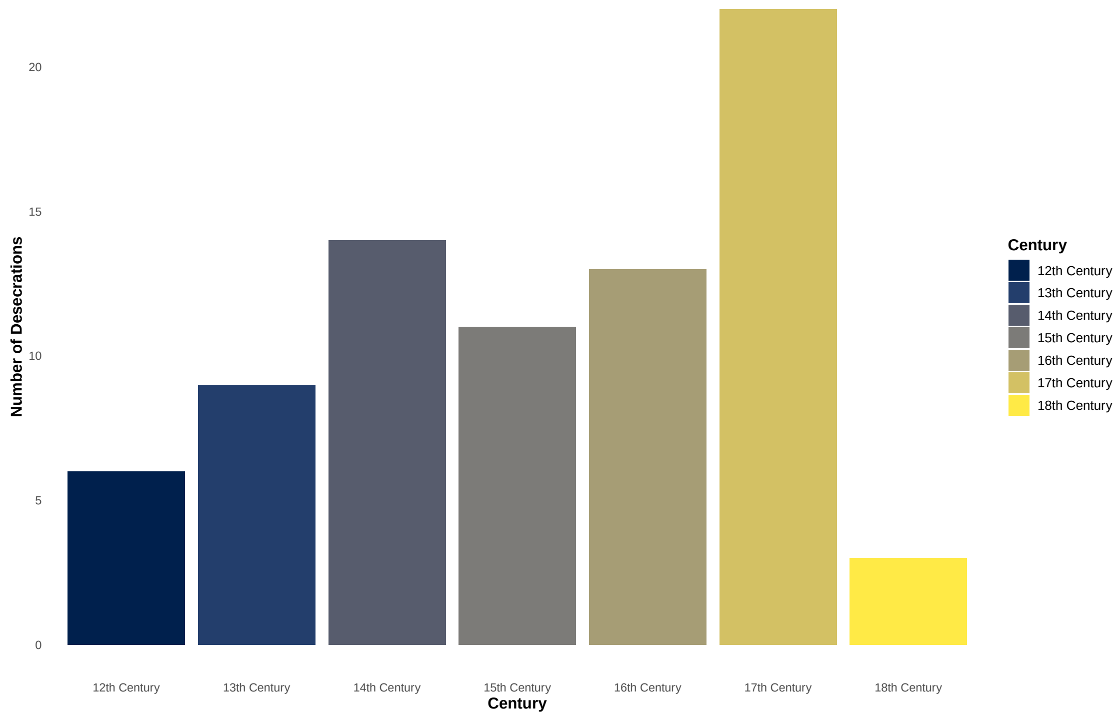

Figure 7: Temple Desecrations by Century. Data sourced from Eaton [2000]

The influence of each site is weighted using the following exponential decay function:

$$W = e^{-k \cdot d}$$

where W is the weight assigned to each site, d is the distance in kilometers from the district center, and $k = 0.01$ is the decay rate. At this rate, a site's influence declines to about 10% of its initial value at a distance of 230 kilometers (see appendix, 9). This reflects the assumption that proximity enhances a site's impact, with more distant sites having a reduced effect. The exponential decay function provides a more realistic representation of how influence diminishes with distance compared to alternatives like inverse distance ($1/d$) or distance squared ($1/d^2$). While these alternatives sharply reduce the influence of distant sites, they may overstate the impact of nearby sites, resulting in overly localized effects. In contrast, the exponential decay function offers a smoother reduction in influence, aligning better with the idea that influence weakens gradually over space without abrupt cutoffs. Additionally, as shown in the first-stage regression later, a more localized influence—whether using inverse distance, distance squared, or a higher value of k in the exponential decay function—predicts the Hindu population share more strongly, causing the coefficient on the Hindu population share to increase.

As a robustness check, I increased the decay rate to test whether a more localized influence would affect the IV estimates. While the higher decay rate led to a stronger prediction of Hindu population share, the IV estimates remained almost unchanged, demonstrating the robustness of the results (see fig. 10 in the appendix section). By selecting an exponential decay function and a value of $k = 0.01$, I adopt a conservative approach, ensuring that even with stricter conditions imposed on the IV, the results remain stable. Also, using exponential decay function avoids the unrealistic assumption of infinite influence at zero distance and provides a flexible, empirically plausible approach for modeling spatial interactions.

The final IV, weighted density of desecration sites for each district, is constructed as the sum of the weighted influences of desecration sites for each district, capturing both the number of sites and their proximity. This approach accounts for spatial dynamics, emphasizing the influence of nearby sites while diminishing the impact of distant ones. To visualize this distribution, I have plotted the weighted density of desecration sites across districts in Figure 8.

6.1 IV Results

To test the relevance of the instrument, I estimate the first-stage regression, where the dependent variable is the Hindu population share in a district and the independent variable is the weighted density of temple desecration sites. The first-stage results, presented in Table 4, confirm the strong relevance of the instrument. The F-statistics range from 13.781 to 27.937 across specifications, consistently exceeding the conventional threshold of 10. Starting from 18.423 in the baseline specification, the F-statistic remains robust and even strengthens to 26.836 in the fully specified model with all controls (Column 6). These results demonstrate that the weighted density of temple desecration sites provides sufficient exogenous variation for reliably predicting Hindu population share, even after accounting for demographic, geographic, colonial, and population distribution controls.

The second-stage 2SLS estimates presented in Table 5 reveal a consistent negative relationship between Hindu population share and overall, Hindu-specific, and female

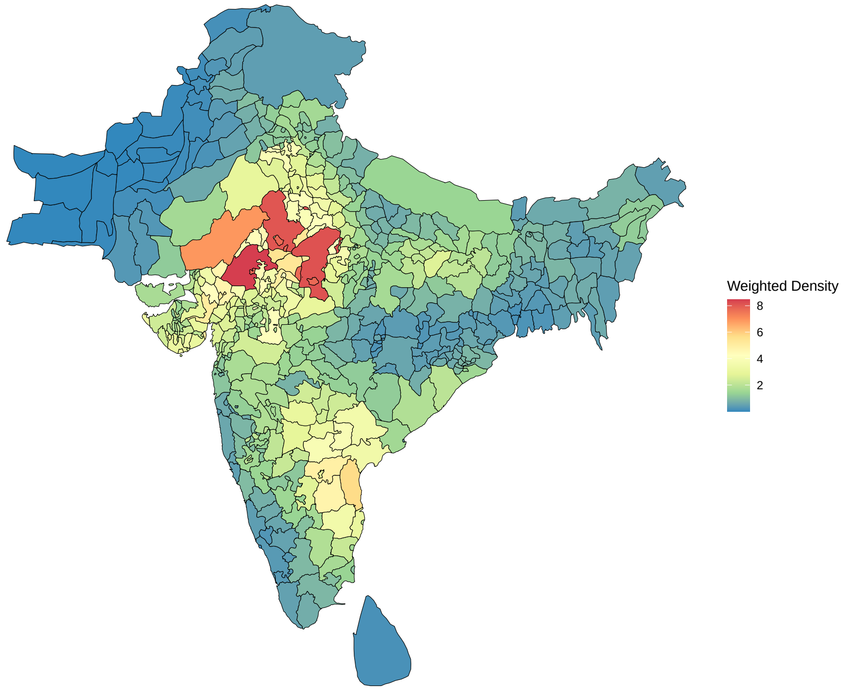

Figure 8: Weighted Density Map of Desecration Sites. Data sourced from Eaton [2000]; map generated by the author.

vaccination rates. The corresponding OLS estimates in Tables 1, 2, and 3 are smaller in magnitude, suggesting a downward bias. This bias may arise because the OLS estimates do not fully capture the variation in religious resistance to vaccination across districts. By using temple desecration sites as an instrument, the 2SLS approach corrects for this potential endogeneity, isolating the exogenous variation in Hindu population share and providing a more accurate estimate of its negative effect on vaccination rates. Panel A shows that a one standard deviation (0.241) increase in Hindu population share leads to a 0.70 to 1.33 percentage point decline in overall vaccination rates, though some coefficients are significant only at the 10% level. Panel B, which focuses specifically on Hindu vaccination rates, highlights a stronger and more statistically significant effect, with declines ranging from 0.89 to 1.98 percentage points. These results are robust across all models, showing significance at the 5% level or better, suggesting that higher Hindu population shares intensify vaccine hesitancy within Hindu communities. Panel C indicates a weaker and less consistent effect on female vaccination rates, with declines of 0.46 to 1.25 percentage points, achieving marginal significance only in the most comprehensive models. The lack

Table 4: First Stage OLS Estimates – Weighted Density and Hindu Share of Population

	Hindu Population Share					
	(1)	(2)	(3)	(4)	(5)	(6)
Weighted Density	0.089***	0.070***	0.062***	0.058***	0.089***	0.060**
	(0.021)	(0.020)	(0.023)	(0.022)	(0.027)	(0.027)
Demographic Controls	No	Yes	Yes	Yes	Yes	Yes
Geographic Controls	No	No	Yes	Yes	Yes	Yes
Colonial Controls	No	No	No	Yes	Yes	Yes
Population Distribution Controls	No	No	No	No	Yes	Yes
Lasso-selected Controls	No	No	No	No	Yes	Yes
Province FE	No	No	No	No	No	Yes
Adjusted R-squared	0.103	0.303	0.316	0.322	0.399	0.617
Observations	104	104	103	103	87	87
F-statistic	18.423	27.937	17.430	13.781	15.463	26.836

Note: Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Standard errors are clustered at the district level. Control variables are categorized as follows: *Demographic Controls* include proportions of other religious groups except Muslims which is the comparison group and logarithm of total population; *Geographic Controls* include logarithm of ruggedness, logarithm of maximum caloric availability and logarithm of minimum distance to river; *Colonial Controls* include standardized years of British rule; *Population Distribution Controls* include population density and gender ratio (number of females per male); *Province Fixed Effects* account for unobserved heterogeneity at the provincial level.

of significance in some coefficients is not surprising. It is likely that elite and upper-caste families from other religious groups, such as Muslims, Sikhs, and others, also discouraged their women from being vaccinated by outside men. This shared resistance across religious groups likely contributed to the weaker overall effect on female vaccination rates.

Table 5: Second-stage 2SLS Estimates

	Panel A: Vaccination Rate					
	(1)	(2)	(3)	(4)	(5)	(6)
Hindu Population Share	-0.029*	-0.032	-0.055*	-0.046**	-0.032**	-0.048*
	(0.016)	(0.021)	(0.029)	(0.023)	(0.015)	(0.025)
Demographic Controls	No	Yes	Yes	Yes	Yes	Yes
Geographic Controls	No	No	Yes	Yes	Yes	Yes
Colonial Controls	No	No	No	Yes	Yes	Yes
Population Distribution Controls	No	No	No	No	Yes	Yes
Lasso-selected Controls	No	No	No	No	Yes	Yes
Province FE	No	No	No	No	No	Yes
Observations	104	104	103	103	87	87
	Panel B: Hindu Vaccination Rate					
	(1)	(2)	(3)	(4)	(5)	(6)
Hindu Population Share	-0.037**	-0.033**	-0.055***	-0.055***	-0.053***	-0.082**
	(0.015)	(0.015)	(0.018)	(0.019)	(0.018)	(0.041)
Demographic Controls	No	Yes	Yes	Yes	Yes	Yes
Geographic Controls	No	No	Yes	Yes	Yes	Yes
Colonial Controls	No	No	No	Yes	Yes	Yes
Population Distribution Controls	No	No	No	No	Yes	Yes
Lasso-selected Controls	No	No	No	No	Yes	Yes
Province FE	No	No	No	No	No	Yes
Observations	104	104	103	103	87	87
	Panel C: Female Vaccination Rate					
	(1)	(2)	(3)	(4)	(5)	(6)
Hindu Population Share	-0.019	-0.024	-0.037	-0.029	-0.026*	-0.052*
	(0.015)	(0.022)	(0.024)	(0.023)	(0.016)	(0.029)
Demographic Controls	No	Yes	Yes	Yes	Yes	Yes
Geographic Controls	No	No	Yes	Yes	Yes	Yes
Colonial Controls	No	No	No	Yes	Yes	Yes
Population Distribution Controls	No	No	No	No	Yes	Yes
Lasso-selected Controls	No	No	No	No	Yes	Yes
Province FE	No	No	No	No	No	Yes
Observations	95	95	94	94	84	84

Note: Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Standard errors are clustered at the district level. Control variables are categorized as follows: *Demographic Controls* include proportions of other religious groups and logarithm of total population; *Geographic Controls* include logarithm of ruggedness, logarithm of maximum caloric availability and logarithm of minimum distance to river; *Colonial Controls* include standardized years of British rule; *Population Distribution Controls* include population density and gender ratio (number of females per male); *Province Fixed Effects* account for unobserved heterogeneity at the provincial level.

7 Robustness Check

7.1 Placebo Test Using Muslim Vaccination Rate

To address potential concerns about the specificity of the my findings, I conduct a placebo test using Muslim vaccination rates as the dependent variable. If the negative relationship between Hindu population share and vaccination rates were driven by unobserved factors affecting all religious groups, I would expect to see a similar pattern for Muslims. Table 6 presents these results. Across all specifications, including the specification with full controls and province fixed effects (column 4), I find no statistically significant relationship between Hindu population share and Muslim vaccination rates across districts. These null findings for Muslim communities confirm that the negative effect on vaccination rates is specific to Hindus and not due to omitted variables affecting all religious groups, such as health infrastructure.

Table 6: Placebo Test: OLS Estimates of Hindu Population Share and Muslim Vaccination Rates

	Muslim Vaccination Rate			
	(1)	(2)	(3)	(4)
Hindu Population Share	-0.014	-0.010	-0.005	0.034
	(0.008)	(0.011)	(0.019)	(0.051)
Demographic Controls	No	Yes	Yes	Yes
Geographic Controls	No	Yes	Yes	Yes
Colonial Controls	No	Yes	Yes	Yes
Population Distribution Controls	No	No	Yes	Yes
Province FE	No	No	No	Yes
Adjusted R-squared	-0.011	-0.033	-0.055	0.018
Observations	109	109	90	90

Note: Standard errors in parentheses. sym* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are clustered at the district level. Control variables are categorized as follows: *Demographic Controls* include proportions of other religious groups except Muslims and logarithm of total population; *Geographic Controls* include logarithm of ruggedness, logarithm of maximum caloric availability and logarithm of minimum distance to river; *Colonial Controls* include standardized years of British rule; *Population Distribution Controls* include population density and gender ratio (number of females per male); *Province Fixed Effects* account for unobserved heterogeneity at the provincial level.

7.2 Sentiment Analysis of the Vaccination Reports Using Natural Language Processing

To further validate the relationship between Hindu population share in a district and vaccine hesitancy observed in the regression analysis, I conduct a robustness check using sentiment analysis of historical vaccination reports. The aim of this analysis is to determine whether districts with higher proportions of Hindus express more negative sentiment toward vaccination efforts. By combining computational text analysis with traditional econometric techniques, this approach provides an additional robustness check to quantitatively assess whether religious bias contributes to vaccine hesitancy.

I begin this analysis by extracting and preprocessing the text from digitized reports. The text is standardized by converting it to lowercase, removing punctuation and numbers, and breaking it down into trigrams—three-word sequences that capture contextual meaning. Trigrams are selected because they provide a more contextualized interpretation of the text, balancing specificity and the broader context when examining language related to vaccination and religious attitudes.

Next, I match these trigrams with the districts from my vaccination dataset to calculate the sentiment scores for each district. For district-level matching of trigrams, I use a multi-stage process. First, I apply string matching to identify district names in the text, allowing for minor spelling variations by comparing the characters of words and identifying close matches based on similarity. When string matching proves insufficient due to OCR errors, I implement phonetic matching, which converts words into phonetic codes to account for differences in spelling based on how they sound. Finally, I use the Jaro-Winkler distance method to further refine the accuracy of matching, particularly for district names with slight variations, by measuring the similarity of strings and accounting for shared prefixes.

For sentiment classification, I employed a pre-trained distilled BERT model, a streamlined version of the BERT (Bidirectional Encoder Representations from Transformers) architecture. This model captured the context of each trigram, classifying the sentiment as positive or negative. BERT's ability to understand the relationship between words in a sequence made it ideal for handling complex and subtle sentiment. The sentiment classification for each trigram was weighted by the model's confidence score, and I calculated a weighted average sentiment score for each district by aggregating these results.

The sentiment scores were then merged with district-level data on Hindu and high-caste Hindu population shares. As shown in Figure 9, the analysis reveals a significant negative relationship between high-caste Hindu population share and sentiment in vaccination reports. Districts with higher proportions of high-caste Hindus exhibited more negative sentiment, while the overall Hindu population share showed no significant relationship. These findings further substantiate the econometric analysis and support the argument that caste dynamics, along with the broader influence of upper-caste Hindus in reinforcing religious principles and beliefs, contributed to vaccine hesitancy. This analysis highlights the role of caste in shaping vaccination attitudes, with upper-caste Hindus not only resisting vaccination but also promoting other cultural and religious norms. While sentiment analysis is limited by the ambiguities of historical records, it provides valuable insights into how caste and religious factors influenced vaccine resistance in colonial India.

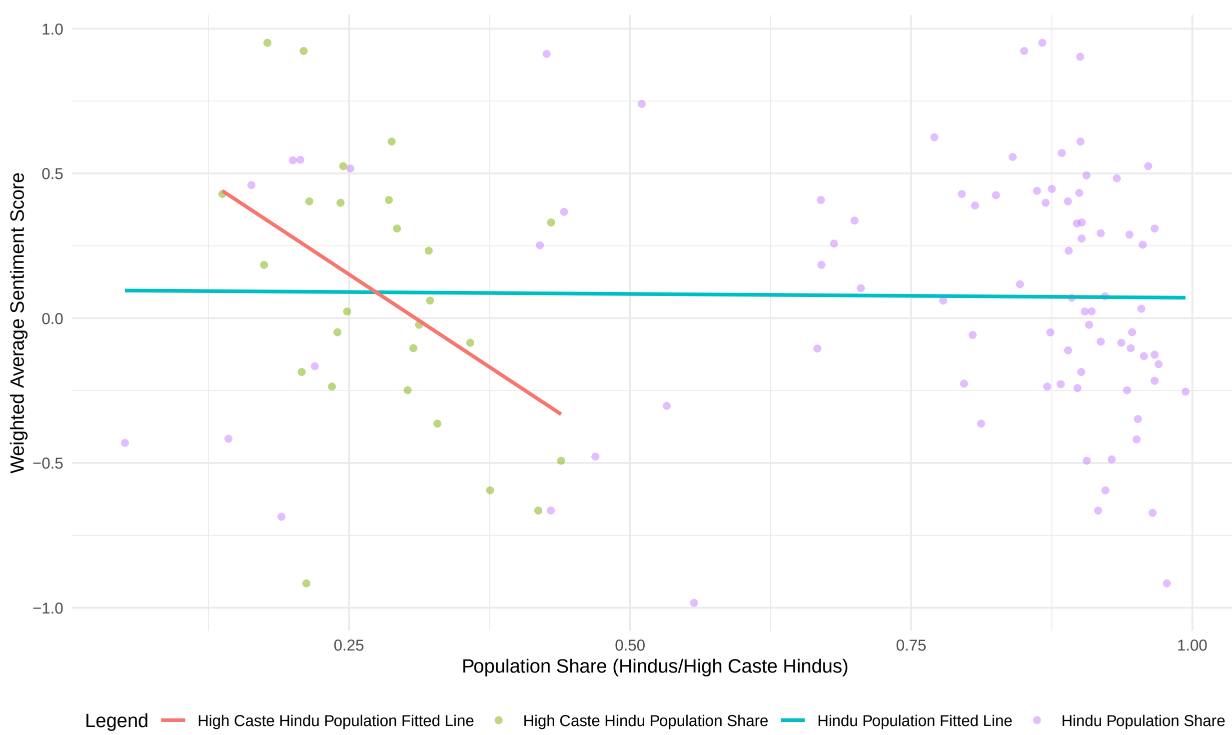

Figure 9: Weighted Sentiment Scores vs. Population Share of Hindus and High Caste Hindus

8 The Impact of Reduced Vaccination Rates on Widowhood and Unmarried Ratios

Given the lower vaccination rates in Hindu-majority districts, it is crucial to assess the potential demographic and social consequences of this hesitancy. Low vaccination uptake increases exposure to smallpox, a disease known for its high mortality and disfiguring effects, which historically had significant social consequences, particularly in marriage prospects. For instance, smallpox survivors with facial scars often faced challenges in the marriage market, as research on 18th- and 19th-century Sweden shows. Sköld [2003] and others [Ager et al., 2018, Voth and Leunig, 1996] demonstrate that individuals with visible disfigurements from smallpox were more likely to marry later, remain unmarried, or choose partners with similar scars. These findings suggest that the social impacts of smallpox extend beyond health outcomes, affecting long-term demographic patterns.

In colonial India, where physical appearance played a crucial role in marriageability, disfigurement from smallpox likely had significant social repercussions, especially for women. Physical beauty was a key factor in determining marriage prospects, and smallpox scars would have greatly reduced these opportunities [Reinke-Williams, 2018]. This explains the higher unmarried ratios observed in districts with lower vaccination rates, where more individuals would have borne visible scars from the disease. Additionally, the widowhood ratio sheds light on the mortality effects of smallpox. Higher mortality rates, particularly among men of marriageable age, would have naturally led to an increase in widows. Evidence from other regions indicates that smallpox caused substantial mortality among young adults [Davenport et al., 2011, Banthia and Dyson, 1999], and in Hindu-majority districts with lower vaccination rates, this likely contributed to a higher number of widows at younger ages.

To explore the medium-term effects of low vaccination rates on widowhood and unmarried ratios, I use smallpox vaccination data for infants under 1 year old from campaigns conducted between 1868 and 1878. From the 1891 census, I extracted information on Hindu widowhood and unmarried status for individuals aged 10-25 years. This cohort, vaccinated (or not) during infancy, offers an ideal sample for studying social outcomes approximately 20 years later. To account for the potential positive effects of early childhood vaccination, I control for the vaccination ratio of infants under 1 year old and include an interaction term between the Hindu population share between 1868 and 1878 and the vaccination ratio of infants under 1 year old. By focusing on this group, I assess whether infant vaccination rates had a lasting impact on marital status, thereby linking early vaccination behavior to medium-term demographic outcomes like widowhood and unmarried ratios in adulthood.

The OLS regression results in Table 7 confirm these hypotheses. A one standard deviation (0.241) increase in Hindu population share increases the unmarried ratio of Hindus, calculated as the number of unmarried Hindus aged 10 to 25 divided by the total population in the same age group, by 17.7 percentage points. Similarly, the widowhood ratio, measured as the number of Hindu widows aged 10 to 25 divided by the total population in this age group, increases by 12.6 percentage points. Both effects are statistically significant at the 1% level.

Table 7: OLS Estimates of Widowhood (10-25 years) and Unmarried Ratios (10-25years) for Hindus Using 1891 Census Data

	Unmarried Ratio of Hindus (10-25 Years)	**Widowed Ratio of Hindus** (10-25 Years)
Hindu Share of Population	0.733^{***} (0.096)	0.521^{***} (0.123)
Under 1 Vax Ratio * Hindu Share	Yes	Yes
Under 1 Vax Ratio	Yes	Yes
Demographic Controls	Yes	Yes
Colonial Controls	Yes	Yes
Geographic Controls	Yes	Yes
Socioeconomic Controls	Yes	Yes
Province FE	Yes	Yes
Observations	99	99

Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Standard errors are clustered at the district level. Control variables are categorized as follows: *Under 1 vax ratio* is the ratio of under one year old infants vaccinated out of total vaccinated *Demographic Controls* include proportions of other religious groups except Muslims which is the comparison group and logarithm of total population; *Geographic Controls* include logarithm of ruggedness, logarithm of maximum caloric availability and logarithm of minimum distance to river; *Colonial Controls* include standardized years of British rule; *Population Distribution Controls* include population density and gender ratio (number of females per male); *Province Fixed Effects* account for unobserved heterogeneity at the provincial level.

9 Conclusion

This paper advances our understanding of the interplay between religion and public health interventions, focusing on the smallpox vaccination campaigns in colonial India. Through a novel district-level dataset spanning 1868-1878, and using an instrumental variables approach based on the location of Hindu temple desecration sites, I show that Hindu-dominated districts exhibited significantly lower vaccination rates. The results demonstrate how deeply rooted religious beliefs can create barriers to the adoption of life-saving technologies, with medium-term demographic effects manifesting in higher widowhood and unmarried ratios.

Crucially, this research contributes to the broader economics literature in several ways. First, it provides empirical evidence that religious and cultural resistance can significantly influence health outcomes, even in the face of public health initiatives. Second, by linking lower vaccination rates to adverse social outcomes decades later, the paper establishes a medium-term causal relationship between cultural resistance and demographic shifts. These findings underscore the importance of integrating cultural understanding into economic models of health behavior, particularly in heterogeneous societies.

Moreover, this paper has contemporary relevance. As global health challenges persist, from the COVID-19 pandemic to ongoing vaccination efforts in various regions, the lessons drawn from colonial India remain pertinent. Policymakers must account for cultural and religious factors when designing and implementing public health interventions. Ignoring these dimensions risks undermining the effectiveness of health campaigns, particularly in communities with strong religious or cultural identities.

Finally, this research opens avenues for future studies to explore the role of religion and culture in other historical contexts and modern public health efforts. By quantifying the impact of religious beliefs on health behaviors and outcomes, I offer a framework for examining how non-economic factors shape public health and demographic trends over time.

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Appendix

Table 8: Summary Statistics

Variable	Count	Mean	SD	Median	Min	Max
Standardized Years Under British Rule	99	-0.000	1.000	0.266	-1.284	3.571
High Caste Hindu Vaccination Rate	30	0.012	0.010	0.008	0.003	0.044
male Vaccination Rate	101	0.019	0.013	0.016	0.001	0.072
Female Vaccination Rate	101	0.019	0.013	0.017	0.001	0.057
Hindu Vaccination Rate	110	0.020	0.018	0.016	0.001	0.136
District Level Vaccination rate	110	0.020	0.014	0.017	0.001	0.081
Lower Caste Hindu Vaccination rate	30	0.020	0.013	0.016	0.006	0.062
Muslim Vaccination Rate	110	0.023	0.034	0.017	0.001	0.327
Weighted Average Sentiment Score	83	0.077	0.435	0.070	-0.983	0.951
Muslim Share of Population	110	0.212	0.222	0.109	0.006	0.947
High Caste Hindu Share of Population	30	0.298	0.103	0.287	0.137	0.599
Under 1 Year Olds Vaccination Ratio	110	0.300	0.194	0.279	0.015	1.003
Lower Caste Hindu Population Share	30	0.702	0.103	0.713	0.401	0.863
Hindu Population Share	110	0.768	0.241	0.874	0.051	0.994
Gender Ratio	99	0.923	0.092	0.935	0.560	1.108
Population Density	96	1.521	0.961	1.370	0.182	5.526
Log (Distance to Ganaga + 1) kms	110	4.518	1.702	4.501	2.303	7.172
Log of Max Caloric Availability (100 kms)	109	9.355	0.156	9.370	8.872	9.632
Log of Ruggedness (100 kms)	109	9.757	1.237	9.618	8.202	12.610

Log of Min Distance to River	109	10.180	1.425	10.441	6.080	12.291
Log of Min Distance to Sea	109	12.680	1.655	13.421	5.795	13.948
Under 1 year Olds Vaccinated	110	4131.070	3534.435	3180.917	168.667	21591.000
Number of Muslims Vaccinated	110	4990.916	11195.613	1352.200	3.000	81953.500
Number of Females Vaccinated	110	7772.051	8479.953	6386.917	466.333	56906.500
Number of Males Vaccinated	110	8274.310	9006.057	6734.750	757.000	61761.500
Number of Hindus Vaccinated	110	9706.802	8807.714	7282.042	163.000	50983.000
Total Number of People Vaccinated	110	16395.972	17449.641	13500.900	1224.000	116201.500
Total Population	110	854215.589	479219.534	793275.167	30377.000	2209904.000

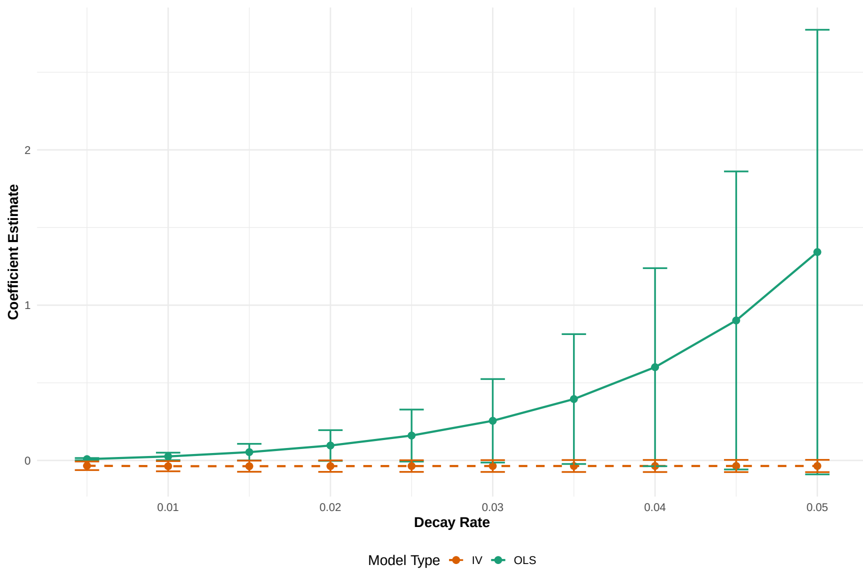

Figure 10: Comparison of OLS and IV Coefficients Across Decay Rates

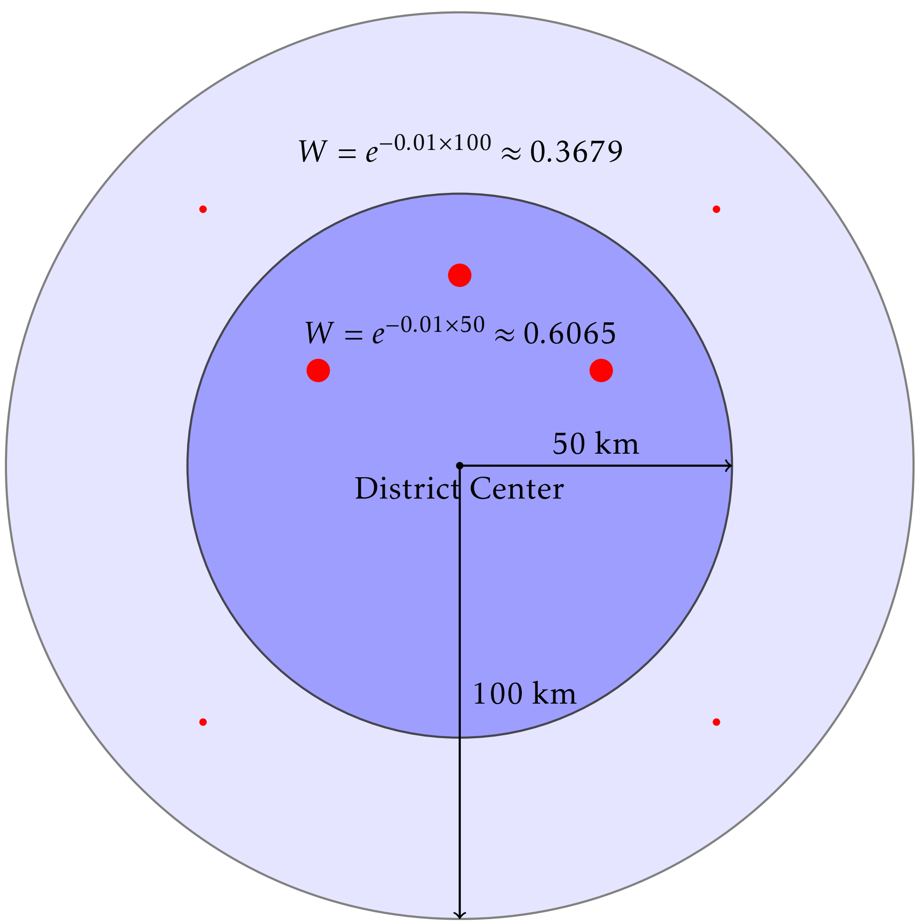

Figure 11: Exponential Decay of Influence with Desecration Sites at 50 km and 100 km Buffers

Exponential Decay Rate

The influence (W) of a desecration site decreases exponentially with distance (d) from the district center:

$$W = e^{-k \cdot d}$$

- W: Weighted influence
- k: Decay rate (0.01)
- d: Distance in kilometers

Calculating Distance for 10% Influence

To determine the distance at which the influence reduces to 10% ($W = 0.1$) with a decay rate (k) of 0.01:

$$0.1 = e^{-0.01 \times d}$$

Taking the natural logarithm of both sides:

$$\ln(0.1) = -0.01 \times d$$

Solving for d:

$$d = \frac{\ln(0.1)}{-0.01} \approx \frac{-2.302585}{-0.01} \approx 230.26 \text{ km}$$

Interpretation of Decay Rate $k = 0.01$

A decay rate of $k = 0.01$ in the exponential decay function indicates that the influence of a desecration site decreases multiplicatively with distance. Specifically:

$$\begin{aligned}
\text{At } d = 1 \text{ km:} \quad & W = e^{-0.01\times 1} \approx 0.99005 \quad (99\%) \\
\text{At } d = 50 \text{ km:} \quad & W = e^{-0.01\times 50} \approx 0.6065 \quad (60.65\%) \\
\text{At } d = 100 \text{ km:} \quad & W = e^{-0.01\times 100} \approx 0.3679 \quad (36.79\%) \\
\text{At } d = 1000 \text{ km:} \quad & W = e^{-0.01\times 1000} \approx 0.000045 \quad (0.0045\%)
\end{aligned}$$