Effect of COVID-19 Pandemic on Routine Childhood Immunization*

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Abstract

An estimated 48 million children across the world did not receive a single dose of routine vaccination between 2019 and 2021, leaving them exposed to vaccine-preventable diseases (VPDs) such as polio (WHO and UNICEF, 2022). This paper presents evidence on the potential channels explaining the decline in routine childhood immunization during the COVID-19 pandemic in India. Using a household survey on retrospective births, we exploit temporal and regional variations in the severity of the pandemic and lockdown-induced mobility restrictions to find a decline in coverage for routine immunization for children. Further, we also observe a drop in childhood immunization rates due to variations in monthly COVID-19 vaccines across districts, suggesting resource reallocation towards adult vaccination against the coronavirus. While pre-pandemic gender biases in immunization rates were not present, our findings show that girls faced increased barriers to receiving post-birth vaccines due to higher restrictions on movement. However, the pandemic severity or administration of the COVID-19 vaccines did not deferentially impact girls compared to boys. Our results emphasize the need for government catch-up programs for missed vaccinations to prevent potential outbreaks of VPDs.

Keywords: COVID-19, immunization, India

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1 Introduction

In 2021, two years after the coronavirus pandemic outbreak, a joint report by the World Health Organization and UNICEF highlighted that the world witnessed the lowest routine vaccination coverage documented since 2008. As a result, an estimated 67 million under-vaccinated children were exposed to vaccine-preventable diseases (VPDs) such as diphtheria, measles, and polio between 2019 to 2021 (WHO and UNICEF, 2022). As of 17 May 2023, India accounted for 6% and 8% of total COVID-infected cases and deaths globally (WHO, 2023). The number of zero-dose children, or those who were not given any routine vaccinations in the country, increased from 1.3 million in 2019 to 2.7 million in 2021, which accounted for 10.8% of the global drop in immunizations (UNICEF, 2023). If past experiences are any indication, the indirect number of fatalities from measles, HIV, and tuberculosis due to disruptions in immunizations might far outweigh the number of deaths caused by the pandemic itself, such as during the 2014-15 Ebola breakout in West Africa (Takahashi et al., 2015). This paper aims to explore the potential mechanisms explaining the decline in childhood vaccination rates during the COVID-19 pandemic in India.

A rich body of literature emphasizes both the short and long-term importance of childhood vaccination, including improved anthropometric measures (Upadhyay and Srivastava, 2017), reduced fertility rates (Bhalotra et al., 2022), better test scores (Arsenault et al., 2020), increased wages and per-capita expenditure in the future (Summan et al., 2022). Delayed vaccination, as opposed to complete omission, has also been shown to result in a prolonged risk of disease exposure and transmission of VPDs among children (Guerra, 2007; Nayar et al., 2022). India's Universal Immunization Programme (UIP), one of the largest childhood vaccination programs worldwide, provides free vaccines against VPDs, including BCG (Bacillus Calmette Guerin), DPT (Diphtheria, Pertussis, and Tetanus Toxoid), OPV (Oral Polio Vaccine), Measles, Hepatitis B, TT (Tetanus Toxoid), Hib-containing Pentavalent vaccine (DPT+HepB+Hib), etc. Despite the increase in UIP's budget from 1.17 billion USD in 2018 to 1.58 billion USD in 2020, India recorded the highest number of zero-dose children at the end of 2021 (Schueller et al., 2022). The outbreak of the COVID-19 pandemic substantially impacted healthcare delivery, leading to disruptions in routine immunization services due to strain on healthcare systems, fear of infection, and limited mobility that restricted access to healthcare facilities (Summan et al., 2023; Raut and Huy, 2022; Jain et al., 2021). Disruptions in the supply chain and shortages of healthcare staff further contributed to the decline, leaving many children at risk of contracting vaccine-preventable diseases. Our study examines three underlying factors explaining this decline - severity of the pandemic, lockdown-induced mobility restrictions, and the distribution of new COVID-19 vaccines in India.

We use two measures to quantify the severity of the pandemic, the total number of laboratory confirmations of COVID-19 infection (irrespective of clinical signs and symptoms) and the number of deaths due to COVID as a proportion of 100 confirmed cases, also referred to as the Case Fatality Rate (CFR). The severity of the pandemic captures the perceived risk associated with accessing healthcare services due to the fear of contracting the virus, which hinders families from seeking childhood vaccinations to minimize exposure. For an increase of 100 average cases in the past 30 days to vaccine eligibility, we observe a 0.4–1.8 percentage points ($p < 0.05$) decline in the likelihood of receiving a vaccine administered at birth, while the magnitude of the decline increases to 1.5–7.7 ($p < 0.01$) percentage points for vaccines due at six, ten and fourteen weeks, respectively. Similar results are observed while examining the impact of average CFR. However, the magnitude of the decline is higher due to average cases as compared to average CFR. We also investigate the impact of limitations on mobility, such as government-imposed lockdowns, on vaccination rates. Our results show that for every 20% increase in average mobility restrictions relative to the baseline period, we observe a decline of 0.3–0.5 percentage points for vaccines administered at birth, 1.4–1.8 percentage points at six weeks, 1.8–3 percentage points at ten weeks, and 3.4–4.4 percentage points at 14 weeks, respectively.

We also investigate the potential implications of COVID-19 vaccine distribution on routine immunization rates. Currently, the UIP in India provides 390 million doses of vaccine spread across a year, covering approximately 4% of the total population, including infants and pregnant women. However, with the emergency-use approval of AstraZeneca-Oxford University's Covishield and Bharat Biotech's Covaxin in January 2021, the government aimed to administer 400-500 million

COVID-vaccine doses within two quarters. This became the largest vaccine drive against COVID-19 worldwide and required double the capacity of healthcare professionals (Bhuyan, 2020). Various media reported possible shortages of ancillary items, such as glass vials and syringes, cold chain storage, and logistics (Dhillon, 2020). States like Delhi began training healthcare staff, including medical officers, vaccination officers, ASHA workers, etc., in preparation for the COVID-19 vaccination as early as December 2020 (Sen, 2020). Consequently, the temporary reorientation of resources from both the public and private sectors toward coronavirus vaccination might have impacted routine immunization efforts for children. By exploiting variation in the COVID-19 vaccine doses administered 30 days prior to the date of vaccine eligibility across districts over time, we find a decline of 0.8–1.4 percentage points for vaccines administered before 6 weeks, while the decline increased to 2–2.5 percentage points for vaccines due at 10 and 14 weeks, respectively.

We further investigate the presence of gender disparities in routine immunization amid the pandemic. Although we found no gender differences in vaccination rates pre-pandemic, our results indicate that lockdown-induced mobility restrictions were associated with reduced vaccination rates for girls relative to boys, particularly for vaccines administered post-birth. However, neither the severity of the pandemic nor the administration of the COVID-19 vaccines had a differential effect on childhood vaccines for girls. Therefore, our results suggest that demand-side factors, such as limited access to healthcare due to restricted mobility, negatively affect routine vaccinations for girls.

Our study contributes to the existing literature on the effects of the pandemic on routine immunization in multiple ways. First, to the best of our knowledge, this is the first study that examines the association between the severity of the pandemic and routine immunization. While existing studies have demonstrated a decline in immunization rates due to the COVID-19 pandemic (Summan et al., 2023), our analysis leverages spatial and temporal variations in the number of confirmed cases and deaths to draw meaningful insights. Second, unlike the previous studies that focus solely on the impact of lockdowns (Jain et al., 2021), our study highlights three possible channels that could explain the decline in immunization rates during the pandemic. These include severity of the pandemic (measured by the number of cases or CFR), mobility restrictions due to government-mandated lockdowns, and the redirection of resources toward COVID-19 vaccine administration. Third, our paper offers suggestive evidence of the unintended consequences of the COVID-19 vaccine roll-out on routine immunization. By analyzing district-wise variations in average COVID-19 vaccine doses administered 30 days prior to vaccine eligibility, we find a decrease in the likelihood of receiving routine immunizations. This decrease is speculated to result from the temporary diversion of healthcare resources, including medical professionals, facilities, and cold storage units, towards the COVID-19 vaccination campaign, as highlighted in various media reports and opinion articles.

Finally, our results show that while there were no pre-pandemic gender disparities in routine immunization amongst children, limited mobility significantly decreased the chances of girls receiving routine vaccines. This evidence suggests that intra-household biases against the healthcare needs of girls, rather than fear of contracting the virus or resource diversion towards COVID-19 vaccines, were a significant contributor to the decline in immunization rates for girls. The rest of the paper is organized as follows: Section 2 provides a background on the timeline for the COVID-19 pandemic in India. Sections 3 and 4 discuss the datasets and empirical models, respectively. Section 5 explains the key results, and section 6 concludes.

2 COVID-19 Timeline in India

India recorded its first confirmed case of COVID-19 on January 27, 2020. Within two months, on March 23, the total number of confirmed cases increased to 606, and the incidence rate was doubling every ten days (Google Health). The Government of India (GoI) declared a countrywide 21-day lockdown starting on March 24, 2020, banning all domestic and international flights, trains, and vehicular transport except for essential purposes. The lockdown was extended for 14 days until 3^{rd} May 2020. Later, the states were directed to identify a list of containment zones, consisting of a cluster of houses in a neighborhood, to isolate the residents prohibiting egress or entry. The

GoI-imposed lockdown was extended several times until May 31, 2020. Post that, the government lifted some restrictions by reopening hotels, restaurants, and shopping malls, except in designated containment zones. Starting from July 1, 2020, more businesses and public transport services such as movie theatres and metro rail were permitted. By October, most activities were allowed, and the capacity restraints were eased.

In an effort to vaccinate the entire adult population, two vaccines, AstraZeneca-Oxford University's Covishield and Bharat Biotech's Covaxin, were granted emergency-use approval in January 2021 in India. With each individual receiving two doses, approximately 1.8 billion vaccine doses were projected to be necessary for vaccinating 68% of the Indian population aged 18 years or above (Kant, 2021). Consequently, various state governments started training healthcare workers for the successful execution of the COVID vaccination drive (Sharma, 2020). The first COVID vaccine was administered on 16^{th} January 2021 (MoHFW). As of 23^{rd} May 2023, India had delivered over 2.2 billion doses (MoHFW).

3 Data

We use four main datasets for our analysis - (1) the fifth round of the National and Family Health Survey (NFHS), (2) Google open-source data on new cases and deaths, (3) Google Community Mobility, and (4) COVID-19 vaccine doses from CoWin database.

3.1 National and Family Health Survey (NFHS-5)

The National and Family Health Survey (NFHS) is a comprehensive multi-round survey conducted across all 36 states and union territories (UTs) of India (NFHS-5, 2019). The survey collects information on health, population, women and child nutrition, fertility, family planning, and family welfare. We use the fifth round of the NFHS survey, which was conducted in two phases: Phase-I spanning between June 2019 to March 2020, and Phase II from November 2020 to April 2021. These two phases covered all 707 districts across the country.

The survey collects information on immunization records, including which vaccines were administered and their corresponding dates, for all children born three years before the survey. Consequently, we restrict our sample to surviving children who are three years old at the time of the survey. Amongst the sample of children, 14% did not have a health card that records information on vaccination dates. Since the information is retrospectively collected, we are left with a sample of children born before, during, and after the pandemic despite a gap in the interviews during the pandemic. The distribution for the number of births from 2016 to 2021 is depicted in Figure 1 (a).[1]

3.2 Google COVID-19 Cases Data

The COVID-19 Open Data Repository provides the daily district-wise total number of COVID-positive cases and fatalities from April 2020 to September 2022 (Google Covid-19 Open Data, 2022).[2]. Note that the number of cases can take negative values, which signifies corrections or adjustments in the measurement methodology.[3] As a result of new districts being created, the district names vary between datasets, and we managed to match 685 districts out of the total 707. Of the 22 unmatched districts, 20 belonged to Jammu and Kashmir, for which information on COVID cases was unavailable.[4]

The number of COVID positive cases and deaths for months before March 2020 is assigned as zero. Figure 1 (b) and (c) depict the monthly number of positive cases and death. Notably, both figures have three distinct peaks, namely March-May 2020 (Wave-I), April-June 2021 (Wave-II), and early 2022, respectively. To gauge the severity of the pandemic, we use two measures, the average number of confirmed cases and the Case Fatality Rate (CFR) 30 days prior to the date of vaccine eligibility, where CFR is computed as the proportion of deaths for every 100 confirmed

[1] Since the survey was conducted in two phases, and it records births in the past three years, the number of births before January 2020 is greater than those post-2020.

[2] The Google COVID-19 data was accessed from `www.incovid19.org`, which heavily relied on the open-source database of `https://www.mygov.in/covid19india.org`

[3] On 31^{st} October 2020, significantly negative values were recorded for most districts and hence excluded from our analysis.

[4] The remaining two districts were Kamrup Metropolitan in the state of Assam and Uttar Bastar Kanker in Chhattisgarh, respectively. Also, 28 districts from the COVID cases dataset remained unmatched, that includes all districts formed after March 2017, i.e., after the sample design for NFHS-5 was finalized.

cases. The count of confirmed cases provides an indication of the magnitude of infection, while the Case Fatality Rate (CFR) measures the severity of the disease.

3.3 Google Community Mobility Reports

Next, we use the Google Community Mobility Reports that systematically records the patterns of movement of a population in a geographical location across several types of places, including retail and recreational establishments, grocery stores and pharmacies, parks, transit stations, workplaces, and residential areas for a given period as a measure of restrictions on mobility. For India, at its most granular level, the data capture the daily percentage change in visits to these places relative to the baseline period for all districts over time (Google Covid-19 Community Mobility Reports, 2022). A baseline day is a median value, for the corresponding day of the week, during the 5-week period, Jan 3–Feb 6, 2020, i.e., before the first wave of the COVID-19 pandemic.[5] For our analysis, we use mobility trends to retail outlets that include visits to restaurants, cafes, shopping centers, theme parks, museums, libraries, and movie theaters. Out of the 633 unique districts in the mobility data, we were able to match 631 districts to NFHS-5. The two exceptions were the Mahe district of Kerala and the Alipurduar district of West Bengal. However, about 75 districts from the states of Arunachal Pradesh, Jammu and Kashmir, Telangana, etc., remain unmatched in the NFHS data.[6]

Figure 1 (d) shows the monthly percentage change in mobility restrictions from February 2020 to December 2021. A positive value indicates a higher restriction on mobility as compared to the baseline period (or less movement). In contrast, a negative value means fewer restrictions on mobility, therefore, more movement compared to the baseline. Since the data is available after February 2020, we assume that pre-pandemic mobility levels are zero, i.e., equal to the baseline mobility. We observe two peaks indicating an increase in restrictions on mobility corresponding

[5]Note that the data is sensitive to migration over time. Also, the change is calculated using data on Google account users who have enabled their location history.

[6]Most of the unmatched districts were not created as per 2011 Census data, which appears to be the basis for the mobility data.

to the two COVID-19 waves in India. However, there is a negative overall trend in the graph, suggesting gradual relaxation in mobility constraints. This trend continues till October 2022 when restrictions finally turn negative, indicating higher mobility compared to the baseline period.

3.4 COVID-19 Vaccine Database

Finally, we utilize data on the daily number of COVID-19 vaccine doses administered across districts in India. This data was sourced from the CoWIN website, an online platform created by the Ministry of Health and Family Welfare to record COVID-19 vaccination registrations. The dataset records the total number of COVID-19 vaccines administered, for both Covishield and Covaxin, starting from January 16, 2021, to September 29, 2021. By the end of this period, a total of 879 million vaccine doses had been administered across the country. We successfully matched all districts from this dataset to NFHS, with the only exception of Mumbai Suburban in Maharashtra. We find an overall positive trend in the monthly total number of COVID-19 vaccines administered as shown in Figure 1 (e).

3.5 Summary Statistics

To visualize the spatial and temporal variation in the impact of the pandemic, we plot the district-wise average number of confirmed positive cases, deaths, and mobility restrictions across the two waves in Figure 2 in panels (a), (b), and (c), respectively. Wave I refers to the period from April to May 2020, capturing the initial phase of the pandemic. While Wave II refers to the months of April-June 2021. Though the number of cases and deaths were lower in the first wave the restrictions on mobility were higher in the first wave.[7] Since COVID-19 vaccines were not administered until the first wave, we plot the district-wise total number of COVID vaccines at the end of September 2021, which is the last date in our data, in Figure 3 separately. We further restrict our sample to households that were interviewed after March 1, 2020, which coincides with the start of the

[7] Note that the data is missing for the newly created districts in the state of Telangana, Jammu and Kashmir and north-eastern states as the shape file for the maps correspond to the boundaries in Census 2011.

first wave of the pandemic in India, so as to utilize data on households with children eligible for vaccines both before and after the pandemic period. Consequently, we are left with a final sample from 14 states and 300 districts (Figure A.1). We show the surviving sample and the excluded sample are balanced across all control variables, except for the place of residence and religion indicators (Table A.1).

We report the averages (with standard errors) of various controls for three cohorts of children based on their month of birth in Table 2. The first column consists of children born before March 2020, referred to as the pre-COVID cohort. The second group includes children born between March and December 2020, after the first wave of the COVID-19 pandemic but before the administration of COVID-19 vaccines. The third group comprises children born between December 2020 and March 2021, born after the first wave and after the commencement of the COVID-19 vaccine administration. We find that all three cohorts are balanced across all control variables except for the total number of siblings. Similar to Table 2, we also report the mean and standard error for all vaccines outlined in Table 1. The cohorts in columns (1)-(3)of Table 3 are divided based on the month and year of vaccine eligibility. Overall, the COVID-exposed cohorts (columns (2) and (3)) are less likely to receive the vaccine as compared to the pre-COVID cohort.

4 Empirical Model

We employ the following linear regression model to study the relationship between the COVID-19 pandemic and routine immunization -

$$vaccine_{idt} = \beta_0 + \beta_C pandemic_{dt} + \mathbf{X}_{id}\beta_{\mathbf{X}} + \alpha_d + \gamma_t + \varepsilon_{idt}, \tag{1}$$

where $vaccine_{idt}$ is an indicator variable that takes the value one if a child i, born in district d and eligible for a vaccine on date t, received the vaccine and zero otherwise. We include dummies for all vaccines from birth until 6 months of age, including BCG, Polio, DPT, etc. The main parameter of interest is $pandemic_{dt}$ that takes the following variables – $cases_{dt}$, cfr_{dt}, $mobility_{dt}$

and $doses_{dt}$. $cases_{dt}$ is a continuous variable that records the average number of confirmed COVID-19 cases (in hundreds) in the previous 30 days leading up to the vaccine eligibility date, t in district d. Similarly, cfr_{dt} measures the average Case Fatality Ratio (CFR) for the past 30 days from the eligibility date, t, where CFR is calculated as the number of deaths as a proportion of 100 confirmed cases. $mobility_{dt}$ is a categorical variable that assumes a value of zero if there is a negative or no change in the average restrictions on movement in the previous 30 days from vaccine eligibility. It takes values ranging from one to five for every twenty percent increase in average restrictions on mobility. Therefore, a higher value of $mobility_{dt}$ indicates more stringent restrictions on movement. Finally, $doses_{dt}$ is a continuous variable that records the average number of COVID-19 vaccine doses administered during the 30 days leading up to the eligibility date, t.

$\mathbf{X}_{id}$ includes various time-invariant controls for the child, mother, and household. Child-level controls include sex, birth order, and twin status. Mother-level controls include religion, years of education, the total number of children, and caste. We also include household controls such as an indicator for rural/urban, the number of household members, the sex of the household head, and indicators for wealth. Finally, we include district and month-of-birth fixed effects to account for location and time-specific factors. To account for potential correlation within districts, we cluster the standard errors at the district level.

To ensure a minimum interval of time between two vaccine doses is passed, we calculate the date of eligibility for the higher-dose vaccines based on the vaccination date of the previous dose. For instance, the eligibility date for Polio-1 is determined as 6 weeks after the Polio-0 vaccination date, and similarly, the date for Polio-2 eligibility is set as 4 weeks after Polio-1. If the previous dose was not received, then the date of vaccine eligibility is calculated based on the date of birth. In cases where a higher-dose vaccination was reported but previous doses were marked as not received, we consider the higher-dose value as missing, which accounts for 0.3-3% of the observations. Additionally, if the date of the interview is later than the date of eligibility, we assume that the higher-dose vaccine is missing.

We also estimate the following ordinary least squares (OLS) specification to study whether the relationship between the COVID-19 pandemic and routine immunization varies by gender -

$$
\begin{aligned}
vaccine_{idt} = \beta_0 + \beta_P pandemic_{dt} + \beta_G Girl_{id} + \beta_{GP}(Girl_{id} \times pandemic_{dt}) \\
+ \mathbf{X}_{id}\beta_{\mathbf{X}} + \alpha_d + \gamma_t + \varepsilon_{idt},
\end{aligned}
\tag{2}
$$

where $Girl_{idt}$ is an indicator taking the value one if the sex of the child is female and zero for male. The parameter of interest is β_{GP} which captures the marginal effect on the likelihood of a girl receiving a vaccine relative to a boy for changes in average number of cases, CFR, mobility, and COVID-19 vaccine doses, respectively. The definition of the remaining variables is the same as in equation 1. It is worthwhile to emphasize that both of these equations show mere associations between various COVID statistics and the likelihood of receiving vaccines.

5 Results

5.1 OLS Estimates of the COVID-19 Pandemic on Institutional Delivery

The COVID-19 pandemic could have potentially impacted facility-based deliveries, especially in rural areas due to fear of contracting the virus, mobility restrictions, and strained health facilities. Furthermore, existing literature suggests that children born through institutional delivery were more likely to receive vaccines administered at birth (De and Timilsina, 2020; Moyer et al., 2016). Therefore, prior to examining the effect of the pandemic on routine immunization, we first analyze its impact on the likelihood of institutional delivery. We estimate our model using equation 1, where the outcome variable is 'institutional delivery' that takes the value one if a child is born in a private or public healthcare facility and zero if the child was born at home. Our findings suggest that both case fatality rates (CFR) and restricted mobility are negatively associated with institutional delivery, while the results do not vary by gender (Table 4). On average, for every one COVID death per 100 confirmed cases, the likelihood of a child being born in a health facility falls by 0.3 percentage points. Additionally, a 20% increase in average restrictions on mobility is associated with 0.3 percentage points fall in the probability of institutional delivery. As previously stated, these estimates solely demonstrate an inverse relationship between CFR/mobility and vaccination uptake and not causality.

5.2 OLS Estimates of COVID-19 Pandemic on Childhood Vaccination

The Ministry of Health and Family Welfare (MoHFW) of India publishes the National Immunization Schedule (NIS) for infants, children, and pregnant women outlining the recommended dosage and timing of all necessary vaccinations.[8] A child is considered fully immunized if she receives all due vaccines in the first year of her birth as recommended by the NIS. These vaccines include one dose of bacilli Calmette–Guerin (BCG) vaccine, three doses each of diphtheria, pertussis, and tetanus (DPT), and oral polio vaccine (OPV) and measles-containing vaccine (MCV). Our study focuses on all vaccines administered within the first six months of birth. Among these, BCG, Polio, and Hepatitis B are due at birth, and the three doses of Polio, DPT, and Hepatitis B are due at 6, 10, and 14 weeks, respectively (see Table 1). We report the OLS estimates from equation 1 in Table 5 and Table 6, respectively.

In Panel A, the independent variable corresponds to the average number of confirmed cases (in hundreds) recorded within 30 days from the date of vaccine eligibility. On average, for every 100 new cases, we observe a decline of 0.4-1.8 percentage points in vaccines administered at birth. However, this decline becomes more significant for vaccines scheduled later post-birth. an increase of 100 average cases is associated with a 1.5-2.3 percentage points ($p < 0.01$) decrease in the probability of receiving six-weekly vaccines. Similarly, the probability of receiving vaccines due at 10 and 14 weeks decreased by 2.8-4.9 percentage points ($p < 0.01$) and 6.3-7.7 percentage points ($p < 0.01$), respectively, owing to an increase in 100 average cases three and four months post-birth.

To assess the pandemic's severity, Panel B of Tables 5 and 6 uses the average Case Fatality Rate (CFR) in the 30 days leading up to vaccine eligibility. CFR records the proportion of coronavirus deaths per 100 confirmed cases. Our results indicate that an average of one COVID death per 100

[8] https://main.mohfw.gov.in/sites/default/files/245453521061489663873.pdf

confirmed cases in the 30 days leading up to birth is associated with a reduction of 0.6-1.0 percentage points in the probability of receiving vaccines administered at birth. Also, the magnitude of the decline increases with vaccines administered at later ages. Therefore, the probability of receiving the vaccine administered at six, ten, and fourteen weeks decrease by 1.5-2.0, 1.7-2.6, and 2.6-3.2 percentage points ($p < 0.01$) respectively for an average of one COVID-related mortality per 100 confirmed cases in two, three, and four months after birth. Overall, the magnitude of the decline in vaccination rates caused by the average number of cases is greater compared to CFR.

Next, we look at the impact of government-mandated restrictions on mobility on the probability of receiving the vaccine. Restrictions on mobility could potentially limit access to healthcare services during the pandemic, thereby affecting immunization rates. Our main independent variable in Panel C of Tables 5 and 6 is a categorical variable that takes the value zero if there was no change in average mobility or higher average mobility relative to the pre-COVID period, whereas takes the values one-five for 20 percent increase in average restrictions placed on mobility compared to baseline. We find that for a 20% increase in average restrictions placed on mobility in the past 30 days from the date of vaccine eligibility, the likelihood of receiving vaccines due at birth falls by 0.3-0.5 percentage points ($p < 0.01$). Similar to Panels A and B, the magnitude of decline increased with vaccines administered at later ages.

Finally, in Panel D we explore the impact of the administration of COVID-19 vaccine doses on routine immunization. We find that every 100 COVID-19 vaccines administered on average were associated with a 0.8 percentage point decline in the likelihood of receiving BCG, Polio-0, and Hepatitis-B respectively, while the magnitude of drop was higher to 1.2-1.4 percentage points for vaccines administered at 6 weeks. Similarly, 100 average COVID-19 vaccine doses were associated with a 2.2-2.4 and 2-2.5 percentage points decline in vaccines administered at 10 and 14 weeks, respectively.

It is important to emphasize that the magnitude of the drop in the likelihood of receiving the vaccination is the highest due to the average cases in the past 30 days until vaccine eligibility. Additionally, the decline in receiving the vaccine due to either average COVID cases, CFR, mobility restrictions, or COVID-19 doses grows in magnitude for vaccines due post-birth. Particularly, the pandemic is associated with a 0.8-2.6% decline in vaccines due at birth, while the magnitude increases to 1.6-2.4% for vaccines due at 6 weeks, 3.1-4.6% for those due at 10 weeks and 7.3-8.7% for vaccines due at 14 weeks.

5.3 OLS Estimates of COVID-19 Pandemic by Gender

Next, we proceed to examine the effect of the pandemic on childhood immunization by the gender of the child. Across all panels in Table 7, we find no statistically significant difference in the likelihood of receiving vaccines administered at birth by gender.[9] However, when considering vaccines scheduled at 6, 10, and 14 weeks, respectively, we consistently find a statistically significant decline in the probability of a girl child receiving first, second and third doses of Polio, DPT, and Hepatitis-B due to restrictions on mobility (Panel C in Tables 7 and 8). Additionally, we also observe some statistical significance decline in vaccine uptake due to COVID-19 vaccine doses and CFR for vaccines administered at 10 and 14 weeks respectively, though the significance is not observed across all doses. In particular, a 20% increase in average restrictions on mobility was associated with a drop of 0.4-0.6, 0.9-1.2, 0.7-1 percentage point decline in the likelihood of a girl child receiving vaccines administered at 6,10, and 14 weeks respectively.

Although we did not find any evidence of pre-existing gender bias in childhood vaccination based on NFHS-4 data (2015-16) before the pandemic, our study reveals that such bias emerges when movement is restricted (Table A.2). Particularly, our findings show that girls were less likely to receive vaccines due at later weeks post-birth in districts where higher restrictions were placed on movement. However, no statistically significant difference by gender was observed due to pandemic severity or administration of COVID-19 vaccines. These findings are consistent with the existing literature that show that girls have lower immunization coverage compared to boys, although the gap has narrowed over time (Corsi et al., 2009). Note that if we control for the

[9] The only exception is BCG in Panel D, Table 7. We find that girls were more likely to receive BCG for every 100 COVID-19 vaccines administered.

previous dose in equation 2, the impact of mobility restrictions on subsequent post-birth vaccines for girls is no longer significant. Therefore, there exists a sequential effect of movement restrictions affecting later vaccine doses for the girl children.

6 Conclusion

While prior research has examined the drop in routine immunization rates among children during the pandemic, our study contributes to the existing literature by exploring different reasons behind the drop in routine immunization rates among children during the pandemic. We identify three key channels that contribute to this decline: pandemic severity, government-imposed restrictions on movements, and resource diversion toward COVID-19 vaccination efforts. Our results indicate that girls faced discrimination in vaccination access, primarily due to mobility restrictions, rather than fear of contracting the virus or supply shortages caused by the COVID-19 vaccine administration. These findings suggest the presence of gender biases against girls compared to boys.

Addressing these challenges requires targeted catch-up vaccination programs, closely monitoring areas with low coverage, and ensuring timely booster doses to prevent vaccine-preventable disease outbreaks. While some vaccines have upper age limits for administration, such as HiB and rotavirus, most vaccine-preventable diseases can still be prevented through delayed vaccination. Furthermore, existing studies show that children from less educated, poorer, and lower caste households are more likely to face lower immunization rates (Jain et al., 2021). Considering this, alongside the identified gender disparity in access to vaccinations due to mobility restrictions, comprehensive vaccine delivery mechanisms are essential. This includes deploying mobile vaccination teams and ensuring sufficient vaccine supplies and trained healthcare staff. Finally, public awareness campaigns can play a significant role in building trust and confidence in vaccination programs, dispelling any misconceptions or fears. Overall, a comprehensive and gender-sensitive approach is necessary to ensure resilient immunization coverage, even during times of disruptions like the pandemic.

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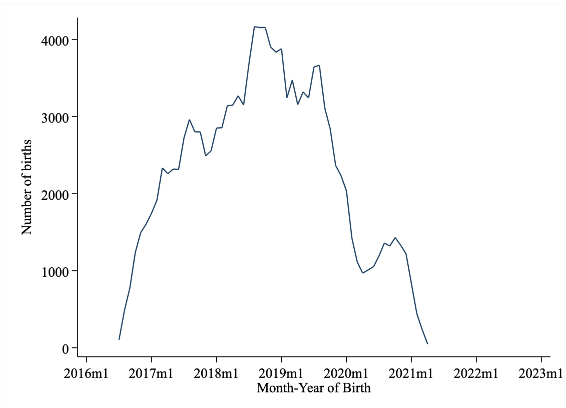
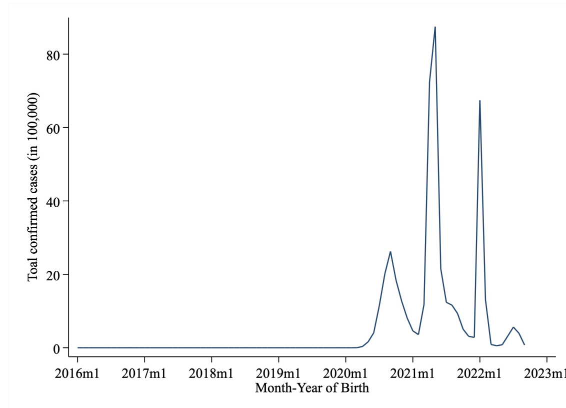
7 Figures

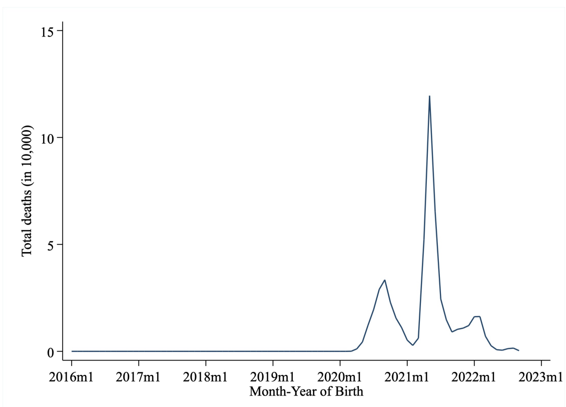
FIGURE 1: Temporal Snapshot of the COVID-related Estimates



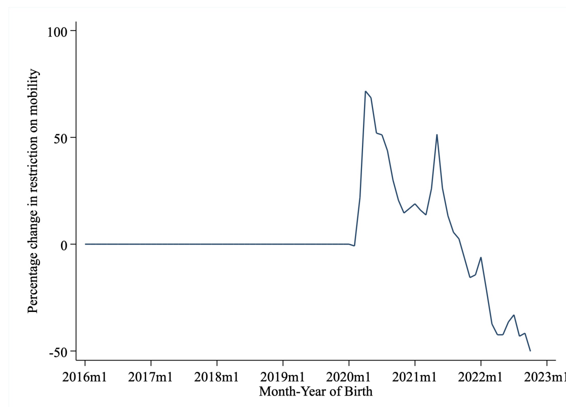
(a) Births over time (NFHS-5)



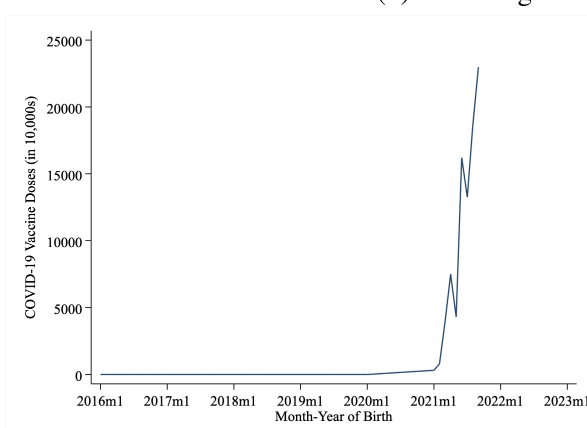
(b) Total confirmed COVID cases



(c) Total COVID deaths



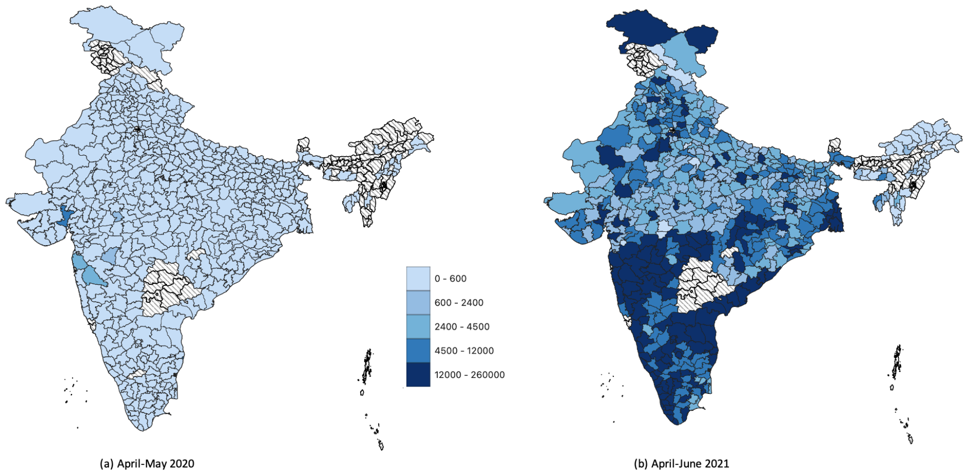
(d) Percentage change in mobility restrictions



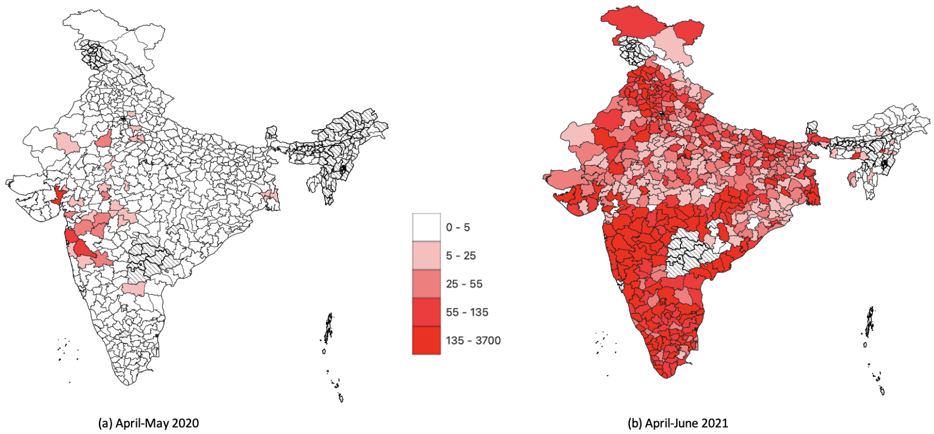
(e) Total COVID-Vaccine Doses

Notes: Subfigure (a) plots the total number of births from July 2016 to April 2021 using NFHS-5 data. Subfigures (b) and (c) plot the month-wise COVID-infected cases and deaths from April 2020 to September 2022 obtained using the Google COVID-19 cases data. Cases (and deaths) prior to and including the month of February 2020, i.e. before COVID, are assumed to be zero. Subfigure (d) plots the monthly percentage change in restriction on mobility relative to the baseline period from February 2020 to December 2021. A baseline day corresponds to the median value for each respective day of the week during the 5-week period from January 3 to February 6, 2020, prior to the outbreak of the first wave of the COVID-19 pandemic in India. Mobility restrictions before (and including) January 2020, i.e. before COVID, are assumed to be zero. Finally, subfigure (e) plots the monthly total number of COVID-19 vaccine doses administered from January 2021 to September 2021.

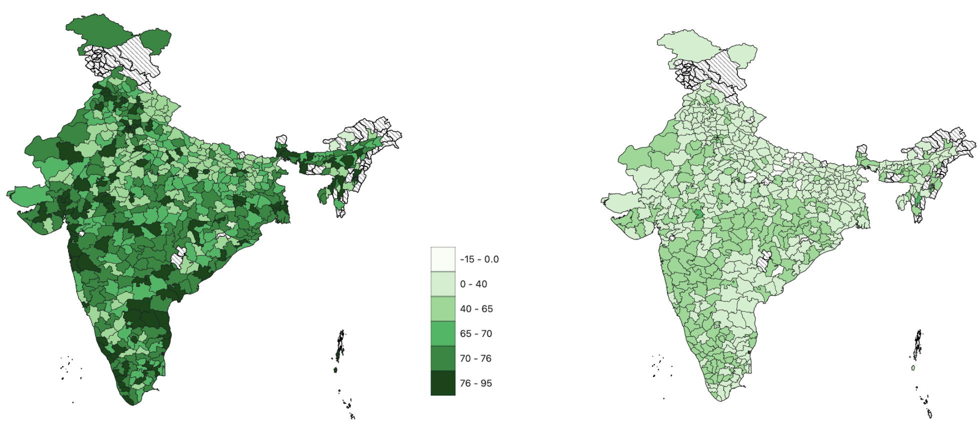
FIGURE 2: District-wise COVID-related Estimates during Two Waves in India



(a) COVID cases



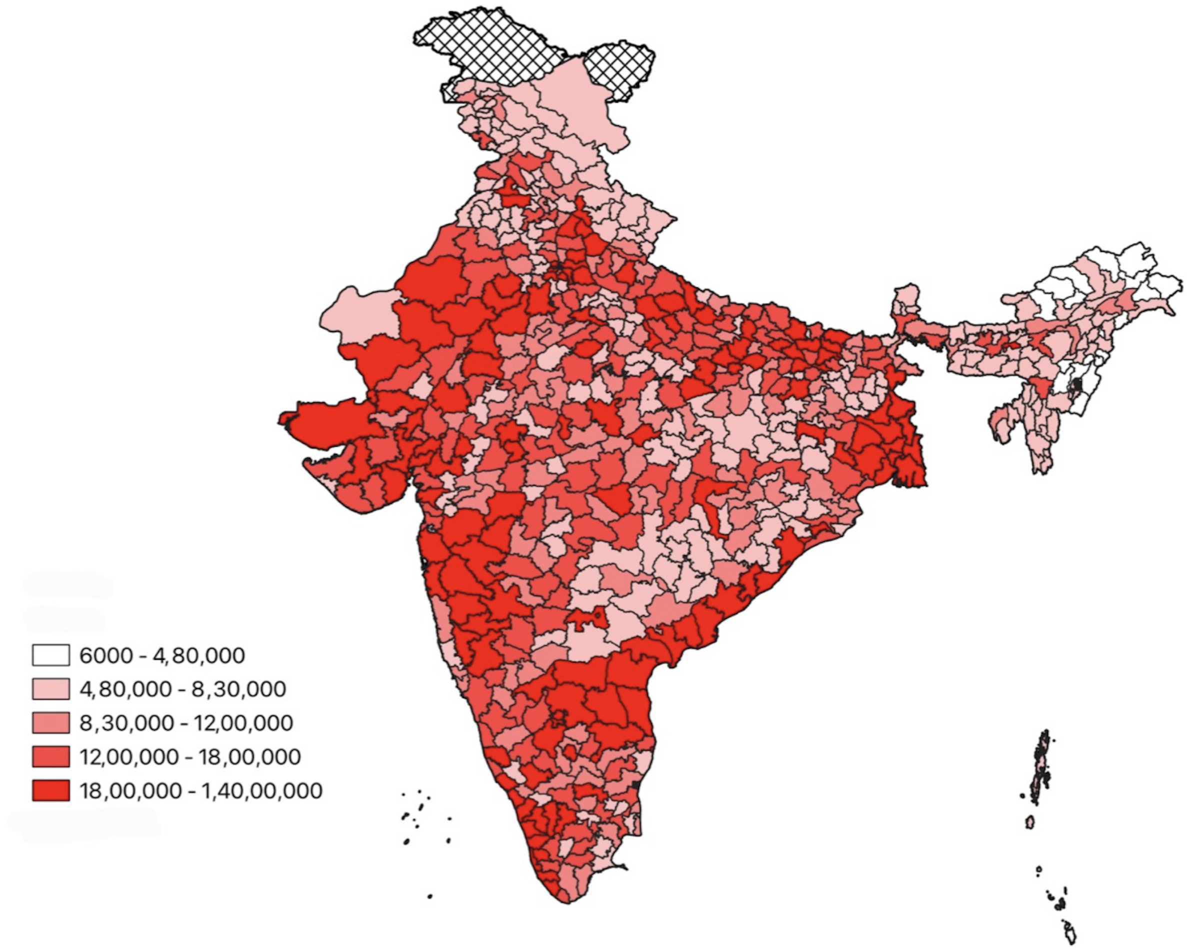
(b) COVID deaths



(c) Restrictions on mobility

Notes: The maps plot the district-wise COVID-infected cases, deaths, and restrictions on mobility for the first (April-May 2020) and second COVID-wave (April-June 2021) in India in sub-figures (a), (b), and (c), respectively. The districts for which COVID-related information was either unavailable or was not matched to the 2011 Census data are denoted by dashed regions across all maps.

FIGURE 3: District-wise Number of COVID-19 Vaccine Doses



Source: NFHS-5 (2019-21)
Notes: The map illustrates the district-wise COVID-19 vaccine doses across India. The districts for which COVID-related information was either unavailable or was not matched to the 2011 Census data are denoted by dashed regions across all maps.

8 Tables

TABLE 1: Immunization Schedule for the First 14 Weeks since Birth

Time of Vaccine	Vaccine Name
At birth	BCG, Polio-0, Hepatitis B-0
6 weeks	Polio-1, DPT-1, Hepatitis B-1
10 weeks	Polio-2, DPT-2, Hepatitis B-2
14 weeks	Polio-3, DPT-3, Hepatitis B-3

Source: Ministry of Health and Family Welfare
Notes: The table describes the vaccination schedule for children of various ages in India, as per the Ministry of Health and Family Welfare.

TABLE 2: Summary Statistics for all Controls

		COVID-Cohort				
	Pre-COVID Cohort	Pre-COVID Vaccine (C)	Post-COVID Vaccine (C+V)	Difference (2-1)	Difference (3-1)	Difference (3-2)
	(1)	(2)	(3)	(4)	(5)	(6)
Birth Order	2.105	2.133	2.205	0.027	0.100	0.073
	(0.021)	(0.030)	(0.074)	(0.031)	(0.073)	(0.070)
Mother's Education (yrs)	7.998	7.949	8.147	-0.049	0.149	0.198
	(0.148)	(0.175)	(0.325)	(0.124)	(0.323)	(0.298)
Total Siblings	2.192	2.288	2.361	0.096***	0.170***	0.074***
	(0.022)	(0.033)	(0.076)	(0.032)	(0.074)	(0.071)
Urban	0.199	0.213	0.193	0.014	-0.006	-0.020
	(0.010)	(0.014)	(0.025)	(0.010)	(0.024)	(0.022)
Hhd Members	6.435	6.420	6.353	-0.015	-0.081	-0.067
	(0.056)	(0.071)	(0.165)	(0.065)	(0.167)	(0.159)
Female-headed Hhd	0.139	0.142	0.114	0.003	-0.025	-0.028
	(0.004)	(0.007)	(0.020)	(0.008)	(0.021)	(0.019)
Poorer	0.212	0.211	0.229	-0.000	0.018	0.018
	(0.006)	(0.009)	(0.024)	(0.009)	(0.023)	(0.023)
Middle	0.181	0.178	0.193	-0.003	0.012	0.015
	(0.006)	(0.009)	(0.023)	(0.009)	(0.024)	(0.022)
Richer	0.170	0.159	0.155	-0.011	-0.016	-0.005
	(0.006)	(0.009)	(0.022)	(0.010)	(0.022)	(0.020)
Richest	0.169	0.163	0.133	-0.006	-0.036	-0.030
	(0.011)	(0.013)	(0.022)	(0.009)	(0.021)	(0.020)
SC	0.227	0.216	0.221	-0.012	-0.007	0.005
	(0.008)	(0.010)	(0.027)	(0.010)	(0.027)	(0.025)
ST	0.198	0.214	0.173	0.016	-0.025	-0.041
	(0.017)	(0.020)	(0.033)	(0.011)	(0.030)	(0.029)
OBC	0.417	0.408	0.418	-0.009	0.000	0.009
	(0.013)	(0.016)	(0.038)	(0.012)	(0.037)	(0.034)
General	0.147	0.148	0.173	0.001	0.026	0.025
	(0.008)	(0.010)	(0.025)	(0.008)	(0.024)	(0.022)
Hindu	0.809	0.801	0.828	-0.008	0.019	0.027
	(0.014)	(0.017)	(0.033)	(0.012)	(0.029)	(0.028)
Muslim	0.101	0.110	0.088	0.010	-0.013	-0.023
	(0.010)	(0.013)	(0.024)	(0.007)	(0.022)	(0.021)
Observations	49613	49613	49613	48894	37899	12433

Source: NFHS-5
Notes: The table reports the mean and standard deviation for different cohorts based on the child's month and year of birth. The averages are reported after including year and month of birth fixed effects and standard errors are clustered at the district level.

TABLE 3: Summary Statistics for Routine Vaccines for First 14 Weeks since Birth

		COVID-Cohort				
	Pre-COVID Cohort	Pre-COVID Vaccine (C)	Post-COVID Vaccine (C+V)	Difference (2-1)	Difference (3-1)	Difference (3-2)
	(1)	(2)	(3)	(4)	(5)	(6)
Vaccines due at birth	37180	11714	719			
BCG	0.941	0.941	0.881	-0.000	-0.060	-0.060
	(0.003)	(0.006)	(0.021)	(0.007)	(0.022)	(0.020)
Polio-0	0.857	0.856	0.782	-0.000	-0.074	-0.074
	(0.007)	(0.010)	(0.027)	(0.010)	(0.027)	(0.025)
Hepatitis-B	0.702	0.666	0.580	-0.036***	-0.121***	-0.086***
	(0.012)	(0.016)	(0.037)	(0.012)	(0.037)	(0.034)
Vaccines due at 6 weeks	35216	12221	2176			
Polio-1	0.894	0.880	0.803	-0.013	-0.091	-0.078
	(0.004)	(0.009)	(0.027)	(0.010)	(0.028)	(0.026)
DPT-1	0.912	0.888	0.813	-0.024**	-0.099**	-0.075**
	(0.004)	(0.009)	(0.026)	(0.010)	(0.028)	(0.026)
HepatitisB-1	0.900	0.874	0.797	-0.025**	-0.103**	-0.077**
	(0.004)	(0.009)	(0.026)	(0.011)	(0.027)	(0.025)
Vaccines due at 10 weeks	33610	12360	3643			
Polio-2	0.854	0.845	0.791	-0.009	-0.062	-0.054
	(0.005)	(0.010)	(0.026)	(0.011)	(0.027)	(0.025)
DPT-2	0.885	0.870	0.807	-0.015	-0.078	-0.063
	(0.005)	(0.010)	(0.026)	(0.012)	(0.027)	(0.025)
HepatitisB-2	0.869	0.852	0.782	-0.017	-0.087	-0.069
	(0.005)	(0.010)	(0.026)	(0.012)	(0.028)	(0.025)
Vaccines due at 14 weeks	31735	12835	5043			
Polio-3	0.795	0.771	0.700	-0.024*	-0.094*	-0.070*
	(0.007)	(0.012)	(0.030)	(0.013)	(0.031)	(0.029)
DPT-3	0.849	0.826	0.756	-0.023*	-0.093*	-0.070*
	(0.006)	(0.011)	(0.029)	(0.013)	(0.030)	(0.030)
HepatitisB-3	0.837	0.807	0.729	-0.030**	-0.108**	-0.078**
	(0.006)	(0.011)	(0.031)	(0.013)	(0.032)	(0.031)

Source: NFHS-5
Notes: The table reports the mean and standard deviation for different groups based on the date of eligibility of the vaccines as per Table 1. The averages are reported after including fixed effects for year and month of vaccine eligibility and standard errors are clustered at the district level.

TABLE 4: OLS estimates: Impact of COVID-19 on Institutional Delivery

	(1)	(2)	(3)	(4)
Panel A: Impact on Institutional Delivery				
Cases (in 100s)	-0.004			
	(0.003)			
Case Fatality Rate (CFR)		-0.003***		
		(0.001)		
Mobility Restrictions			-0.003***	
			(0.001)	
COVID-19 Vaccine Doses (in 100s)				-0.001
				(0.001)
R-Square	0.138	0.138	0.132	0.138
Observations	48,282	48,282	45,251	48,869
Panel B: Impact on Institutional Delivery by Gender				
Girl	-0.003	-0.004	-0.005*	-0.003
	(0.003)	(0.003)	(0.003)	(0.003)
Cases (in 100s)	-0.004			
	(0.005)			
Case Fatality Rate (CFR)		-0.004***		
		(0.001)		
Mobility Restrictions			-0.003***	
			(0.001)	
COVID-19 Vaccine Doses (in 100s)				-0.001
				(0.001)
Girl × Cases	0.001			
	(0.006)			
Girl × CFR		0.002		
		(0.002)		
Girl × Mobility Restriction			0.001	
			(0.002)	
Girl × COVID-19 Vaccine Doses				-0.002
				(0.002)
R-Square	0.138	0.138	0.132	0.138
Observations	48,282	48,282	45,251	48,869

Notes: The outcome variable is an indicator that takes the value one if the birth takes place in a private or public health facility such as a hospital, Primary Health Centre (PHC), or a clinic and zero if the delivery happens at home. Panel B reports the effect of the pandemic on institutional delivery by gender. *Girl* is a dummy that takes the value one if the sex of the child is a girl and zero for a boy. *Cases* indicates the average number of confirmed cases 30 days up to birth (in 100s). *'Case Fatality Rate or CFR'* records the average CFR in the past 30 days to birth, where CFR measures the total COVID deaths as a proportion of 100 confirmed cases. *'Mobility Restrictions'* is a categorical variable that takes the value 0 if there is no change or higher than average mobility in the past 30 days to birth compared to the baseline period. It ranges from values 1 to 5 for every 20% increase in 30-day average restrictions on mobility. We include various time-invariant controls for the child, such as sex, birth order, and twin status; the mother, such as religion, years of education, the total number of children, and caste; and the household, such as an indicator for rural/urban, number of household members, sex of the household head, and a wealth indicator. The model also includes district- and month-of-birth fixed effects. Standard errors are clustered at the district level. * $p<0.10$, ** $p<0.05$ and *** $p<0.01$.

TABLE 5: OLS Estimates: Impact of COVID-19 on Routine Immunization
(Vaccines due at birth and 6 weeks)

	At Birth			Dose - 1 (6 weeks)		
	(1) BCG	(2) Polio-0	(3) HepatitisB	(4) Polio-1	(5) DPT-1	(6) HepatitisB-1
Pre-Pandemic Averages	0.95	0.86	0.70	0.91	0.93	0.91
Panel A: Average COVID-infected cases (in 100s)						
Cases	-0.004	-0.008*	-0.018***	-0.015***	-0.023***	-0.019***
	(0.003)	(0.005)	(0.007)	(0.006)	(0.008)	(0.007)
R-Square	0.052	0.112	0.179	0.052	0.049	0.050
Observations	48,246	48,241	47,998	46,326	46,238	46,176
Panel B: Average Case Fatality Rate (COVID Deaths/Cases $\times$ 100)						
Case Fatality Rate (CFR)	-0.006***	-0.006***	-0.010***	-0.015***	-0.020***	-0.019***
	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
R-Square	0.053	0.113	0.180	0.054	0.054	0.054
Observations	48,246	48,241	47,998	46,326	46,238	46,176
Panel C: Lockdown-induced restrictions on mobility (per 20% change from baseline)						
Mobility Restrictions	-0.004***	-0.003***	-0.005***	-0.014***	-0.018***	-0.017***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
R-Square	0.047	0.108	0.180	0.050	0.051	0.052
Observations	45,223	45,216	44,977	43,431	43,347	43,279
Panel D: Average COVID-19 Vaccine Doses (in 100s)						
COVID-19 Vaccine Doses	-0.008***	-0.008***	-0.008**	-0.012***	-0.014***	-0.013***
	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)
R-Square	0.052	0.113	0.178	0.055	0.054	0.054
Observations	48,834	48,829	48,579	46,792	46,708	46,645

Notes: The outcome variable is a dummy that takes the value one if the child received a vaccine due at birth and 6 weeks, respectively, and zero otherwise. For each vaccine, infants who became eligible to receive it after the interview date were excluded from the sample. *Cases* is a continuous variable that records the average number of COVID-infected cases (in 100s) 30 days prior to the date of vaccine eligibility. *Case Fatality Rate* or CFR as defined in Table 4, records the 30-day average CFR prior to vaccine eligibility. *Mobility Restrictions* is a categorical variable ranging from 0-5 for every 20% increase in average restrictions on mobility relative to the baseline period. The controls are described in Table 4. Standard errors are clustered at the district level. * p<0.10, ** p<0.05 and *** p< 0.01.

TABLE 6: OLS Estimates: Impact of COVID-19 on Routine Immunization
(Vaccines due at 10 and 14 weeks)

	Dose - 2 (10 weeks)			Dose - 3 (14 weeks)		
	(1) Polio-2	(2) DPT-2	(3) HepatitisB-2	(4) Polio-3	(5) DPT-3	(6) HepatitisB-3
Pre-Pandemic Averages	0.87	0.91	0.90	0.81	0.88	0.86
Panel A: Average COVID-infected cases (in 100s)						
Cases	-0.040***	-0.049***	-0.028***	-0.063***	-0.077***	-0.063***
	(0.011)	(0.013)	(0.009)	(0.016)	(0.020)	(0.014)
R-Square	0.069	0.064	0.063	0.083	0.081	0.076
Observations	45,219	45,220	43,423	44,347	44,344	43,447
Panel B: Average Case Fatality Rate (COVID Deaths/Cases $\times$ 100)						
Case Fatality Rate (CFR)	-0.022***	-0.026***	-0.017***	-0.026***	-0.032***	-0.028***
	(0.002)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)
R-Square	0.070	0.067	0.061	0.082	0.083	0.078
Observations	45,219	45,220	43,423	44,347	44,344	43,447
Panel C: Lockdown-induced restrictions on mobility (per 20% change from baseline)						
Mobility Restrictions	-0.025***	-0.030***	-0.018***	-0.035***	-0.044***	-0.034***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)
R-Square	0.069	0.067	0.060	0.084	0.087	0.077
Observations	42,406	42,400	40,716	41,556	41,557	40,715
Panel D: Average COVID-19 Vaccine Doses (in 100s)						
COVID-19 Vaccine Doses	-0.023***	-0.024***	-0.022***	-0.020***	-0.023***	-0.025***
	(0.004)	(0.004)	(0.003)	(0.002)	(0.003)	(0.003)
R-Square	0.085	0.084	0.070	0.102	0.108	0.092
Observations	45,557	45,552	43,820	44,624	44,615	43,735

Notes: The outcome variable is the likelihood of receiving a vaccine due at 10 and 14 weeks, respectively. The independent variables and controls in each panel are described in Table 5. Standard errors are clustered at the district level. * p<0.10, ** p<0.05 and *** p< 0.01.

TABLE 7: **By Gender:** OLS estimates for Impact of COVID-19 on Routine Immunization (Vaccines due at birth and 6 weeks)

	At Birth			Dose - 1 (6 weeks)		
	(1) BCG	(2) Polio-0	(3) HepatitisB	(4) Polio-1	(5) DPT-1	(6) HepatitisB-1
Pre-Pandemic Averages	0.948	0.867	0.706	0.911	0.930	0.914
Panel A: Average COVID-infected cases (in 100s)						
Girl	0.004**	0.006**	0.003	0.003	0.002	0.001
	(0.002)	(0.003)	(0.004)	(0.003)	(0.002)	(0.003)
Cases	0.000	-0.004	-0.017	-0.013*	-0.022***	-0.022***
	(0.004)	(0.008)	(0.010)	(0.008)	(0.008)	(0.008)
Girl × Cases	-0.008	-0.008	-0.003	-0.004	-0.001	0.004
	(0.005)	(0.009)	(0.013)	(0.007)	(0.005)	(0.005)
R-Square	0.052	0.112	0.179	0.052	0.049	0.050
Observations	48,246	48,241	47,998	46,326	46,238	46,176
Panel B: Average Case Fatality Rate (COVID Deaths/Cases ×100)						
Girl	0.004**	0.006*	0.002	0.003	0.003	0.002
	(0.002)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)
CFR	-0.006***	-0.005**	-0.010***	-0.015***	-0.019***	-0.018***
	(0.001)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
Girl × CFR	-0.002	-0.001	0.001	-0.001	-0.000	-0.000
	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)
R-Square	0.053	0.113	0.180	0.054	0.054	0.054
Observations	48,246	48,241	47,998	46,326	46,238	46,176
Panel C: Lockdown-induced restrictions on mobility (per 20% change from baseline)						
Girl	0.005**	0.006*	0.001	0.006**	0.007**	0.005*
	(0.002)	(0.003)	(0.005)	(0.003)	(0.003)	(0.003)
Mobility Restrictions	-0.003***	-0.003*	-0.006***	-0.011***	-0.015***	-0.015***
	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
Girl × Mobility Restrictions	-0.001	-0.001	0.001	-0.006**	-0.006***	-0.004*
	(0.001)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)
R-Square	0.047	0.108	0.180	0.051	0.051	0.052
Observations	45,223	45,216	44,977	43,431	43,347	43,279
Panel D: Average COVID-19 Vaccines (in 100s)						
Girl	0.002	0.005*	0.003	0.004	0.002	0.002
	(0.002)	(0.003)	(0.004)	(0.003)	(0.002)	(0.003)
COVID-19 Vaccine Doses	-0.011***	-0.009***	-0.009***	-0.010***	-0.013***	-0.012***
	(0.003)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)
Girl × COVID-19 Vaccine Doses	0.006**	0.001	0.002	-0.006	-0.002	-0.002
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
R-Square	0.053	0.113	0.178	0.055	0.054	0.054
Observations	48,834	48,829	48,579	46,792	46,708	46,645

Notes: The outcome variable is the likelihood of receiving the vaccine due at birth and 6 weeks, respectively. *Girl* is an indicator variable that takes the value one for a girl child and zero for a boy. The independent variables are defined in Table 5. The controls are described in Table 4. Standard errors are clustered at the district level. * p<0.10, ** p<0.05 and *** p< 0.01.

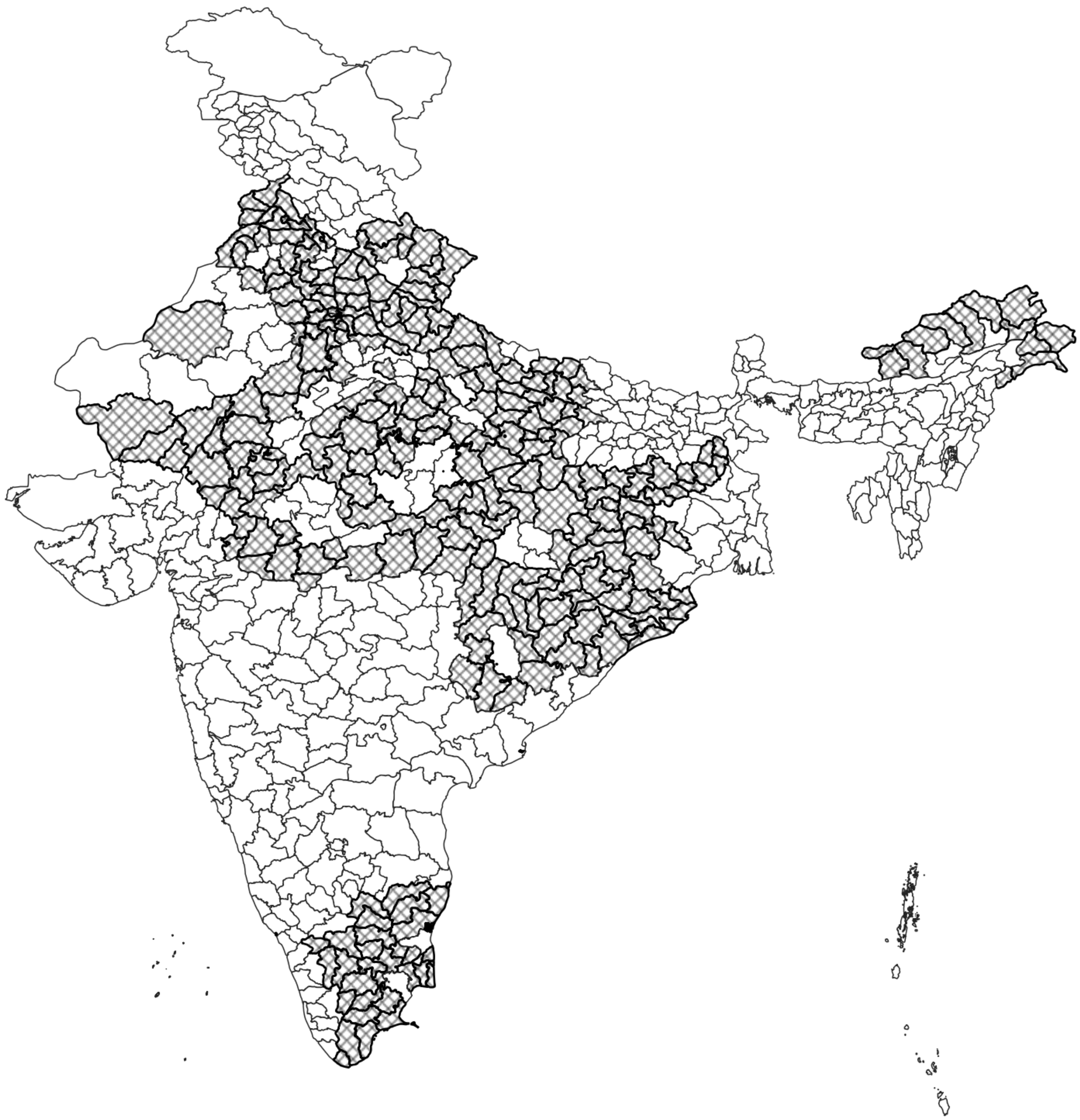
TABLE 8: **By Gender:** OLS Estimates for Impact of COVID-19 on Routine Immunization (Vaccines due at 10 and 14 weeks)

	Dose - 2 (10 weeks)			Dose - 3 (14 weeks)		
	(1) Polio-2	(2) DPT-2	(3) HepatitisB-2	(4) Polio-3	(5) DPT-3	(6) HepatitisB-3
Observations	0.878	0.910	0.910	0.817	0.882	0.863
Panel A: Average COVID-infected cases (in 100s)						
Girl	0.003	0.004	0.005*	0.002	0.003	0.001
	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
Cases	-0.035***	-0.044***	-0.021**	-0.058***	-0.070***	-0.060***
	(0.011)	(0.012)	(0.009)	(0.017)	(0.020)	(0.011)
Girl × Cases	-0.012	-0.011	-0.014	-0.011	-0.016*	-0.006
	(0.011)	(0.013)	(0.010)	(0.011)	(0.009)	(0.011)
R-Square	0.069	0.064	0.063	0.083	0.081	0.076
Observations	45,219	45,220	43,423	44,347	44,344	43,447
Panel B: Average Case Fatality Rate (COVID Deaths/Cases × 100)						
Girl	0.005	0.005*	0.007**	0.006	0.007*	0.005
	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
CFR	-0.019***	-0.024***	-0.015***	-0.020***	-0.027***	-0.023***
	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.004)
Girl × CFR	-0.005	-0.004	-0.005	-0.012***	-0.011***	-0.010***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)
R-Square	0.072	0.069	0.066	0.085	0.086	0.081
Observations	45,219	45,220	43,423	44,347	44,344	43,447
Panel C: Lockdown-induced restrictions on mobility (per 20% change from baseline)						
Girl	0.010**	0.009***	0.010***	0.008	0.008**	0.006
	(0.004)	(0.003)	(0.003)	(0.005)	(0.004)	(0.004)
Mobility Restrictions	-0.019***	-0.025***	-0.014***	-0.030***	-0.041***	-0.031***
	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
Girl × Mobility Restrictions	-0.012***	-0.009***	-0.009***	-0.010**	-0.007*	-0.007**
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.003)
R-Square	0.071	0.069	0.063	0.086	0.088	0.079
Observations	42,406	42,400	40,716	41,556	41,557	40,715
Panel D: Average COVID-19 Vaccines (in 100s)						
Girl	0.005	0.005	0.006**	0.003	0.004	0.002
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
COVID-19 Vaccine Doses	-0.019***	-0.020***	-0.018***	-0.019***	-0.021***	-0.024***
	(0.005)	(0.005)	(0.004)	(0.003)	(0.003)	(0.004)
Girl × COVID-19 Vaccine Doses	-0.008	-0.009*	-0.008*	-0.002	-0.003	-0.001
	(0.005)	(0.005)	(0.005)	(0.003)	(0.003)	(0.003)
R-Square	0.086	0.085	0.071	0.102	0.109	0.092
Observations	45,557	45,552	43,820	44,624	44,615	43,735

Notes: The outcome variable is the likelihood of receiving the vaccine due at 10 and 14 weeks, respectively. *Girl* is an indicator variable that takes the value one for a girl the child and zero for a boy. The independent variables are defined in Table 5. The controls are described in Table 4. Standard errors are clustered at the district level. * p<0.10, ** p<0.05 and *** p< 0.01.

Appendix

FIGURE A.1: Selected Districts for our Sample



Source: NFHS-5 (2019-21)
Notes: The map illustrates the districts where children were interviewed after the pandemic, i.e., March 2020.

TABLE A.1: Balance on Controls After Sample Restrictions

Interviewed:	Before Pandemic	After Pandemic	Difference (2-1)
	(1)	(2)	(3)
Birth Order	2.144	2.113	-0.031
	(0.034)	(0.020)	(0.054)
Mother's Education (in yrs)	7.895	7.804	-0.091
	(0.243)	(0.145)	(0.388)
Total Siblings	2.269	2.202	-0.067
	(0.039)	(0.023)	(0.062)
Urban	0.234	0.182	-0.052***
	(0.011)	(0.007)	(0.018)
Hhd Members	6.223	6.378	0.155
	(0.083)	(0.050)	(0.132)
Female-headed Hhd	0.146	0.157	0.011
	(0.007)	(0.004)	(0.011)
Poorer	0.219	0.239	0.021
	(0.011)	(0.006)	(0.017)
Middle	0.181	0.204	0.023
	(0.009)	(0.006)	(0.015)
Richer	0.176	0.168	-0.008
	(0.010)	(0.006)	(0.016)
Richest	0.135	0.138	0.003
	(0.009)	(0.006)	(0.015)
SC	0.182	0.222	0.040*
	(0.013)	(0.008)	(0.021)
ST	0.249	0.174	-0.075
	(0.031)	(0.019)	(0.050)
OBC	0.379	0.392	0.014
	(0.024)	(0.014)	(0.038)
General	0.142	0.168	0.026
	(0.013)	(0.008)	(0.020)
Hindu	0.690	0.764	0.074**
	(0.020)	(0.012)	(0.032)
Muslim	0.188	0.118	-0.071**
	(0.020)	(0.012)	(0.032)
Observations	82834	49613	132447

Source: NFHS-5
Notes: The table reports mean and standard errors for all control variables after controlling for district-, year-, and month-of-birth fixed effects. The children in column (1) are those who were interviewed prior to March 2020, before the pandemic, and subsequently excluded from our main sample. The children in column (2) were interviewed after March 2020 and hence a part of our main sample. The standard errors are clustered at the district level.

TABLE A.2: **Pre-existing Bias:** OLS Estimates for Impact of COVID-19 on Routine Immunization (NFHS-4)

	At Birth			Dose - 1 (6 weeks)		
	BCG (1)	Polio-0 (2)	HepatitisB (3)	Polio-1 (4)	DPT-1 (5)	HepatitisB-1 (6)
Girl	-0.002 (0.001)	-0.001 (0.002)	-0.003 (0.002)	-0.001 (0.001)	-0.003* (0.001)	-0.001 (0.002)
R-Square	0.120	0.176	0.184	0.079	0.105	0.108
Observations	245,549	245,586	241,929	238,763	237,425	233,566

	Dose - 2 (10 weeks)			Dose - 3 (14 weeks)		
	Polio-2 (1)	DPT-2 (2)	HepatitisB-2 (3)	Polio-3 (4)	DPT-3 (5)	HepatitisB-3 (6)
Girl	-0.002 (0.002)	-0.004** (0.002)	-0.001 (0.002)	0.000 (0.002)	-0.005** (0.002)	-0.000 (0.002)
R-Square	0.084	0.112	0.117	0.086	0.125	0.108
Observations	234,435	233,116	229,384	228,955	228,329	241,929

Source: NFHS Round 4 (2015-16)
Notes: The outcome variable is the likelihood of receiving a vaccine due at birth, 6, 10, and 14 weeks, respectively. *Girl* is an indicator that takes the value one for a girl child and zero for a boy. The controls are defined in Table 4. Standard errors are clustered at the district level. * $p<0.10$, ** $p<0.05$ and *** $p<0.01$.