AEA Papers and Proceedings 2023, 113: 642–646
https://doi.org/10.1257/pandp.20231110

Does Childhood Immunization Rebound after Extreme Shocks? Evidence from Floods and Strikes in Pakistan†

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Between June and August 2022, the provinces of Sindh and Balochistan in Pakistan recorded seven to eight times their monthly rainfall, 33 million people were impacted, and nearly 1,500 people died in the resulting floods (World Weather Attribution 2022). Immunization, along with many other services, was disrupted, with the Kambar district, for example, experiencing a 52 percent fall in the number of children immunized between the second and third weeks of August.

While large, these disruptions were not unprecedented. Data on the universe of vaccinations between 2019 and 2022 from 12 of the lowest immunization coverage districts in the Sindh province of Pakistan reveal four large shocks to Pentavalent-1 coverage: an initial COVID-19 wave, the delta wave in 2021, strike action by vaccinators in 2022, and the 2022 floods (Figure 1). While COVID-19 and the 2022 floods received international attention, strikes produced even larger, if shorter-lived, disruptions.

These shocks were followed by intensive and expensive catch-up outreach efforts. As climate change makes public service disruptions more frequent, it is important to understand the extent to which services bounce back after shocks or whether impacted cohorts remain permanently disadvantaged. Quick recovery of immunization is particularly important, as infectious diseases spread quickly in disaster conditions.

In this paper, we show that flood-impacted areas have not caught up on the vaccinations that would have occurred without the floods, even three months after the main flooding receded. While flood recovery may still be under way, a similar failure to fully catch up on lost vaccinations is seen in the case of earlier strike action.

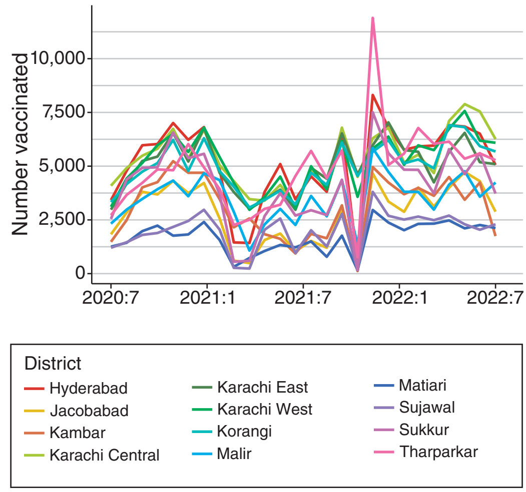

Figure 1. Pentavalent-1 Vaccines across Districts

Note: Each line represents the number of Pentavalent-1 vaccines administered each month in the 12 districts.

I. Floods and Strikes in Sindh

An unusually intense and prolonged monsoon, coupled with water from melting

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† Go to https://doi.org/10.1257/pandp.20231110 to visit the article page for additional materials and author disclosure statement(s).

glaciers, contributed to the worst flooding in Pakistan's history. Climate change was likely a significant contributor, generating a 50 percent increase in 60-day rain intensity in the area (World Weather Attribution 2022). Many of the hardest-hit areas already suffered from high rates of malnutrition and poor access to health facilities. The flooding caused some centers to close temporarily, prevented carers from reaching centers, and disrupted the vaccine supply.

The floods impacted a health system that had only recently recovered from a man-made shock triggered when the public health officials responsible for vaccinating children in some, but not all, Sindh districts took strike action from early November to mid-December 2021 (precise dates varied by district; see online Appendix section A1).

The strikes and floods were followed by intensive government catch-up efforts. Enhanced outreach activities were carried out in strike-hit districts between December 20 and January 10, 2022. During and following the floods, the government and international organizations took action to control the spread of outbreaks, support routine immunization, and provide life-saving essential health services. In this paper, we measure how quickly and to what extent immunization coverage overcame the initial negative shock. Recent work suggests that post-COVID-19 efforts have led to substantial but not full catch-up for those who missed immunization during the height of the epidemic, particularly among those underserved by the health system (Chandir et al. 2021; Jain et al. 2021).

II. Data and Empirical Framework

This paper uses unique administrative child-level data from July 2019 to November 2022 drawn from the Sindh Electronic Immunization Registry (previously known as Zindagi Mehfooz (Safe Life) Program) of the Government of Sindh, Pakistan. An android-based immunization management application is used by all vaccinators in Sindh province (in both private and public facilities) to enroll and collect real-time information on a child's vaccination status by scanning a QR code on the child's immunization card at the time of antigen administration.

For this study, we use child-level data for 0–23-month-old children enrolled in the registry for 12 of the lowest-coverage districts in Sindh.[1] These districts were chosen because they were part of an evaluation of a conditional cash transfer program. The data cover 2.38 million 0–23-month-old children who have received at least one antigen between July 2019 and November 2022, and they include information on antigen, date and place of vaccination, immunization history (including vaccination due date), and gender.

We complement our immunization data with information for floods and strikes at the town level. We retrieved a two-day flood product from MODIS Near Real-Time Global Flood Product processed by the National Aeronautics and Space Administration's (NASA) Land, Atmosphere Near real-time Capability for EOS (LANCE).[2] The two-day flood product aggregates observations for two consecutive days, removing false positives appearing due to cloud shadows. Finally, we matched immunization data with the date of strikes (for details, see online Appendix section A1).

We exploit variation in the exposure of towns in the 12 districts to flooding and strikes for our identification. We use a difference-in-difference (DID) approach to estimate the medium-run effect of floods and strikes on the number of doses of childhood immunizations administered. Our basic specification is as follows:

$$y_{it} = \beta_0 + \beta_1 T_i + \beta_2 Post_{it} + \beta_3 T_i * Post_{it} + \epsilon_{it}, \quad (1)$$

where y_{it} is the log of vaccinations administered by town i and week t, T_i is an indicator capturing exposure to the shocks (i.e., flood or strike) at the town level and 0 otherwise, $Post_t$

[1] The districts include three in Karachi (East, West, and Central), Kamber, Hyderabad, Jacobabad, Sujawal, Tharparkar, Matiari, Sukkur, Korangi, and Malir. These districts had the lowest immunization coverage rates for Penta-3 and Measles-1 vaccines in the 2020 birth cohort, as measured by surviving annual infants in the Electronic Immunization Registry of the Government of Sindh as of August 31, 2021.

[2] We acknowledge the use of data and/or imagery from NASA's LANCE system (https://earthdata.nasa.gov/lance), part of NASA's Earth Observing System Data and Information System.

TABLE 1—IMPACT OF SHOCKS (FLOODS AND STRIKES) ON THE NUMBER OF DOSES OF VACCINES ADMINISTERED (IN LOGS)

Shock	Floods				Strikes			
Dependent variable	Penta-1		Total vaccines		Penta-1		Total vaccines	
Model	DID (1)	CS (2)	DID (3)	CS (4)	DID (5)	CS (6)	DID (7)	CS (8)
T*Post	−0.1697 (0.0583)	−0.1313 (0.1117)	−0.1746 (0.0541)	−0.1658 (0.0959)	−0.6438 (0.0581)	−0.3294 (0.1358)	−0.6626 (0.0660)	−0.3225 (0.14979)
N	2,384	2,384	2,384	2,384	2,793	2,793	2,793	2,793

Notes: Standard errors are in parentheses. Fixed effects include town and time fixed effects. The outcome of interest is the log of the number of doses of Penta-1 and the total vaccines administered (including Bacillus Calmette–Guérin (BCG), Pentavalent-1, Pentavalent-2, Pentavalent-3, Measles-1, and Measles-2). T*Post is the average treatment effect of shocks (strikes and floods). DID is the average effect of the shock estimated through difference-in-differences. CS refers to estimates from the Callaway and Sant'Anna (2021) method. The sample includes data ten weeks before and after the shocks. *N* refers to the sample size.

is an indicator equal to 1 for post shock[3], and $T_i * Post_t$ is the average effect of shocks on our outcomes of interest. Our DID estimate β_1 captures the change in the log number of vaccines administered for towns exposed to shocks compared to changes in outcomes among those not exposed to shocks.

We also estimate our model using the Callaway and Sant'Anna (2021) method that allows for the staggered rollout of events, as we have some variation in the timing of strikes and floods between towns. This also allows us to estimate treatment effects for different periods after the shock and thus trace the dynamics of the shock. Specifically, we estimate the change in log vaccines in towns exposed to shocks versus those unexposed for each week preceding the shock (which gives us our pre-trends) and each week after the shock. For both methods, standard errors are robust and clustered at the district level. We use balanced panel data aggregated at the town level for ten weeks before and after the shock.

Our time window is chosen to avoid overlap with other shocks, including the rollout of a conditional cash transfer program in some districts between February and July 2022. We check robustness to using a longer time window (13 weeks). We address the large variation in immunization numbers by day of the week and town-varying shocks by taking weekly averages of immunizations and comparing the change in the log of the number of vaccines in a town or district with the change in the log number of vaccinations in other towns at the same time to net out town-specific effects.

While our main outcome is total vaccines, we also show results for Penta-1, the vaccine that shows the most variation in response to shocks.[4] Results for other routine childhood immunizations are in online Appendix Section A4.

Because caregivers may respond to disruptions by seeking care in unimpacted towns, which would risk an overestimate of the impact of shocks, we assign all children to their town of enrollment rather than the town in which they receive their subsequent vaccines. As a robustness check, we restrict the analysis to later vaccines, as children eligible for these vaccines will have been born (and likely receive their first vaccine) preshock.

III. Findings

Immunizations declined by 0.17 log points (19 percent) more in flooded towns than nonflooded towns post flood in the DID estimation (Table 1, column 3). This means that 11,500 children missed vaccinations as a result of the floods despite catch-up efforts. The Callaway

[3] For strikes, the shock is coded as 1 for Matiari, Sujawal, Malir, Kambar, Jacobabad, Sukkur, and Tharparkar between November 1, 2021, and December 11, 2021, and for Karachi (East, West, and Central) and Korangi between November 15 and November 30, 2021. For floods, the shock is coded as 1 after August 16, 2022, for most towns and August 28, 2022, for a few others, and as 0 otherwise.

[4] Total vaccines include BCG, Penta-1, Penta-2, Penta-3, Measles-1, and Measles-2.

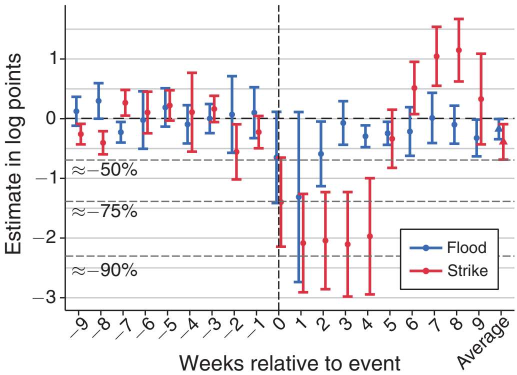

Figure 2. Callaway and Sant'Anna (2021) Estimates for the Total Number of Doses for All Vaccines

Notes: The outcome of interest is the log of the total number of doses of vaccines administered (including BCG, Penta-1, Penta-2, Penta-3, Measles-1, and Measles-2). Estimates derived from Callaway and Sant'Anna (2021) method. Red dots represent estimate for strikes, and blue dots are for floods. Bars around the estimates represent confidence intervals. The sample is ten weeks before and after the shock.

and Sant'Anna (2021) estimate is similar (column 4), as is the estimate for Penta-1 (column 1) and other vaccines (see online Appendix Section A4). Thus, despite government and international community efforts, there is a risk of vaccination rates being permanently lower in children exposed to last summer's floods.

One concern might be that the response to the floods is still ongoing and catch-up may take longer. Indeed, we see little evidence that flood-hit towns have experienced higher vaccination rates in recent weeks (blue dots in Figure 2), suggesting that little effective catch-up has yet occurred. We therefore also analyze a previous shock (a vaccinator strike) where we observe the full catch-up phase.

We find that immunizations in strike towns were 0.66 log points (48 percent) lower than in nonstrike towns over the entire post period in the DID estimation (Table 1, column 7) and 0.32 log points or 38 percent lower using Callaway and Sant'Anna (2021) (column 8). In total, nearly 15,300 children were never vaccinated due to the strikes. Results are similar for Penta-1 (columns 5 and 6) and other vaccines (see online Appendix A4).

Callaway and Sant'Anna (2021) event study estimates show that immunization fell below that of strike comparator towns for at least four weeks due to strikes but that the intense outreach following the strikes led to higher vaccinations in strike towns for three to four weeks (online Appendix Figure A2; red dots indicate weekly Callaway and Sant'Anna (2021) strike estimates). The catch-up period appears to be over by week 10. The aggregate post treatment estimation suggests that the intensive catch-up effort was not sufficient to avoid a net loss of vaccinations from the strikes, just as in the case of floods.

We find a statistically significant increase in switching vaccine locations in shock-affected towns post shock. However, the magnitude of the effect is small: an increase from five switchers a week to ten (online Appendix Section A2, Figure A1). As a result, our findings are not sensitive to assigning children to their town of enrollment versus town of vaccination, and the magnitude of the effect is similar for Measles-2 and Penta-1.

Heterogeneity in Effects.—To understand which children are impacted by the shock, we test for heterogeneous treatment effects with respect to gender and mother's education (online Appendix A5). We do not find any statistically significant differences in the impact of either shock on immunization by gender of the child or the mother's education.

IV. Conclusion

Immunization in the ten lowest-coverage countries has plateaued over the last decade (hovering around 80 percent for infants receiving three doses of the diphtheria-tetanus-pertussis vaccine (World Health Organization 2022)). But this decade-long trend obscures huge time variation caused by natural and man-made catastrophes, including floods, strikes, riots, and epidemics like COVID-19 (Andrabi, Daniels, and Das 2021; Chandir et al. 2021). Many of these disruptions are followed by expensive and intensive catch-up efforts by governments, the international community, and nongovernmental organizations. Our data suggest that while many children are reached by these catch-up efforts, some children who would have received vaccination in the absence of the shock remain unvaccinated even after catch-up efforts have been concluded.

The magnitude of the effect is not small. We find a shortfall of 11,500 vaccinations in flooded towns versus nonflooded towns and 15,300 fewer vaccinations in strike versus nonstrike towns two and a half months after the shock. The results are of a similar magnitude, although more noisy over a longer time window.

Nor are these shocks uncommon: four large disruptions to vaccination supply were witnessed in the Pakistan province of Sindh in just three years. If the experience of Pakistan is representative going forward, then vaccine supply disruptions in general and public service disruptions more generally could be major contributors to poorer health. Our findings are in line with those from other settings where natural shocks and disruptions led to a substantial decline in health and education outcomes, especially for children (Andrabi, Daniels, and Das 2021; Mahmud and Riley 2021; Stillman and Thomas 2008). Our findings from Sindh suggest the need for further study on the frequency and long-term impact of vaccines and other health supply disruptions on long-term health outcomes.

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