Extreme Heat and Public Services:

Evidence from Vaccinations in Pakistan

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Abstract

Extreme temperatures pose risks for public services where delivery mechanisms depend on physical effort. This paper studies how temperature affects access to health services in the setting of field vaccinations in Pakistan, a nation plagued by extreme heat. We find that occurrences of extreme heat reduce completed vaccinations in a day by 8% translating to reductions in timely vaccination of newborns for recommendation doses by 5.4 to 7.4%. Vaccinator and citizen effort appear to both contribute to these patterns. These findings highlight the susceptibility of key inputs to public health to the rising prevalence of extreme temperatures.

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1 Introduction

There is emerging evidence that extreme temperatures impact economic activity. Evidence from the private sector documents reductions in worker effort as well as productivity conditional on effort (Hsiang, 2010; Adhvaryu et al., 2020). Less well-understood is the impact extreme temperatures may have on outcomes in the public domain, specifically in the delivery of public goods and services.

The relationship between temperature and output in the public sphere may differ fundamentally from the private sphere. First, public services are directed at ameliorating social challenges or forestalling harms, as opposed to producing output for the market. While existing evidence thus far finds immediate impacts of heat on productivity in settings like factory production (Sudarshan et al., 2021), extreme temperatures could carry longer-run implications in the public setting for the challenges public services are intended to address. Second, whereas in the private sphere, the literature has thus far focused on the supply side, extreme heat could shape the effectiveness of public service delivery through both supply- and demand-side channels: heat can impact the work of public agents tasked with delivering services or goods while also affecting how citizens seek out access. Understanding these channels is crucial to informing policies that could mitigate the harms of extreme heat.

The increasing prevalence of extreme heat (NOAA, 2019), adds urgency to the task of making systems resilient to temperature fluctuation. Examining this question in low-income countries is of particular importance given the likely impacts of extreme heat on public service delivery through multiple channels. Much of the work of public services is done by "frontline" agents (public health workers, agricultural extension, even taxation) for whom the manual and physical, effort-intensive nature of their work may make their effectiveness particularly susceptible to fluctuations in environmental conditions. Moreover, demand for public services is more sensitive to constraints in the developing world, where information and social norms-related frictions work to exclude many from access even when supply is undistorted (Hoy et al., 2022).

Pakistan ranks globally among the countries most exposed to extreme heat events (ur Rehman, 2025; Saeed, 2025). Access to many public services in Pakistan relies on the physical presence of the personnel who deliver them. Nowhere is this more true than in the health sector, where provider absenteeism is a primary barrier to care (Callen et al., 2020). The essential nature of this physical labor is highlighted by critical services, such as vaccine delivery, which depend on teams of agents who both travel to health facilities in rural areas and perform community visits to actively seek out patients to administer doses.

In this paper, we leverage a novel dataset capturing the daily work of field vaccination teams linked to satellite temperature data. We study how doses completed by vaccinators respond to fluctuations in temperature, accounting for differences in delivery outcomes across areas, vaccination staff, and other environmental factors like precipitation. We find that extreme heat events (above 90° Fahrenheit) reduce delivered doses in a day by 8% (5.6 percentage points). We then link temperature data to a national survey of households that captures the vaccination status of household members to examine effects among infants, for whom timely vaccination is most crucial. We link births within 60-day windows after extreme heat events to demonstrate a pattern in vaccine completion identical to the findings in the administrative data: completion of vaccines within the recommended window decline by 5.4 to 7.4%.

As the vaccination structure in Pakistan involves both mobile and stationary delivery by field agents, we are able to gain insight into the role of supply- and demand-side channels through which these effects materialize. While extreme heat can affect the effort of field staff, it may also shape citizen willingness to seek out vaccinations. We find larger impacts for more mobile versus more stationary agents, suggesting that both mechanisms are at work in our setting.

Our findings significantly extend the literature on the economic impacts of climate change by demonstrating how extreme heat undermines the fundamental capacity of public health systems. We extend the research on environmental factors and job efficiency by identifying a channel of failure in the public sector, a hitherto understudied area. Prior work establishes that adverse environmental conditions, such as high temperatures, diminish labor productivity across diverse settings, affecting performance in factory settings (e.g., Adhvaryu et al., 2020) and the quality of public governance (e.g., Obradovich et al., 2018; Behrer and Bolotnyy, 2024). We build upon this foundation by providing empirical evidence that extreme heat induces provider absenteeism and reduces the mobility of essential front-line health agents, resulting in a failure in the last-mile delivery of a critical public service (vaccination).

Second, this paper adds to the literature on the link between weather shocks, climate change, and health outcomes. Existing studies highlight the detrimental health effects of environmental hazards, whether through exposure to pollution (Hoffman and Rud, 2024) or the direct physiological impact of temperature extremes, which are strongly linked to increased mortality and morbidity (e.g., Gasparrini et al., 2015; Barreca, 2019). Our contribution here is to identify potential impact of extreme heat on demand for protection against preventable diseases. By documenting that heat reduces vaccination coverage, partially through lower demand, our findings highlight the critical, longer-run public health challenges posed by extreme environmental conditions.

2 Setting

Pakistan ranks low on vaccination rates of children against preventable diseases (Saeed and Hashmi, 2021) despite having an extensive public health system. The main responsibility for vaccinating children lies with provincial Expanded Program on Immunization (EPI) of the Department of Health. In Punjab, the focus of this paper, EPI is tasked with immunizing about 3.39 million children in the age range of 0-23 months against 12 vaccine preventable diseases. These vaccines are administered through a combination of fixed point and mobile teams of vaccinators.

EPI organizes teams of vaccinators at the local levels around health centers. Each center has two vaccinators to serve a population of approximately 20,000 [1]. The centers are provided with vaccines by the district and provincial EPI teams. The vaccination team at the center develops a plan to vaccinate children in their catchment area under the supervision of the head of the health center (usually a medical doctor).

Vaccinators operate in two modes: stationary and mobile. Mobile vaccinators collect vaccines from the center and travel across the catchment area to deliver vaccination services to the population closer to their homes. Parents can also visit health centers directly to vaccinate their children, especially for vaccines that are not usually not provided outside the clinic [2]. These vaccinations are delivered by the stationary vaccinator available in the health center during the work hours. The two vaccinators can alternate between these roles depending on the local plan developed at the health facility. In addition to these two modes, the Department of Health also organizes large campaigns by sending vaccinators door-to-door to vaccinate children against certain communicable diseases, such as polio and measles.

Before 2014, the Department of Health relied on paper-based records and registers to keep track of vaccination rates in the province. This system resulted in highly frag-

[1]Not every area has a health facility, a large part of the province lacks coverage

[2]For example, the BCG vaccine has to be administered at or soon after birth, as a result this vaccine is administered only in facilities

mented and unreliable record keeping. However, in 2014 the Department in partnership with Punjab Information Technology Board developed and pilot tested a mobile phone recording system, called Evaccs (Razaq et al., 2016). The Evaccs system represents a comprehensive digital health information system designed to modernize vaccination tracking and immunization program management across the province. The system was developed for deployment at multiple points including mobile vaccination teams conducting outreach in remote areas, community-based vaccination programs, dedicated Expanded Program on Immunization (EPI) centers, and health centers. Unlike the old paper-based system, data collection protocols are standardized across all entry points, requiring health workers to input vaccination information directly into the app during vaccination sessions. The application geo stamp and time stamps the data, before sending it to the central repository. After the successful pilot, the system was rolled out to 3750 vaccinators employed by the Department of Health covering the whole province.

In this paper, we use the data stored at the back-end of the system that provides information on the vaccine type, the time of vaccination, and geo-stamp of where the vaccination was performed. We use these details to match vaccinations to temperature data at the time-geography level to study how temperature fluctuation in a location affects delivery.

3 Data

The Evaccs data cover vaccinations delivered by vaccinators between 2016 and 2018, including information on the date and location of each vaccination, when the digital health information system provided standardized reporting.[3] Each vaccination record contains the exact longitude and latitude coordinates, along with the precise date and time at which the vaccination is administered. Complementary information includes the IMEI number of the vaccinator's device, the type of vaccine administered, and whether the child was a resident or a guest.[4] In total, we have 2,286,910 vaccination records linked to 13,405 distinct IMEI numbers over three years. Using the geographic information of vaccination locations, we identified that the records cover 152 tehsils across Punjab. We then aggregated the number of vaccinations by tehsil and date, creating an indicator for whether a vaccination occurred in each tehsil on a given day.

[3] We obtained the dataset beginning in 2014, when the program was launched, but the data from the first two years were pilot-tested and are incomplete.

[4] An IMEI (International Mobile Equipment Identity) number is a unique 15-digit serial number that serves as a digital fingerprint for a mobile device, identifying its make, model, and status for network and security purposes.

We draw temperature data from a daily updated 0.01° $\times$ 0.01° gridded dataset covering Pakistan from 2016 to 2019, provided by the NASA Goddard Earth Sciences Data and Information Services Center (GES DISC).[5] The dataset includes near-surface air temperature and surface radiative temperature, along with measures of total precipitation rate, specific humidity, surface pressure, and evapotranspiration. Following the literature, we include these additional variables as controls when studying the effects of heat on completed vaccinations. Since the dataset provides high-resolution grids, we use the longitude and latitude information to map locations within each tehsil and then compute the average daily weather conditions at the tehsil level. This allows us to align the temperature data with the vaccination data.

To examine effects on vaccine completion, we rely on the Pakistan Social and Living Standards Measurement for 2019 and 2020. The PSLM is a nation-wide survey of households that collects household rosters and records vaccination history (self-reported and verified through records shown to enumerators by respondents) as well as a range of other measures, including household characteristics, educational and other health outcomes. We link this data at the time-geography level to the temperature data, studying children born in specific windows around extreme heat events to estimate impacts on completed vaccinations within the first months of infancy during which vaccination is most crucial. The data allows us to match backwards in time based on the birth dates of household members: e.g., a child listed as 2 years old in 2019 can be linked through their location and date of birth to temperatures in 2017.

4 Empirical Strategy

To assess extensive margin effects, we estimate regressions of the form:

$$y_{idmy} = \beta_k \sum T_{idmyk} + \delta_p \sum R_{idymp} + \eta_i + \delta_d + \omega_m + \nu_y + \varepsilon_{idmy} \qquad (1)$$

where y_{idmy} is an indicator variable for an event occurring (e.g., any vaccination) in tehsil i on day d of month m of year y. T_{idmyk} is an indicator for whether the maximum temperature measured in tehsil i on day d is in the k^{th} temperature bin. R_{idymp} is an indicator for whether daily rainfall in a tehsil is in the p^{th} precipitation bin. We include tehsil fixed

[5]This dataset is based on the Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS) Central Asia model (McNally et al., 2022). At the time of writing, the version we use—the FLDAS-Central Asia Noah 3.6 dataset (GES DISC product FLDAS_NOAH001_G_CA_D) has been decommissioned. Users are advised to transition to the updated FLDAS2 Noah-MP Central Asia dataset (GES DISC product FLDAS_NOAHMP001_G_CA_D).

effects (η_i) to account for time-invariant, location-specific factors affecting vaccination effort (e.g., distance from district hospital) and day-of-the-week (δ_d), month (ω_m), and year (ν_y) fixed effects to account for variation in vaccination effort over the course of the week and year (e.g., decreasing effort over week, specialized vaccination campaigns in particular months).

Following, Behrer and Bolotnyy (2024), we estimate a fixed effects Poisson model to reflect the skewed tehsil-day distribution of vaccinations and the presence of many zero-vaccination days in individual tehsils. Specifically, we assume that vaccinations V_{idmy} follow a Poisson distribution and assume the standard exponential form for the conditional mean $\mu(\mathbf{X}_{idmy})$ of vaccinations given covariates ($\mathbf{X}_{idmy}$) and take logs of both sides to return the estimating equation:

$$log\Big(\mu(\mathbf{X}_{idmy})\Big) = \beta_k \sum T_{idmyk} + \delta_p \sum R_{idymp} + \eta_i + \delta_d + \omega_m + \nu_y + \varepsilon_{idmy} \qquad (2)$$

where terms are identified identically as in equation (1). Estimation proceeds via maximum likelihood, which produces unbiased estimates even if the distribution of vaccinations (V_{idmy}) is non-Poisson ([cite Wooldridge 1997, 1999, 2019]).

5 Results

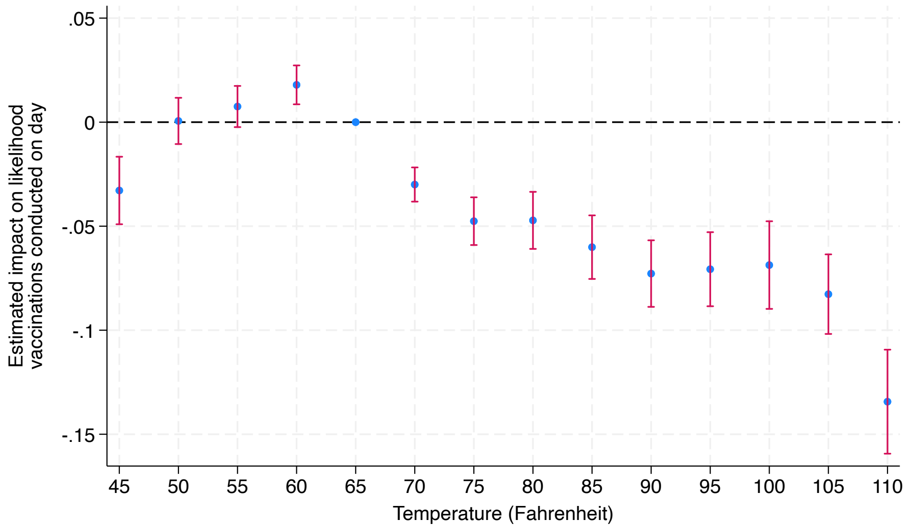
5.1 Impacts of Vaccinator Effort

We first examine the effects of temperature along the extensive margin of vaccination effort. Using estimates from a version of equation (1), Figure 1 plots the likelihood that any vaccination is conducted (in a given tehsil on a given day) across temperature bins.

We then examine impacts on the count of vaccinations using the fixed effects Poisson model (equation (2)). Figure 2 plots the estimated differences in tehsil-day vaccination counts relative to the excluded temperature bin of 60–65 degrees Fahrenheit.

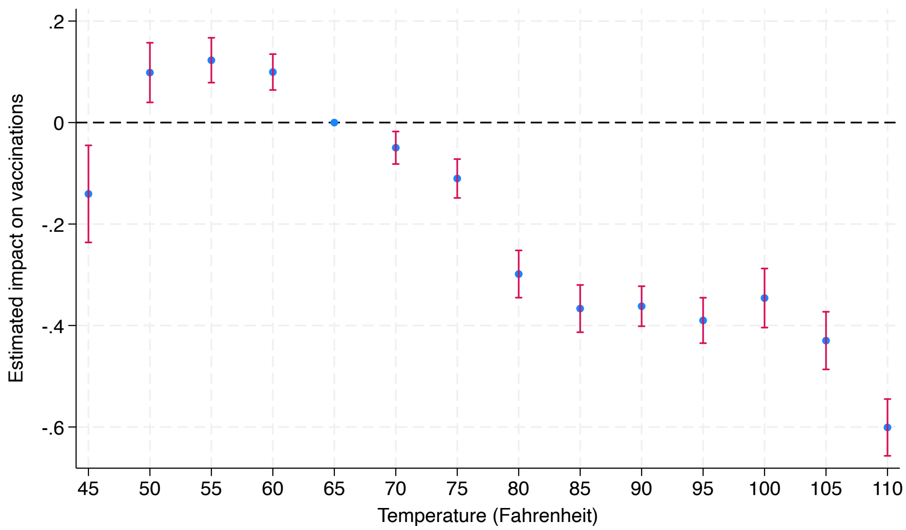
We summarize these effects in Table 1, collapsing temperatures into wider bins map colloquial categorizations of extreme heat events for ease of interpretation: (75–90] degrees and above 90 degrees Fahrenheit.

Figure 1: Effect of temperature on vaccinations: extensive margin



Notes: This figure reports estimates from a version of equation (1), plotting the relationship between temperature and the likelihood that any vaccinations occurred in a given tehsil and day. Temperature bins represent 5 degree Fahrenheit intervals. The dependent variable is an indicator for at least one vaccination occurring in tehsil i on day d.

Figure 2: Effect of temperature on total vaccinations



Notes: This figure reports estimates from the fixed effect Poisson model (equation (2)), plotting the relationship between temperature and the count of vaccinations that occurred in a given tehsil and day. Temperature bins represent 5 degree Fahrenheit intervals. The dependent variable is an indicator for at least one vaccination occurring in tehsil i on day d.

Table 1: Effect of Temperature on Vaccinations

	Any vaccinations (1)	Count of vaccinations (2)
Temperature (75–90]°F	-0.039***	-0.197***
	(0.005)	(0.021)
Temperature Above 90°F	-0.056***	-0.251***
	(0.007)	(0.017)
Observations	222,072	222,072
Clusters	152	152
Mean below 75°F	0.7	44.324
Tehsil FE	Yes	Yes
DOW FE	Yes	Yes
Month FE	Yes	Yes
Year FE	Yes	Yes
Rain Controls	Yes	Yes

Notes: This table reports estimates from equation (1) (Column 1) and the fixed effects Poisson model (equation (2)) (Column 2) of the relationship between vaccination effort and temperature. The dependent variable in Column 1 is an indicator for any vaccinations occurring in a tehsil and day. The dependent variable in Column 2 is the count of vaccinations in a tehsil and day. We include tehsil, day-of-the-week, month, and year fixed effects and control for binned precipitation levels. We cluster standard errors at the teshil level.

Daily temperatures between 75 and 90 degrees Fahrenheit reduce the likelihood vaccinations take place in a tehsil by 3.9 percentage points (5.5%), while temperatures above 90 degrees do so by 5.6 percentage points (8%). Estimates from the fixed effects Poisson model can be exponentiated to obtain multiplicative factors. In other words, temperatures in the 75 to 90 degree range result in a $\left(1 - e^{-0.197}\right) \cdot 100 = 17.9\%$ lower vaccination count, while temperatures above 90 degrees result in a $\left(1 - e^{-0.251}\right) \cdot 100 = 22.2\%$ lower count.

5.2 Impacts on Access to Vaccines

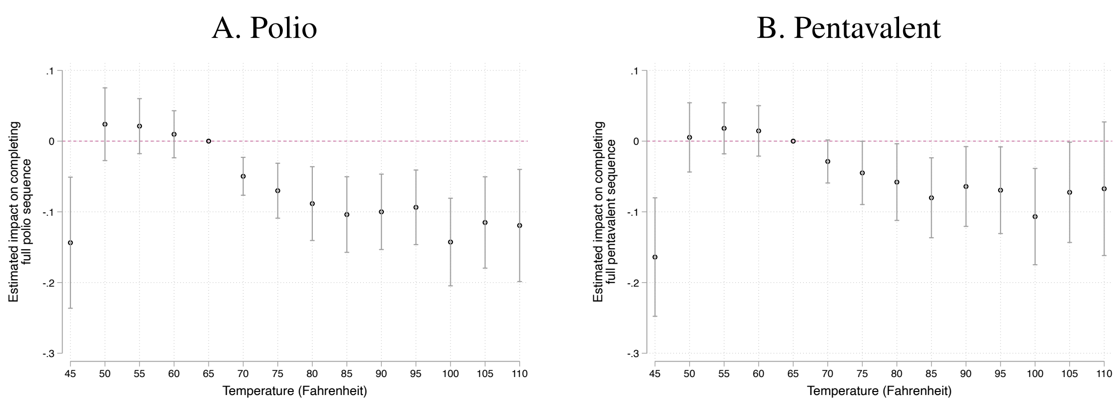
We next study how effects on vaccine delivery map to access among the ultimate target population for vaccinations: children born within the jurisdictions of the public workers in our sample. We focus on vaccines that are intended to be delivered at various points in early childhood: polio and pentavalent (diphtheria, pertussis, tetanus, hepatitis B, and Hemophilus influenza type B (Hib)) vaccines. We focus on these vaccinations given their importance to health. The harms of polio infection are severe, involving risk of permanent disability. Moreover, polio eradication is an ongoing effort in Pakistan: it remains one of the few countries in the world where polio remains endemic (Asghar, 2020). The pentavalent vaccine protects against diphtheria, pertussis, tetanus, hepatitis B and Hemophilus influenza type B (Hib), diseases that can have devastating impact if contracted during childhood (Bairwa et al., 2012).

We estimate a version of equation (1) at the week level, focusing on the week when children turn two months old, which is viewed as critical period for providing even partial protection against communicable illness. We consider other recommended vaccination timings in [tbd] and placebo tests for periods before birth and after early childhood vaccination windows in [tbd]. Specifically, we match children in the PLSM sample to days 60 days after birth in our temperature data. We estimate effects at the week level to account for imperfect timing of vaccinations on the precise date infants turn two months of age.[6]

Figure 3 plots the relationship between temperatures when infants are two months of age and the likelihood of completing the full vaccine sequence for polio and the pentavalent innoculations.

We estimate impacts for the same bins as in Table 1 for a range of vaccines in Table 2.

Figure 3: Effect of temperature vaccine access: Polio and Pentavalent



Notes: This figure reports estimates from a version of equation (2), plotting the relationship between temperature and the likelihood that a child received a vaccination against polio (Panel A) or the pentavalent vaccine (Panel B) in a given tehsil and day two months after their birth. Temperature bins represent 5 degree Fahrenheit intervals. The dependent variable is an indicator for at least one vaccination occurring in tehsil i on day d.

[6] When estimating this specification we exclude day-of-week fixed effects but include month and year fixed effects, along with tehsil fixed effects and precipitation bins estimated at the weekly level.

Table 2: Effect of Temperature on Vaccine Access

		Completion of sequence for:					
	Immunized	Polio	Penta	Measles	Pneumo	IPV	BCG
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Temperature (75–90]°F	0.006	-0.059***	-0.045**	0.022	-0.032*	-0.056***	0.004
	(0.005)	(0.018)	(0.019)	(0.019)	(0.018)	(0.021)	(0.009)
Temperature Above 90°F	0.004	-0.062***	-0.046*	0.044	-0.026	-0.055**	-0.002
	(0.007)	(0.024)	(0.025)	(0.028)	(0.026)	(0.027)	(0.013)
Observations	12,060	11,888	11,888	11,888	11,888	11,888	11,888
Clusters	111	111	111	111	111	111	111
Mean below 75°F	.982	.843	.852	.577	.854	.838	.98
Tehsil FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Rain Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports estimates from equation (2) of the relationship between vaccine access and temperature when a child is two months old. The dependent variable in Column 1 is an indicator for a child born 60 days before the temperature estimated in their tehsil on a given day, pooling days within the same week. The dependent variables are indicators for being immunized at all (Column 1) and completing the full sequence for vaccines (Columns 2-6). We include tehsil, month, and year fixed effects and control for binned precipitation levels at the week level. We cluster standard errors at the teshil level.

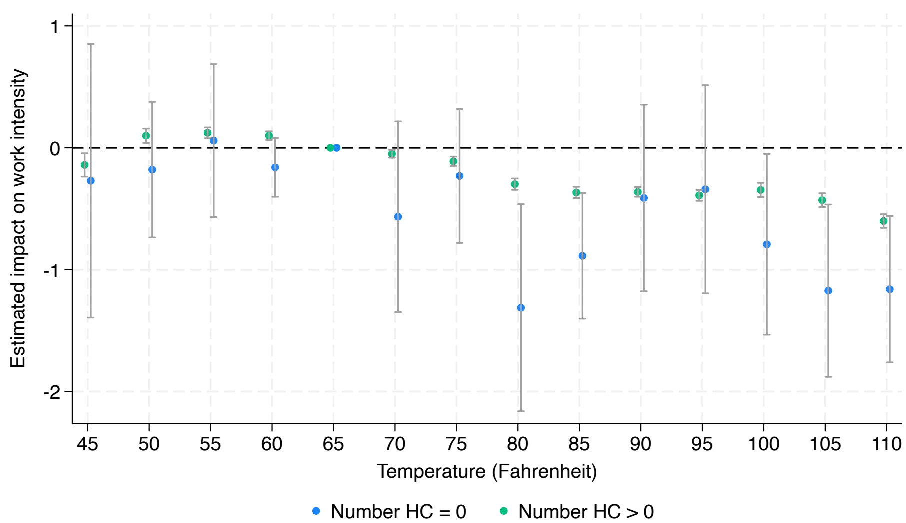
6 Channels

The primary mechanisms of interest in our setting of public health services delivery are the channels of field agent effort and citizen willingness to seek access. Existing evidence suggests supply-side effort is likely to be impacted when outcomes depend on inputs vulnerable to temperature fluctuations, such as hours spent traveling, moving around on foot, and time spent out in the sun. The nature of vaccination work in Pakistan — involving deployment of agents into communities to seek out patients and deliver doses — makes it susceptible to extreme heat events. On the other hand, what is unique about public service delivery is the extent to which it also relies on demand side channels, or citizens' willingness to venture outside of their homes in search of care. This is the case in our context where willingness to accept vaccines depends in knowledge of their value but also households making efforts to seek out vaccination opportunities in their communities. Extreme heat may thus constrain demand simultaneous to its impacts on supply.

We explore these channels by classifying vaccination staff into more and less mobile groups. Some agents stick close to health center locations, suggesting they operate as "stationary" staff tasked with receiving visitors to clinics. Other are substantially mobile, traversing radii of 60km or more in a single month. Comparing the relationship between vaccine doses delivered and heat events between these two groups of personnel can reveal to what extent demand-side channels play a role: while the outcomes among mobile agents may be more susceptible to temperature fluctuations through both supply and demand mechanisms, the work of stationary agents will likely be most affected through impacts on demand.

Figure 4 compares effects on doses across more mobile and more stationary agents. We proxy agent type by whether a health center is located in their domain. We find that effects are larger for location without health centers, consistent with the presence of both demand- and supply-side effects. These results should be interpreted with a grain of salt, however, as the comparison does not account for potential differences that may exist across the locations in which each type operates or in the characteristics of agent types, which we lack sufficient data to address.

Figure 4: Effect of temperature on total vaccinations by health center location



Notes: This figure reports estimates from the fixed effect Poisson model (equation (2)), plotting the relationship between temperature and the count of vaccinations that occurred in a given tehsil and day by whether a tehsil has a health center or not. Regressions are run separately for locations with no health center and with at least one. Temperature bins represent 5 degree Fahrenheit intervals. The dependent variable is an indicator for at least one vaccination occurring in tehsil i on day d. Blue circles represent estimates for locations with no health center, and green triangles represent locations with at least one health center.

7 Conclusion

This paper documents a relationship between extreme heat and the effectiveness of public health service delivery at a granular level. We show that rises in temperature are linked to reductions in completed vaccinations, leveraging rich administrative data and national survey data from Pakistan. Both vaccinator effort and citizen willingness to seek out access emerge as potential channels, highlighting the role of supply and demand channels in constraining access.

Though the effects we document are relative modest when limited to the day a heat event occurs, the rising prevalence of extreme heat in nations like Pakistan highlights the potential dangers of aggregate impacts of temperature-related disruptions on fundamental health systems. Future research that decomposes effects into supply- and demand-side mechanisms with greater precision could fruitfully contribute towards policies aimed at making public service delivery resilient to climate change.

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