When Parents Meet the State: Capacity, Climate, and Early-Life Investments

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Abstract

We study how institutional capacity shapes the realization of early-life investments under climate stress. Building on the technology of skill formation, we model vaccination as an early input whose effectiveness depends not only on household behavior but also on a system-level factor: state capacity. Capacity raises baseline delivery and buffers shocks, so the marginal effectiveness of household effort is higher in stronger systems. This interaction generates dynamic complementarities and the possibility of a state-capacity trap: identical climatic shocks depress investment in fragile systems but are absorbed in resilient ones. We test these predictions using harmonized district-level data from India and Pakistan (2010–2021), linking child vaccination outcomes to gridded temperature anomalies. Our outcomes are completion of two system-dependent, multi-dose vaccines—Polio and DPT—and our capacity proxy is health-card coverage. Reduced-form estimates show that hotter-than-normal conditions substantially reduce Polio completion in low-capacity districts, while effects are near zero where capacity is high; DPT estimates are directionally similar but less precise. Cross-border comparisons mirror these patterns: Indian districts—on the higher-capacity branch—exhibit

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stronger buffering and higher baseline coverage, while most Pakistani districts remain below the resilience threshold, where capacity improvements yield smaller marginal gains. The results provide micro evidence that institutional capability governs whether intended investments are realized when systems are stressed. They connect human-capital production, climate shocks, and comparative development by showing that adaptation hinges as much on governance as on geography.

1 Introduction

Why do some societies maintain steady human-capital investments under stress while others experience sharp declines? In settings where public systems function reliably, household effort translates into realized investments; where institutions are fragile, identical effort may fail to produce outcomes. This paper examines how institutional capacity conditions the determinants of early-life investment when environmental stress occurs. We focus on childhood vaccination—an archetypal preventive health investment that depends on both household behavior and the stability of public delivery systems. Our central idea is that the household and the state jointly determine whether investments are realized: capacity governs the extent to which private intentions become completed actions. Where institutions are strong, incentives and feasibility remain intact; where they are weak, shocks and administrative breakdowns distort or deter investment.

Conceptually, the paper extends the technology of skill formation (Cunha and Heckman, 2007; Heckman, 2006; Cunha et al., 2010; Attanasio et al., 2022) by embedding household investment decisions within an institutional environment. In canonical models, child outcomes evolve as a dynamic production function in which early inputs raise later human capital through complementarity with existing ability. We enrich this framework by introducing *state capacity* as a higher-order factor that governs the translation of household intent into realized investment. Capacity affects not the productivity of parental inputs directly but their reliability: whether a motivated household can convert intention into completion depends on the functionality of the public delivery system. When administrative systems maintain vaccine cold chains, records, and outreach, identical parental intent yields higher realized investment; when institutions are fragile, the same intent translates into lower completion rates. Climatic shocks—such as temperature anomalies—act as exogenous stressors that strain these systems. Because their effects depend on local administrative strength, the joint technology exhibits cross-level complementarities: the marginal effectiveness of household effort rises with state capacity. Over time, this interaction creates feedback dynamics.

High-capacity systems sustain investment flows and thereby reinforce reliability and trust; low-capacity systems transmit shocks into forgone investments and eroded expectations of service, further weakening capability. This feedback structure generates what we call a *state-capacity trap*—an institutional analogue to household-level poverty traps, where similar external shocks yield persistently different equilibria depending on initial capability. The model implies that climatic shocks will depress realized investments on average, but their effects will diminish and eventually vanish as administrative capacity rises.

We test these predictions in South Asia, focusing on India and Pakistan—two countries with common colonial foundations, similar geography, and shared exposure to climatic stress, yet sharply divergent trajectories of state development.

At independence, India and Pakistan inherited near-identical colonial administrative architectures centered on the Indian Civil Service; Partition largely divided a common bureaucratic template between the two states (Metcalf and Metcalf, 2015; Talbot, 2015). Over subsequent decades, India's largely continuous—if imperfect—democratic governance supported the expansion of bureaucratic capability, statistical systems (e.g., large-scale household surveys), and public health delivery (Kohli, 2004; Drèze and Sen, 2013). By contrast, Pakistan's repeated episodes of military rule disrupted institutional continuity and eroded administrative capacity (Jalal, 1990; Talbot, 2015; Mian, 2024). Pakistan's alternating civilian and military regimes fragmented continuity, producing weaker and more uneven capacity (Mian, 2024).

Despite similar climates, these divergent paths generated large and persistent gaps in human-capital outcomes: since the 1980s, Pakistan's infant mortality rate has remained roughly twice India's, and immunization coverage diverged even more sharply. Our analysis focuses on districts along the Indo–Pak border—Sindh and southern Punjab in Pakistan, and Punjab, Gujarat, and Rajasthan in India—regions that share agroecological conditions and similar exposure to temperature variation but differ markedly in administrative reliability. This geography provides a quasi-natural contrast for isolating how capacity mediates the

relationship between climate shocks and household investment.[1]

Our empirical analysis draws on a harmonized dataset that integrates district-level immunization outcomes, temperature anomalies, and administrative indicators for India and Pakistan between 2010 and 2021. The data are structured as repeated cross-sectional panels at the district–cohort–survey level. For Pakistan, we use multiple rounds of the *Pakistan Social and Living Standards Measurement Survey* (2010–11, 2012–13, 2014–15, and 2019–20); for India, we use the *National Family Health Survey* (2015–16 and 2019–21). These nationally representative surveys provide detailed child-level records of vaccination receipt and health-card verification, enabling us to construct consistent measures of realized early-life investment across contexts. Our primary outcomes are the completion rates of **Polio** and **DPT** vaccinations—two core multi-dose vaccines that critically depend on both household follow-through and institutional continuity. Unlike one-time vaccines, Polio and DPT require multiple contacts, functioning cold chains, and accurate record systems; their completion rates therefore serve as sensitive indicators of public-health reliability (Ozawa et al., 2017). Health-card coverage at the district level serves as an institutional proxy for administrative reliability, capturing record-keeping, outreach, and logistical functionality. Climatic exposure is measured using $0.5^\circ \times 0.5^\circ$ gridded monthly temperature data from the *Climatic Research Unit Time-Series* (CRU TS v4.08; Harris et al. 2020), supplemented by higher-resolution ERA5 reanalysis data ($0.25^\circ \times 0.25^\circ$) for robustness. Temperature data are spatially aligned with district boundaries in both countries using inverse-distance weighting around district centroids and buffered to ensure coverage of all administrative units. Monthly temperature deviations are computed relative to a 30-year rolling baseline (1981–2010) following World Meteorological Organization guidelines. These deviations and standardized z-scores capture the intensity of heat shocks relative to long-term norms. To ensure comparability, the sample focuses on contiguous provinces and states along the Indo–Pak border—Punjab and Sindh

[1]We use *state capacity* in the political-economy sense—the ability of the nation-state to deliver public goods. For subnational units, we use *province* for Pakistan and *state* for India. Our analysis aggregates child observations to district–cohort cells and links them to district–province (Pakistan) and district–state (India) measures of administrative strength.

in Pakistan, and Punjab, Gujarat, and Rajasthan in India—which share agroecological conditions and exposure to similar temperature variability. The harmonized data thus combine micro-level information on household vaccination behavior with high-resolution environmental and administrative data, enabling a unified analysis of how climate shocks interact with state capacity to shape early-life human-capital investment.

The results align closely with the theoretical predictions. Hotter-than-average conditions significantly reduce Polio completion in low-capacity districts but have negligible effects in high-capacity ones. For DPT, the point estimates are directionally similar but less precise—consistent with the model's threshold structure in which low-capacity systems exhibit steep fragility while higher-capacity systems flatten out. Districts with above-average health-card coverage achieve both higher baseline vaccination and weaker sensitivity to climatic stress, implying that capacity enhances not only the level but also the resilience of service delivery. The same pattern holds across borders: Indian districts—particularly those in Punjab and Gujarat—exhibit strong buffering, while Pakistani districts in Sindh and southern Punjab remain fragile to the same shocks. These effects persist after including district-specific time trends and alternative climatic measures. Together, the results reveal a systematic interaction between environmental stress and institutional capability in shaping early-life human-capital investment.

The paper contributes to three strands of literature. First, it speaks to work on the determinants of child vaccination and preventive health behavior, emphasizing how service reliability shapes the realization of parental investment intentions (e.g., Dupas, 2011; Björkman and Svensson, 2009; Baranov et al., 2020). Second, it contributes to research on climate and development by highlighting the role of institutions in mediating the effects of environmental stress (Dell et al., 2014; Burke et al., 2015; Carleton et al., 2022). Third, it connects to comparative development and political economy by linking macro-institutional differences to micro-level investment behavior (Acemoglu et al., 2005; Besley and Persson, 2011; Khwaja and Mian, 2005; Mian, 2024; Rosenzweig and Udry, 2020; Banerjee and Ma-

jid, 2025). In doing so, it provides a behavioral microfoundation for why some states absorb shocks while others amplify them: when capacity is high, climate shocks have little effect on human-capital investment; when capacity is low, identical shocks trigger cumulative fragility.

Two clarifications guide interpretation. First, we study the determinants of early-life investments rather than their long-run impacts; our contribution is to explain *when* investments occur under stress, not *what* they produce. Second, health-card coverage, while an observable proxy for administrative reliability, may capture multiple dimensions of state performance—information systems, logistics, and outreach. We address this by focusing on comparative statics—how the elasticity of investment to climate shocks varies across capacity strata and borders—rather than levels alone, and by demonstrating consistent patterns across alternative specifications and robustness checks.

By bringing together insights from human-capital theory, institutional economics, and the political economy of development, the paper links the microeconomics of parental decision-making to the macroeconomics of state capability. It shows that the capacity to invest in children is not solely a household attribute but a co-produced outcome of administrative reliability and environmental stability. In fragile systems, shocks propagate downward; in capable systems, they are absorbed, sustaining the accumulation of human capital over time.

2 Theoretical Framework: Climate, State Capacity, and Early-Life Investment

This section develops a simple dynamic framework linking climate stress, state capacity, and the productivity of early-life health investments. It extends the canonical Heckman–Cunha model of skill formation to a *system-level setting*, where vaccination coverage is an investment in population health capital whose efficiency depends on the state's institutional capability and exposure to climate stress. The framework motivates our empirical specification and provides clear testable predictions.

2.1 Vaccination as an Early-Life Investment in the Technology of Skill Formation

Following Cunha and Heckman (2007) and Almond and Currie (2011), we interpret early-life health inputs as investments in the "technology of skill formation," where health and human capital evolve through dynamic complementarities and self-productivity. We adapt this logic to a system-level context in which the *state* itself acts as the producer of these investments.

Let S_t denote the population's average capability stock (including health capital), and I_t denote the realized early-life investment (vaccination completion). Then:

$$S_{t+1} = A(H_t, T_t)\, G(S_t, I_t), \tag{1}$$

where H_t represents state capacity, T_t represents climate stress (e.g., temperature anomaly), $G(S_t, I_t)$ is the micro-level health-production technology, and $A(H_t, T_t)$ captures the institutional and climatic productivity of that process.

Micro-level (Heckman–Almond) technology. Following the canonical CES form:

$$G(S_t, I_t) = [\phi\, S_t^{\rho} + (1-\phi)\, I_t^{\rho}]^{1/\rho}, \quad \rho < 1,\ \phi \in (0,1),$$

which implies $G_S > 0$ (self-productivity) and $G_{SI} > 0$ (dynamic complementarity). Here, vaccination is an *early-life investment* that builds the health component of human capital and increases the productivity of later inputs such as schooling and nutrition. Its effectiveness depends on the efficiency with which the state delivers and sustains immunization services.

Institutional productivity and climate. The term $A(H_t, T_t)$ governs how efficiently inputs are translated into outcomes:

$$A_H > 0, \quad A_T < 0, \quad A_{HT} > 0.$$

State capacity improves monitoring, logistics, and data systems, thereby raising the productivity of vaccination investments. Climate stress—especially heat—reduces efficiency through absenteeism, infrastructure strain, and vaccine spoilage. Crucially, the cross-partial $A_{HT} > 0$ implies that capacity buffers climatic damage: strong systems are more resilient.

Climate also affects the *realized investment* I_t through delivery:

$$I_t = I(H_t, T_t), \qquad I_H > 0,\ I_T < 0,\ I_{HT} > 0.$$

Thus, heat depresses both delivery and productivity, while capacity mitigates both effects.

Empirical interpretation. In our empirical setting, health-card coverage proxies for H_t: the administrative and informational infrastructure of the health system, including record-keeping, outreach, and trust. Vaccination completion, I_t, represents the realized early-life investment. Climate shocks (T_t) directly disrupt both service delivery and institutional efficiency. The Indo–Pak border provides a natural test: Indian districts (high H_t) operate above the threshold of resilience, whereas many Pakistani districts (low H_t) remain below it.

2.2 Comparative Statics and Predictions

Substituting $I(H_t, T_t)$ into (1) gives:

$$S_{t+1} = A(H_t, T_t)\, G(S_t, I(H_t, T_t)).$$

Differentiating with respect to T_t and H_t yields:

$$\frac{\partial S_{t+1}}{\partial T_t} < 0, \quad \frac{\partial^2 S_{t+1}}{\partial H_t \partial T_t} > 0.$$

Hence, hotter conditions reduce the productivity of early-life investments, but this effect diminishes as state capacity rises. Because observed vaccination coverage $Y_{v,dt}$ is monotonic

in S_{t+1}, it inherits these signs in the reduced form:

$$Y_{v,dt} = \beta_0 + \beta_T T_{dt} + \beta_H H_{dt} + \beta_{TH}(T_{dt} \times H_{dt}) + \varepsilon_{v,dt}. \tag{2}$$

Predicted signs:

$$\beta_T < 0, \qquad \beta_H > 0, \qquad \beta_{TH} > 0.$$

Prediction 1 (Climate penalty). Higher temperatures reduce realized vaccination investments.

Prediction 2 (Capacity lift). Stronger state capacity increases baseline coverage and resilience.

Prediction 3 (Buffering). The climate penalty is smaller in high-capacity districts, i.e. $\partial^2 Y / \partial H \partial T > 0$.

2.3 Dynamic Complementarities and the State-Capacity Trap

State capacity itself evolves through administrative learning and public trust:

$$H_{t+1} = (1 - \delta) H_t + \pi\, Y_{t+1} - \chi\, T_t, \tag{3}$$

where $\pi > 0$ captures institutional learning from successful delivery and $\chi > 0$ represents climate-induced erosion. Substituting (1)–(3) yields an S-shaped dynamic map:

$$H_{t+1} = \Phi(H_t; T_t),$$

with two stable equilibria and a threshold K^*. Below K^*, low capacity and high climate sensitivity reinforce fragility; above it, high capacity and resilience reinforce one another.

Prediction 4 (Capacity trap). Low-capacity districts experience self-reinforcing fragility under repeated shocks, while high-capacity districts remain resilient.

Observed differences in the magnitude of climate–capacity interactions across settings reflect where each system lies relative to this threshold, not differences in behavioral responsiveness.

Interpretation. Countries or districts clustered below K^*—such as much of Pakistan—will display large negative direct effects of climate stress but relatively weak β_{TH} interactions, since capacity remains too low for complementarities to fully manifest. Conversely, systems that lie above K^*—as in most Indian districts—exhibit strong buffering and pronounced positive β_{TH}, indicating that the same underlying complementarities become visible only once baseline capacity surpasses the resilience threshold. Thus, cross-national differences in slope magnitudes represent different positions on a common non-linear state-capacity curve.

2.4 Extension and Empirical Interpretation

This framework extends the Heckman–Cunha model from the individual to the institutional domain: the state functions as the *production technology* converting investments into population health. Vaccination coverage is the realized investment I_t, and health-card coverage is an observable proxy for H_t, the state's administrative capacity. Climate shocks (T_t) lower both investment and productivity. Formally, $\frac{\partial^2 Y}{\partial H \partial T} > 0$ implies that stronger institutions attenuate the effect of heat on coverage.

Empirically, this yields clear predictions along the Indo–Pak border: Indian districts—characterized by higher H_t—lie on the resilient branch ($H_t > K^*$) with small or null temperature effects; Pakistani districts—characterized by lower H_t—remain on the fragile branch ($H_t < K^*$), where heat shocks produce large coverage losses. The observed positive interaction $\widehat{\beta}_{TH} > 0$ therefore represents the reduced-form footprint of these underlying complementarities between state capacity, climate stress, and early-life health investment.

2.5 Empirical Implications

The model implies the following reduced-form predictions that our tables speak to directly:

P1 Climate Sensitivity. Temperature shocks reduce immunization coverage ($\beta_T < 0$).

P2 Institutional Lift. Higher capacity raises baseline coverage ($\beta_H > 0$).

P3′ Convex Buffering. The (negative) heat slope flattens as capacity rises: the interaction term is positive and grows with H (captured by $\beta_{TH} > 0$ and stronger in higher-H settings).

P4′ Reduced-Form Threshold / Regimes. Identical shocks have markedly smaller effects in high-H places than in low-H places (India vs. Pakistan; high- vs. low-capacity districts within countries), consistent with being on opposite sides of a capacity threshold.

P5′ Dynamic Persistence in Fragile Regimes. Shock scarring (lasting deficits following hot periods) appears in low-capacity districts but attenuates in high-capacity districts, consistent with fragile vs. resilient regimes.

3 Econometric Specification

All outcomes are vaccination indicators for Polio or DPT. $\text{WeatherShock}_{dct}$ measures deviations from 30-year temperature normals over birth → survey. Standard errors clustered by district.

Model 1: Baseline (Bordering States)

$$\begin{aligned} Y_{idct} = \beta_0 + \beta_T\, T_{dt} \\ + \lambda_d \times \text{BirthYear}_i + \lambda_d \times \text{BirthMonth}_i \\ + \tau_c + \gamma_t + \varepsilon_{idct}. \end{aligned} \tag{4}$$

Model 2: Climate × Capacity (Bordering States)

$$\begin{aligned} Y_{idct} = \beta_0 &+ \beta_T\, T_{dt} + \beta_H\, \text{AboveAvgHC}_{dt} \\ &+ \beta_{TH}(T_{dt} \times \text{AboveAvgHC}_{dt}) \\ &+ \lambda_d \times \text{BirthYear}_i + \lambda_d \times \text{BirthMonth}_i + \tau_c + \gamma_t + \varepsilon_{idct}. \end{aligned} \tag{5}$$

Model 3: Cross-Border (India vs. Pakistan)

$$\begin{aligned} Y_{idct} = \beta_0 &+ \beta_T\, T_{dt} + \beta_{IND}\, \text{India}_d \\ &+ \beta_{T\times IND}(T_{dt} \times \text{India}_d) \\ &+ \lambda_d \times \text{BirthYear}_i + \lambda_d \times \text{BirthMonth}_i + \tau_c + \gamma_t + \varepsilon_{idct}. \end{aligned} \tag{6}$$

Model 4: Within-Country Heterogeneity by Capacity

$$\begin{aligned} Y_{idct} = \beta_0 &+ \beta_T\, T_{dt} + \beta'_H(\text{Country} \times \text{AboveAvgHC}_{dt}) \\ &+ \beta'_{TH}(T_{dt} \times \text{Country} \times \text{AboveAvgHC}_{dt}) \\ &+ \lambda_d \times \text{BirthYear}_i + \lambda_d \times \text{BirthMonth}_i + \tau_c + \gamma_t + \varepsilon_{idct}. \end{aligned} \tag{7}$$

Model 5: Robustness with District Quadratic Time Trends

$$\begin{aligned} Y_{idct} = \beta_0 + \beta_T\, T_{dt} + \beta_H\, \text{AboveAvgHC}_{dt} + \beta_{TH}(T_{dt} \times \text{AboveAvgHC}_{dt}) \\ + \lambda_d^{(1)} \times \text{BirthYear}_i + \lambda_d^{(2)} \times \text{BirthYear}_i^2 + \tau_c + \gamma_t + \varepsilon_{idct}. \end{aligned} \tag{8}$$

4 Mapping Predictions to Empirical Tests

5 Data

Our empirical analysis combines nationally representative household survey data on childhood immunization from India and Pakistan with high-resolution gridded climate data and district-level indicators of administrative capacity. The resulting dataset spans the period 2010–2021 and is structured as a repeated cross-sectional panel at the district–cohort–survey level, harmonized to enable direct cross-country comparison.

Table 1: Mapping of Theoretical Predictions to Empirical Tests

Prediction	**Mechanism**	**Empirical Spec / Table**	**Expected Sign**	**Interpretation**
P1: Climate Sensitivity	Direct temperature effect	Table 3	$\beta_T < 0$	Heat reduces completion
P2: Institutional Lift	Capacity raises baseline	Table 4	$\beta_H > 0$	Higher capacity $\Rightarrow$ higher coverage
P3: Dynamic Complementarities	Capacity buffers heat more where H is high	Table 4	$\beta_{TH} > 0$	Smaller heat penalty in high-H areas
P4: Cross-Border Threshold	Avg. capacity differs by country	Table 5	$\beta_{T\times IND} > 0$	India less sensitive to heat than Pakistan
P5: Robustness (Trends)	Slow-moving trends absorbed	Table 7	Signs persist	Not driven by secular rollout

5.1 Household Surveys

For India, we use data from the *National Family Health Survey* (NFHS-4, 2015–16; NFHS-5, 2019–21), conducted by the International Institute for Population Sciences (IIPS) under the supervision of the Ministry of Health and Family Welfare. For Pakistan, we rely on four rounds of the *Pakistan Social and Living Standards Measurement Survey* (PSLM, 2010–11, 2012–13, 2014–15, 2019–20) collected by the Pakistan Bureau of Statistics. Both surveys employ multi-stage stratified sampling and are designed to be nationally representative of households, women aged 15–49, and children under five. The NFHS and PSLM instruments share nearly identical vaccination modules and record each child's immunization history from health cards and maternal recall. Following standard practice in the global immunization literature (e.g., Björkman Nyqvist et al., 2019), we restrict the sample to living children aged 12–23 months to capture completion within the first two years of life.

5.2 Vaccination Outcomes

The primary outcomes are the completion rates for the Polio and Diphtheria–Pertussis–Tetanus (DPT/DTP) series, measured as the share of children who received all recommended doses by age two. Both are multi-dose schedules that require repeated contacts with providers and functioning cold-chain systems (World Health Organization, 2016, 2015). As a result, completion is highly sensitive to delivery reliability—record-keeping, outreach, and uninterrupted refrigeration—factors known to be vulnerable to temperature excursions and service disruptions (Matthias et al., 2007; Ashok et al., 2017).In each survey, vaccination status is coded as 1 if the child received all doses and 0 otherwise. We compute district-level means of these indicators for each birth-cohort–survey cell, using sampling weights to preserve national representativeness.

5.3 Administrative Capacity

We measure subnational administrative capacity using the proportion of children in each district whose vaccination information was verified by a *health card*. This variable captures the reliability of record-keeping and the functionality of outreach and cold-chain systems, and it closely aligns with administrative indicators used in other analyses of health-system performance in low- and middle-income countries (Dupas, 2011). Districts with higher health-card coverage have more complete data systems and higher baseline immunization rates, consistent with their classification as high-capacity units. To facilitate interpretation, we standardize this variable within each country and construct an indicator for districts above the national mean.

5.4 Climate Data

Climatic exposure is measured using gridded temperature data from the *Climatic Research Unit Time-Series* dataset (CRU TS v4.08; Harris et al. 2020) at 0.5°×0.5° resolution. For

robustness, we replicate key analyses using ERA5 reanalysis data at 0.25°×0.25° resolution. We assign each district the inverse-distance-weighted average of grid-cell values whose centroids fall within or near its boundaries. Monthly mean temperatures are aggregated to annual averages for each district, and deviations are computed relative to a 30-year baseline (1981–2010) following World Meteorological Organization guidelines. These standardized anomalies capture temporary departures from long-run climate norms and have been widely used in prior work linking climate shocks to economic and health outcomes (Dell et al., 2014; Burke et al., 2015; Carleton et al., 2022). All temperature variables are demeaned within country to ensure comparability across national scales.

5.5 Harmonization and Sample Definition

We harmonize administrative boundaries across survey years using official district-mapping concordances from India's Census of 2011 and Pakistan's 2017 Census. All data are aggregated to 300–350 consistent district units. To maintain comparability, we restrict the analytic sample to contiguous provinces and states along the Indo–Pak border: Punjab and Sindh in Pakistan, and Punjab, Gujarat, and Rajasthan in India. These regions share agroecological conditions and exposure to similar temperature variability but differ markedly in administrative capacity, providing a natural contrast for our identification strategy. The merged dataset covers approximately 80,000 child observations, representing 40,000 in Pakistan and 40,000 in India after applying age and data-quality filters.

5.6 Descriptive Statistics

Table 2 presents summary statistics for key variables. Average completion of the Polio series is 59% in Pakistan and 74% in India, while DPT completion averages 58% and 72%, respectively. Mean health-card coverage is roughly 60% in Pakistan and 80% in India, consistent with large cross-national differences in administrative reliability. Temperature deviations during the study period range from -1.2°C to +1.6°C relative to the long-term

mean, providing sufficient variation to identify the effects of heat stress. All regressions are weighted by district population, with standard errors clustered at the district level.

Table 2: Summary Statistics (District–Cohort Level, 2010–2021)

	Pakistan	India
Polio completion (%)	59.5	74.1
DPT completion (%)	57.9	72.0
Health card coverage (%)	60.3	79.7
Mean temperature deviation (°C)	0.04	0.07
Observations (district–cohort)	1,200	1,350

5.7 Measurement Considerations

Vaccination data may be affected by recall error when health cards are unavailable. However, restricting to card-verified observations yields qualitatively similar patterns. We further verify that the relationship between health-card coverage and mean vaccination levels is monotonic, supporting its interpretation as an indicator of institutional capacity rather than data quality per se. Climate data are cross-validated against ERA5 to ensure robustness to measurement error in local temperature interpolation. Finally, survey timing does not systematically vary with local climate, minimizing concern that data collection coincides with seasonal anomalies.

Overall, the data provide a high-frequency, cross-nationally comparable lens on how climatic shocks interact with state capacity to shape early-life human-capital investments through vaccination behavior.

6 Results

We begin by presenting descriptive evidence and then estimate a sequence of models that progressively incorporate institutional capacity and country heterogeneity. Throughout, coefficients are interpreted as percentage-point (p.p.) changes in vaccination completion associated with one-degree Celsius deviations from the long-term temperature mean. The average

completion rates are roughly 60% in Pakistan and 70–75% in India, so a one-degree change can be interpreted as a 10–12% shift relative to baseline coverage.

6.1 Baseline Patterns and Motivation

Figures 1 and 2 plot district-level averages of card-verified DPT and Polio coverage across the Indo–Pak border. A striking discontinuity is visible: even contiguous districts—Lahore and Amritsar, Hyderabad (Sindh) and Kutch (Gujarat)—show gaps exceeding 20–30 p.p. These differences emerge despite shared climate and geography, suggesting that variation in institutional reliability rather than ecology drives the divide. Indian districts display both higher mean coverage and lower spatial dispersion, consistent with stronger administrative capability and smoother delivery systems.

6.2 Baseline Climate Effects (M1)

Table 3 reports the reduced-form relationship between temperature anomalies and vaccination outcomes. In this baseline specification without capacity controls, hotter-than-average conditions are associated with significantly lower Polio completion (–6.99 p.p., $p < 0.05$) and a smaller, imprecisely estimated decline in DPT (–3.84 p.p.). Given average coverage of roughly 59 p.p. in the sample, the Polio effect represents a 12 percent reduction relative to the mean. This pattern is consistent with service disruptions that accompany heat extremes—power outages affecting vaccine refrigeration, absenteeism among health workers, or declines in household mobility on high-temperature days. The weaker and noisier DPT effect foreshadows the central theme of this paper: that institutional buffering mediates both the magnitude and the precision of climatic impacts.

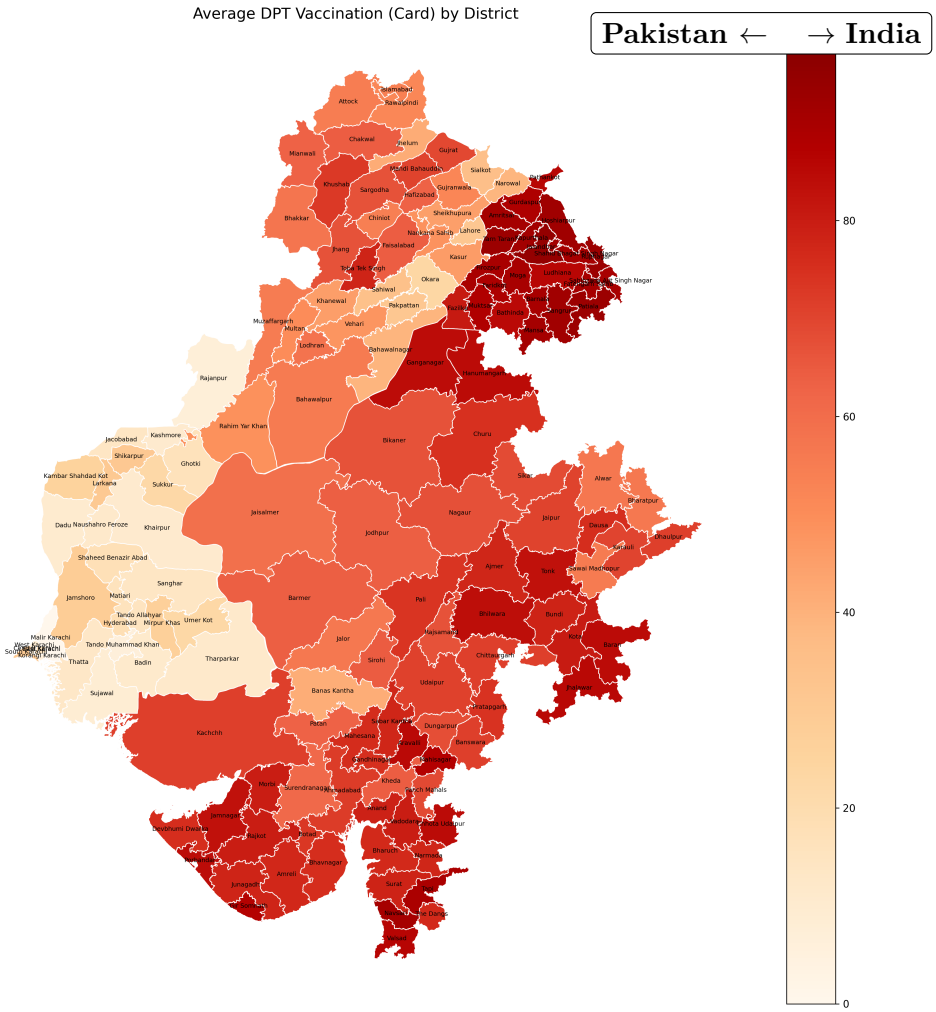


Figure 1: Average DPT vaccination (card) by district, Indo–Pak border. Cue indicates Pakistan (west/left) and India (east/right).

Table 3: Baseline Climate Effects (Model M1)

	(1) Polio	(2) DPT
Average Temperature Deviation	−6.989**	−3.839
	(3.133)	(2.920)
Sample size	38,532	40,953
Mean dep. var.	59.53	57.86

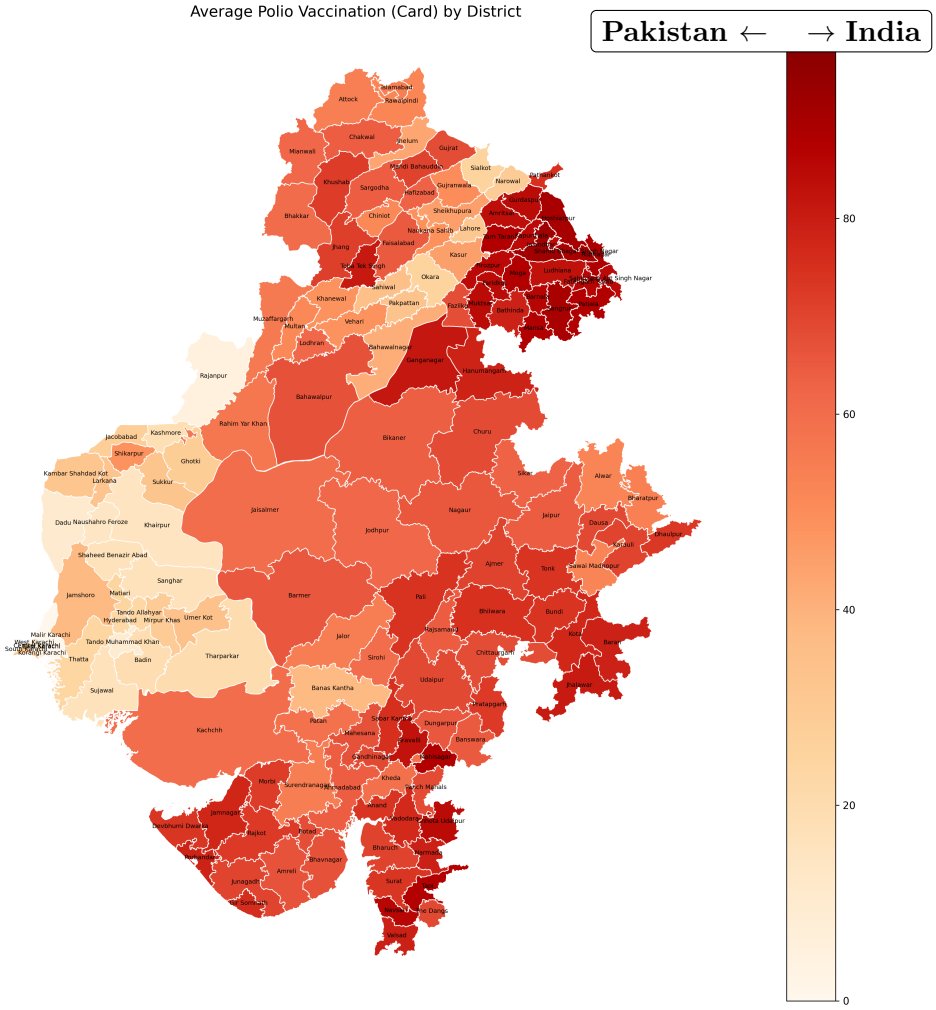


Figure 2: Average Polio vaccination (card) by district, Indo–Pak border. Cue indicates Pakistan (west/left) and India (east/right).

6.3 Climate–Capacity Interactions (M2)

Introducing health-card coverage as a proxy for administrative reliability dramatically alters the picture (Table 4). Districts with above-average capacity exhibit 13 p.p. higher vaccination levels even in normal years, highlighting the first channel through which capacity matters—raising the baseline. The second channel is resilience: the interaction between temperature deviation and capacity is positive and highly significant (about +9 p.p. for Polio, +7 p.p. for DPT). Together, these estimates imply that while a one-degree anomaly lowers Polio completion by nearly 12 p.p. in low-capacity districts, the corresponding loss in high-capacity districts is close to zero. For DPT, the buffering is comparable in sign but smaller in magnitude and statistical precision, consistent with the greater standard deviation of DPT coverage within each country. In percentage terms, high-capacity districts absorb roughly 80 percent of the shock that would otherwise occur in fragile systems, confirming that administrative reliability mitigates environmental stress.

Table 4: Climate × Capacity (Model M2)

	(1) Polio	(2) DPT
Average Temperature Deviation	-11.95^{***}	-7.216^{**}
Above Avg Health Card (HC)	13.35^{***}	13.19^{***}
WeatherShock × HC	8.906^{***}	6.916^{**}
Sample size	38,532	40,953
Mean dep. var.	59.53	57.86

6.4 Cross-Border Differences (M3)

The Indo–Pak comparison formalizes these capacity contrasts. When we interact temperature deviations with a dummy for Indian districts (Table 5), the estimated coefficient is positive and significant for both vaccines. A one-degree anomaly reduces Polio coverage by roughly 10 p.p. in Pakistan but by less than 2 p.p. in India; DPT shows a similar attenuation. The magnitude implies that Indian districts are roughly five times less climate-sensitive than Pakistani ones. This asymmetry aligns with the theoretical model's prediction

that once capacity surpasses a critical threshold K^*, the relationship between shocks and realized investment flattens out. India's higher position on the capacity distribution thus places it on the resilient branch of the state-capacity curve, while Pakistan remains on the fragile side, where shocks transmit strongly to outcomes. The difference should therefore be interpreted not as differing responsiveness, but as differing *positions* on the same nonlinear capacity–resilience curve.

Table 5: Climate Sensitivity: India vs. Pakistan (Model M3)

	(1) Polio	(2) DPT
Average Temperature Deviation	-10.46^{***}	-6.782^{*}
India (=1)	-2622.7	-1820.2
WeatherShock × India	8.369^{*}	7.988^{*}
Sample size	38,532	40,953
Mean dep. var.	59.53	57.86

6.5 Within-Country Heterogeneity (M4)

Table 6 explores heterogeneity in capacity within each country. In both India and Pakistan, high-capacity districts enjoy substantially higher average coverage and smaller weather penalties. However, the extent of buffering differs sharply. In India, the interaction term between temperature and capacity is large and precise—around +12–13 p.p.—indicating that administrative reliability nearly eliminates climatic losses. In Pakistan, the corresponding interactions are smaller (6–7 p.p.) and less precisely estimated, implying that while capacity still helps, its protective power is partial.

These differences are consistent with the model's nonlinearity: Pakistan's districts cluster below K^*, where marginal returns to capacity are small, whereas India's districts straddle or exceed that threshold, revealing the convex portion of the capacity–resilience function. The "stronger" interactions in India therefore signal that its districts have entered the regime where complementarities are fully active, not that capacity matters less in Pakistan.

Table 6: Within-Country Heterogeneity by Capacity (Model M4)

	India		Pakistan	
	Polio	DPT	Polio	DPT
Average Temperature Deviation	-10.27^{**}	-12.11^{***}	-10.57^{*}	-8.034^{*}
Above Avg HC (=1)	11.02^{***}	9.766^{***}	14.31^{***}	16.80^{***}
WeatherShock × HC	12.28^{***}	13.59^{***}	6.133	6.637^{*}
Sample size	18,418	17,462	20,113	23,490
Mean dep. var.	71.17	74.13	48.87	45.77

6.6 Robustness with District Time Trends (M5)

Finally, Table 7 incorporates flexible district-specific time trends to rule out gradual improvements in health programs or demographic composition. The main results remain intact. Polio completion still declines significantly with heat in low-capacity areas (–6.4 p.p.), while the capacity interaction remains positive and significant. For DPT, the estimates remain in the expected direction but, as throughout, are less precise. That the overall pattern persists under such demanding controls supports the interpretation that these effects reflect short-run climate stress rather than long-term program trends.

Table 7: District Time-Trend Robustness (Model M5)

	(1) Polio	(2) DPT
Average Temperature Deviation	-6.402^{*}	−4.270
Above Avg HC	13.93^{***}	13.52^{***}
WeatherShock × HC	5.373^{*}	6.037^{**}
Sample size	38,549	40,961
Mean dep. var.	59.52	57.85

Importantly, the persistence of these patterns across specifications reinforces the threshold interpretation: India's high-capacity regime exhibits full buffering of shocks, while Pakistan's low-capacity regime exhibits limited responsiveness. The curvature implied by these cross-regime differences provides reduced-form evidence of a state-capacity trap.

6.7 Discussion and Magnitude of Effects

Across specifications, three patterns stand out. First, the direct effect of temperature on vaccination is economically meaningful: for Polio, a 1°C increase—roughly one standard deviation of annual variation—lowers coverage by about 7–12 p.p., equivalent to 10–15 percent of mean completion. Second, administrative capacity provides both a level effect and a buffering effect. High-capacity districts not only vaccinate 10–15 p.p. more children on average but also exhibit near-zero responsiveness to heat anomalies, while fragile districts experience large declines. Third, these interactions are mirrored across borders: Indian districts in Punjab, Gujarat, and Rajasthan show the same convex buffering pattern seen within high-capacity districts, while Pakistani districts in Sindh and southern Punjab resemble the fragile regime. The cross-country difference thus maps closely onto the theoretical prediction of multiple equilibria in the capacity–resilience space.

Taken together, Models M1–M5 reveal that vulnerability to climate stress is not uniform but depends critically on the institutional infrastructure that mediates the delivery of basic public goods. Where state capacity is strong, shocks are absorbed and investment remains steady; where capacity is weak, shocks cascade into lower coverage and future fragility. This empirical asymmetry between India and Pakistan encapsulates a broader principle: climate adaptation in the developing world depends less on geography than on governance.

7 Discussion and Policy Implications

State capacity consistently raises baseline immunization coverage ($\beta_H > 0$), and its role in cushioning climatic shocks grows disproportionately with capacity ($\frac{\partial \beta_{TH}}{\partial H} > 0$). This nonlinearity creates the possibility of a *state-capacity poverty trap*: low-capacity districts remain fragile and unresponsive to marginal reforms, whereas high-capacity districts experience self-reinforcing stability. The India–Pakistan contrast exemplifies this dynamic: India sits above the resilience threshold, where capacity and adaptation reinforce one another; Pakistan re-

mains below it, where shocks translate directly into forgone investments.

Magnitude and external benchmarks. In low-capacity districts, a 1°C increase in average temperature reduces *Polio* completion by about 7–12 percentage points—roughly 10–15% of mean coverage in our pooled sample. This is a large effect in policy terms: it is comparable to closing a typical decade of secular progress in a fragile system, and it rivals the cross-district gaps associated with substantial differences in observable household resources. At the macro level, prior work documents sizable temperature effects on growth and productivity that are non-linear and stronger in hot, poorer settings (Dell et al., 2014, 2012, JEL review; AEJ Macroeconomics) and concave globally with peak productivity near 13°C (Burke et al., 2015). On health, recent estimates show mortality–temperature relationships that are steep at hot tails and flattened by income and adaptation (Carleton et al., 2022). Our reduced-form magnitudes are thus directionally consistent with this literature: when systems are fragile, heat shocks translate into meaningful losses in service delivery and, by implication, in the inputs that sustain human capital. By contrast, in high-capacity settings—especially in Indian districts—the estimated heat penalty is statistically indistinguishable from zero, indicating near-complete buffering. This cross-regime difference in slopes is precisely what the threshold model predicts: stronger β_{TH} effects are *observed* where baseline capacity is already high, not because capacity "matters less" in Pakistan, but because most Pakistani districts lie below the range where complementarities fully manifest.

Relation to micro evidence on service reliability. Our findings complement micro studies showing that reliable delivery dramatically increases uptake of preventive services. Clustered RCT evidence from rural India demonstrates large gains in immunization when the state (or NGO acting as state) makes services predictably available, with further improvements when small incentives reduce friction (Banerjee et al., 2010). Community-based monitoring in Uganda increased provider performance and utilization by strengthening accountability in routine primary care (Björkman and Svensson, 2009). Viewed through our

framework, these studies lift the delivery frontier locally; our cross-country and within-country results show how *systemic* capacity shifts the entire climate–investment mapping, turning severe heat penalties into negligible ones.

Relation to parental investment responses under macro volatility. This paper complements and extends our earlier work on parental responses to fetal shocks (Banerjee and Majid, 2025), which showed that household investment behavior is state-contingent: parents compensate for adverse in-utero shocks when macroeconomic conditions are favorable but reinforce endowment inequalities when economies contract. In that study—also focused on vaccination outcomes such as Polio and DPT—the direction of parental response hinged on the broader macro environment. Here, we find an analogous mechanism operating at the institutional level: the same climatic shocks yield sharply different effects depending on the strength of the state apparatus that mediates service delivery. Whereas the REStat paper identified how *macroeconomic volatility* governs household capacity to buffer shocks, this study shows that *state capacity* determines whether climate stress is absorbed or amplified within the public delivery system. In both settings, realized child investment depends not only on biological endowments or household intent but on the reliability of the surrounding macro-institutional context. Together, the two papers trace a continuum from micro to meso: from parents deciding whether to follow through on vaccination in adverse times, to states deciding—implicitly through capacity—whether households' intentions can be translated into actual protection. Both reveal that when background systems are fragile, identical shocks propagate into lower human-capital accumulation, while in resilient environments, they are neutralized.

Policy. The evidence implies that climate adaptation and state-building are complements. In fragile systems, marginal fixes are unlikely to move districts across the resilience threshold K^*: investments must target administrative reliability—cold chain, staffing continuity, record systems (cards and digital registries), last-mile logistics, and real-time monitoring—so

that intended household investments become realized actions even under stress. Once K^* is crossed, incremental improvements yield convex, compounding returns: high-capacity districts both vaccinate more children on average and absorb heat shocks with little loss. Framed this way, institutional strengthening is a form of *climate insurance* for human capital: it preserves the flow of early-life investments as environmental volatility rises.

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