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Claude Diebolt, Joel Huesler

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Claude Diebolt[1] and Joel Huesler[2]

[1]BETA/CNRS, Faculty of Economics, University of Strasbourg, Strasbourg, France,
cdiebolt@unistra.fr

[2]School of Business, Lucerne University of Applied Sciences and Art, Switzerland,
joelhuesler@gmail.com

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Abstract

This chapter synthesizes global evidence on how climate-related and disaster shocks affect human capital formation through educational attainment, learning outcomes, child health, and long-run economic mobility. Drawing on quasi-experimental and experimental evidence from low-, middle-, and high-income countries, the review documents substantial heterogeneity in impacts driven by shock type, timing, baseline poverty, and institutional capacity. Short-run disruptions to school attendance and health are well-documented, though evidence on learning losses and long-run earnings effects remains considerably thinner and warrants urgent attention. Key transmission mechanisms are mapped—including household budget constraints, child labor responses, school infrastructure damage, disease burden, and fetal and early-life programming—alongside a critical evaluation of causal identification strategies and their limitations. Policy evidence indicates that well-designed social protection programs, resilient school infrastructure, early warning systems, and education continuity planning can mitigate impacts, though rigorous evaluations remain scarce and external validity concerns persist. Five priority research gaps are identified: measuring and mitigating learning losses; understanding cumulative effects of repeated shocks; evaluating cost-effective adaptation strategies; linking childhood exposure to long-run labor outcomes; and studying behavioral adaptation to increasing climate risk.

Keywords: Human Capital, Climate Shocks, Natural Disasters, Child Health, Education, Economic History.

JEL Classification: I25, J24, N30, N50, Q54

1 Introduction

1.1 Why Climate and Disaster Shocks Matter for Human Capital

Human capital, defined as the stock of knowledge, skills, health, and cognitive capacity embodied in individuals, constitutes a fundamental determinant of economic growth, poverty reduction, and intergenerational mobility (Becker, 1964; Lucas, 1988; Mankiw et al., 1992; Schultz, 1961). The theoretical foundations established by Becker (1964) and extended by subsequent scholars emphasize that investments in education and health during childhood and adolescence create productivity gains that compound over the lifecycle through direct returns in labor markets and indirect returns through improved decision-making, health behaviors, and fertility choices (Cunha and Heckman, 2007; Heckman, 2006; Cunha et al., 2010). The dynamic complementarity of skill formation implies that early investments raise the productivity of later investments, creating critical periods during which disruptions can have particularly severe and long-lasting consequences for individual well-being and aggregate economic performance (Cunha and Heckman, 2007).

Climate-related and disaster shocks represent an increasingly salient threat to human capital accumulation globally, with particular severity in low- and middle-income countries (LMICs) where both exposure to hazards and vulnerability to their impacts are substantially elevated (Hallegatte et al., 2016; Carleton and Hsiang, 2016; Hsiang et al., 2013). The emerging climate-economy literature, comprehensively synthesized by Dell et al. (2014), establishes that temperature shocks generate substantial macroeconomic costs through multiple channels including agricultural productivity, labor supply, and human capital formation, with effects that may be highly non-linear. Burke et al. (2015) demonstrate that the relationship between temperature and economic output exhibits a strong concave shape, with productivity declining sharply above optimal temperature thresholds—a finding with profound implications for human capital investments in warming regions. Dell et al. (2012) provide complementary evidence that temperature shocks reduce economic growth in poor countries, with effects that persist and potentially accumulate over time.

These shocks encompass droughts arising from prolonged precipitation deficits, floods resulting from extreme rainfall or storm surge, tropical cyclones and hurricanes bringing destructive winds and precipitation, heatwaves characterized by sustained temperature extremes, and wildfires often exacerbated by drought and heat conditions (Meier et al., 2025; Huesler, 2024a,b; Huesler and Strobl, 2025; Strobl, 2011, 2012; Ouattara and Strobl, 2013). Their impacts on human capital operate through multiple simultaneous channels including direct damage to educational and health infrastructure, disruption of household livelihoods and income streams, increased disease burden and mortality risk, displacement and forced migration, strain on public

sector budgets and service delivery capacity, and psychological trauma and stress (Baez et al., 2010; Alderman et al., 2006). Baez et al. (2010) provide a systematic assessment of natural disaster impacts on human capital, documenting that severe events generate both immediate disruptions to schooling and health alongside longer-term effects operating through household impoverishment, with recovery trajectories critically dependent on the speed and adequacy of relief and reconstruction efforts. The projected intensification of extreme weather events under anthropogenic climate change, documented extensively in successive Intergovernmental Panel on Climate Change (IPCC) assessment reports, raises profound concerns about widening inequality in human capital formation both within and across countries (IPCC, 2021, 2014; Burke et al., 2015).

Understanding the causal effects of climate and disaster shocks on human capital holds critical importance for multiple interconnected reasons. From a welfare economics perspective, children represent a particularly vulnerable population whose life prospects can be permanently damaged by shocks during sensitive developmental periods, while the high returns to early-life investments documented by Heckman (2006) and Cunha and Heckman (2007) imply that disruptions during these periods impose substantial lifetime costs. Evidence synthesized by Currie (2009) demonstrates that shocks during pregnancy and the first two years of life have especially persistent effects on cognitive development, health capital, and adult productivity, operating through biological programming mechanisms that create lasting deficits in human capital accumulation. Currie (2009) further establishes that these early-life health shocks exhibit strong socioeconomic gradients, with children from disadvantaged backgrounds experiencing both higher exposure and larger marginal impacts, thereby amplifying inequality across generations. The integration of environmental shocks into this framework, as developed by Graff Zivin and Neidell (2013), reveals that pollution, climate extremes, and natural disasters constitute critical determinants of the health–human capital nexus, with effects that may be underappreciated in standard models of skill formation.

From an efficiency perspective, the presence of credit constraints, missing insurance markets, and incomplete risk-coping mechanisms implies that households facing climate shocks will suboptimally reduce investments in children's human capital to smooth current consumption, creating deadweight welfare losses and justifying targeted policy interventions (Jacoby and Skoufias, 1997; Dehejia and Gatti, 2006; Morduch, 1995). Jacoby and Skoufias (1997) demonstrate that household responses to income shocks include substantial reductions in school enrollment, particularly among girls and in credit-constrained households, consistent with inefficient disinvestment in human capital. These enrollment responses suggest that households discount future

returns to education at rates substantially higher than market interest rates when liquidity constraints bind, implying that social protection programs relaxing these constraints could generate large welfare gains through improved intertemporal allocation of resources.

From a distributional and equity perspective, climate shocks operate regressively, imposing disproportionate burdens on poor households, rural populations, and vulnerable groups including women and children in societies with strong gender norms favoring male education (Hallegatte and Rozenberg, 2017; Shah and Steinberg, 2017). This regressive incidence threatens to exacerbate existing inequalities in human capital, undermine intergenerational mobility, and slow poverty reduction efforts in the world's poorest regions. Hsiang and Jina (2015) demonstrate that repeated cyclone exposure creates persistent depreciation of both physical and human capital stocks, reducing long-run growth rates in affected regions through mechanisms that include disrupted education, health deterioration, and erosion of productive infrastructure.

A longer historical perspective further highlights the importance of these questions. Long before climate change emerged as a major policy concern, societies repeatedly faced droughts, harvest failures, floods, epidemics, and other environmental shocks that shaped nutrition, health, educational opportunities, and social mobility. Economic historians have shown that such shocks often left persistent marks on human development, affecting not only contemporaneous welfare but also the accumulation of human capital across generations. While the nature and scale of contemporary climate risks differ in important respects, many of the underlying mechanisms linking environmental stress to human capital formation have deep historical roots. The historical record therefore provides a valuable complement to modern empirical evidence, offering insights into both vulnerability and resilience under conditions of climatic stress.

This chapter provides a comprehensive synthesis of empirical evidence from economics, public health, demography, and related social science disciplines examining how climate-related and disaster shocks causally affect human capital formation across the lifecycle from conception through adulthood. The focus centers on acute extreme events including droughts, floods, tropical storms and cyclones, heatwaves and temperature anomalies, extreme precipitation events, and wildfires, rather than gradual climatic trends such as secular temperature increases or long-run changes in precipitation patterns. This focus reflects both the distinct identification challenges posed by separating effects of slow-moving climate change from confounding factors, and the availability of quasi-experimental variation in the timing and spatial distribution of discrete shock events that facilitates credible causal inference (Deschênes and Greenstone, 2007; Burke et al., 2015; Dell et al., 2014). As Dell et al. (2014) emphasize, the "weather shock" approach exploiting short-run climate variation provides more credible causal identification than cross-sectional comparisons

of climate levels, though extrapolating from temporary shocks to permanent climate change requires careful attention to adaptation dynamics and potential non-linearities in dose–response relationships.

1.2 Defining Human Capital Outcomes

The empirical evidence is organized around four analytically distinct but interconnected categories of human capital outcomes, recognizing that these represent different dimensions of skill and capability formation across the lifecycle. *Schooling attendance and enrollment* captures the flow of educational investments through measures including school participation rates, dropout and re-enrollment patterns, grade progression, and ultimate school completion. These outcomes represent the most commonly studied dependent variables in the literature due to their relative availability in household surveys and administrative data systems, though they measure educational inputs or time allocation rather than actual human capital acquisition (Hanushek and Woessmann, 2008; Glewwe, 2002; Altinok et al., 2026). The distinction between enrollment (formal registration) and attendance (actual presence) matters substantially in contexts where enrollment may persist despite irregular attendance, creating measurement challenges addressed in Section 5.

Learning, test scores, and educational attainment captures the stock of cognitive achievement and educational credentials through standardized test performance in literacy and numeracy, cognitive assessments, completed years of schooling, and educational qualifications obtained. These outcomes more directly measure acquired human capital as opposed to mere time spent in educational institutions, addressing the critique raised by Hanushek and Woessmann (2008) and Hanushek and Woessmann (2013) that schooling quantity provides an incomplete indicator of human capital formation when learning quality varies substantially. The growing availability of standardized learning assessments in developing countries through initiatives including the Trends in International Mathematics and Science Study (TIMSS), the Progress in International Reading Literacy Study (PIRLS), PISA for Development, and national learning assessments has enabled more direct measurement of cognitive achievement, though coverage remains limited relative to enrollment data (Glewwe and Muralidharan, 2014).

Child health and cognition encompasses anthropometric measures including height-for-age, weight-for-age, and stunting indicators, disease burden and mortality risk, cognitive and socioemotional development, and mental health outcomes. Health is conceptualized as a dimension of human capital formation rather than merely consumption, emphasizing the productive consequences of health status for learning capacity, labor force participation, and productivity in

adulthood (Grossman, 1972; Strauss and Thomas, 1998). The fetal origins literature initiated by Barker (1990) and extended to economic outcomes by Almond (2006), Almond and Mazumder (2005), and numerous subsequent studies demonstrates that health shocks during critical developmental windows, particularly the in-utero period and first two years of life, generate persistent effects on cognition, educational attainment, and adult earnings through biological programming mechanisms. The work of Alderman et al. (2006) on long-term consequences of early childhood malnutrition and Victora et al. (2008) on maternal and child undernutrition establishes that these early-life health deficits translate into measurable reductions in schooling, test scores, and adult productivity.

Long-run earnings, labor outcomes, and mobility directly measures the productive value of human capital through adult wages and earnings, employment rates and labor force participation, occupational attainment and sector of employment, and intergenerational mobility in education and income. These outcomes represent the ultimate test of whether childhood shocks generate persistent human capital losses with real economic consequences, though their measurement requires longitudinal data spanning decades or carefully constructed retrospective cohort designs that link childhood exposure to adult outcomes (Maccini and Yang, 2009; Almond, 2006). The relative scarcity of long-run labor market evidence reflects both the substantial data requirements for following cohorts into adulthood and the challenge of maintaining identification assumptions over extended time periods when numerous confounding factors may emerge.

This taxonomic structure reflects the lifecycle nature of human capital formation wherein shocks at different developmental stages operate through distinct mechanisms and generate heterogeneous consequences. While the evidence is organized synthetically around these four outcome categories, these outcomes are interconnected through multiple pathways, with health affecting learning capacity, learning affecting future health behaviors and outcomes, and both jointly determining labor productivity and earnings.

1.3 Defining Climate and Disaster Shocks

Climate and disaster shocks are defined as discrete, time-limited extreme events associated with weather and climate variability, distinguished from gradual trends or chronic environmental stressors. The operational scope of this review encompasses five primary categories of hydrometeorological hazards. *Droughts* are characterized by prolonged periods of precipitation deficit relative to historical norms, operationalized through various measurement approaches including the standardized precipitation index (SPI), the Palmer Drought Severity Index (PDSI), and satellite-derived vegetation indices such as the Normalized Difference Vegetation Index (NDVI) (Sheffield

et al., 2012; Heim Jr, 2002). *Floods* encompass excessive precipitation events, riverine overflow, and coastal storm surge (Jonkman, 2005). *Tropical storms, cyclones, and hurricanes* represent intense rotating storm systems with extreme wind speeds and heavy precipitation (Knutson et al., 2010; Emanuel, 2005). *Heatwaves and temperature anomalies* are defined by sustained periods of extreme high temperatures, measured through cumulative degree-days, temperature deviations from historical means, or wet-bulb globe temperature measures (Zhao et al., 2021; Kjellstrom et al., 2009). *Wildfires* represent large-scale uncontrolled fires measured through burned area extent or particulate matter exposure from smoke (Dennison et al., 2014; Jayachandran, 2009).

The focus on acute extreme events rather than gradual climate change reflects important methodological considerations. Discrete shock events provide quasi-experimental variation in the timing and spatial distribution of treatment exposure that can be plausibly argued to be exogenous (Deschênes and Greenstone, 2007; Hsiang, 2016). In contrast, slow-moving climate trends are confounded with numerous other factors including economic development, infrastructure investments, and demographic transitions (Burke et al., 2015; Carleton and Hsiang, 2016). The distinction between shocks and trends is neither sharp nor absolute, as many regions experience effectively permanent regime shifts in climate conditions, and the literature's separation of acute shocks from chronic climate change represents an analytical convenience that facilitates identification rather than a hard boundary in the underlying processes.

Importantly, climate change fundamentally alters the frequency distribution, intensity, and spatial incidence of the extreme events that constitute the focus of this review. Substantial evidence from climate science demonstrates that anthropogenic warming has already increased the probability and severity of certain extreme events including heatwaves, heavy precipitation, and droughts in some regions (IPCC, 2021; Trenberth, 2012). Studies of acute shocks in the historical record thus provide crucial information for understanding potential future impacts of climate change. Geophysical disasters including earthquakes, tsunamis, and volcanic eruptions are briefly acknowledged but not reviewed, as these fall outside the scope of climate-related hazards.

1.4 Scope and Roadmap

This chapter focuses on causal evidence linking climate and disaster shocks to human capital outcomes, emphasizing identification strategies, mechanisms, heterogeneity, and policy implications. The review maintains global scope, covering both LMICs and high-income countries where relevant, though the bulk of evidence derives from developing countries due to greater exposure and more salient effects. Section 2 presents the conceptual framework mapping pathways

from shocks to human capital. Section 3 synthesizes evidence by outcome category. Section 4 maps mechanisms and sources of heterogeneity. Section 5 discusses identification strategies, data sources, and threats to validity. Section 6 reviews policy and adaptation evidence. Section 7 identifies priority research gaps. Section 8 provides a summary.

2 Conceptual Framework

A coherent analytical framework for understanding how climate and disaster shocks affect human capital must integrate multiple interconnected elements: household decision-making regarding educational investments and child time allocation; school supply constraints and public service delivery; health production functions and biological programming; and general equilibrium effects operating through markets and community-level responses. A simple economic model is developed to organize theoretical predictions, drawing on foundational contributions from Becker (1964), Jacoby and Skoufias (1997), Edmonds (2005), and the fetal origins literature initiated by Barker (1990) and extended by Almond and Mazumder (2005). Figure 1 summarizes the resulting pathways linking shocks to human capital outcomes, distinguishing well-established channels from those with weaker or more context-dependent empirical support.

2.1 Household Demand for Schooling and Health Investments

Consider a forward-looking household that allocates child time between schooling, work activities, and leisure or home production, while simultaneously allocating consumption between current goods and investments in children's human capital. The household maximizes expected lifetime utility subject to budget and time constraints. In the absence of perfect credit markets and insurance, households cannot fully smooth consumption across states and must adjust current investments to maintain consumption when adverse shocks occur, creating potential for inefficient underinvestment in human capital (Jacoby and Skoufias, 1997; Morduch, 1995).

Climate and disaster shocks enter this optimization problem through multiple simultaneous channels. The *income effect* operates through shock-induced reductions in household income arising from crop failures and livestock losses, destruction of productive assets and capital, and increased expenditures on disaster recovery and reconstruction (Carter et al., 2007). If schooling and health inputs are normal goods and households cannot borrow to smooth over temporary income shortfalls, adverse shocks mechanically reduce demand for schooling and health investments (Jacoby and Skoufias, 1997; Jensen, 2000). The magnitude of this income effect depends critically on shock severity and persistence, availability of liquid assets and credit access, insurance and social protection coverage, and the strength of informal risk-sharing arrangements

(Townsend, 1994; Fafchamps, 1992).

Price effects constitute a second channel wherein shocks alter the relative costs of schooling and nutrition. Food price spikes following droughts or floods raise the cost of adequate nutrition, an effect particularly salient for net food-consuming households in both rural and urban areas (Barrett et al., 2008; Arndt et al., 2016). The returns to schooling perceived by households may also shift in response to shocks. Rosenzweig and Binswanger (1993) provide evidence suggesting that households in risky environments value the portfolio diversification benefits of education, which facilitates migration and access to non-agricultural employment less correlated with local climate shocks than farming income.

Credit constraints represent a particularly binding mechanism. When households lack access to formal credit markets or functioning insurance, they cannot smooth consumption over negative income realizations and must make costly adjustments including reducing educational investments or liquidating productive assets at distressed prices (Dehejia and Gatti, 2006). Beegle et al. (2006) and Edmonds (2005) demonstrate that agricultural shocks increase child labor and reduce school attendance, particularly in subsistence farming contexts where children represent a flexible labor input.

2.2 School Supply and Infrastructure

Climate shocks disrupt the supply of schooling through multiple channels beyond household demand responses. Infrastructure damage represents the most visible supply constraint, as floods, storms, and earthquakes physically destroy school buildings or force temporary closures while reconstruction proceeds (Baez et al., 2010). Teacher availability constitutes another key supply constraint, as disasters can displace teachers, increase absenteeism, or strain public budgets that fund teacher salaries. Displacement and migration triggered by shocks create spatial mismatches between school supply and student demand.

Supply disruptions reduce schooling even when household demand remains constant. Gradual-onset droughts may primarily affect household demand through income losses, while sudden-onset floods and hurricanes generate both demand and supply shocks simultaneously through combined effects on household livelihoods and physical infrastructure. Even when schools physically reopen, quality may remain degraded if teacher–student ratios increase, damaged materials are not replaced, or deferred maintenance creates unsafe learning environments.

2.3 Health Production and Fetal Origins

Health capital is produced via investments in nutrition, sanitation, healthcare, and disease prevention, with production functions that exhibit particular sensitivity during critical developmental windows (Grossman, 1972). Climate shocks affect health production through multiple biological and environmental channels. Disease ecology shifts following extreme events, as floods increase vector-borne diseases including malaria and dengue, droughts reduce water quality increasing diarrheal disease risk, and heatwaves cause heat stress while exacerbating cardiovascular and respiratory conditions (Patz et al., 2005). Nutrition deteriorates when droughts and floods reduce food availability and spike prices, causing undernutrition and micronutrient deficiencies that are particularly harmful for pregnant women and young children (Currie and Rossin-Slater, 2013).

The fetal origins hypothesis developed by Barker (1990) and extended by economists including Almond (2006) and Almond and Mazumder (2005) establishes that health and nutritional shocks during pregnancy have persistent effects on offspring outcomes including cognitive development, educational attainment, and adult labor market productivity. Mechanisms include maternal malnutrition affecting fetal growth and brain development, maternal disease and infections affecting fetal health, and maternal stress altering fetal programming through hormonal and epigenetic pathways.

Evidence from famines, disease outbreaks, and environmental shocks demonstrates that early-life exposure, particularly during the in-utero period and first two years of life, generates especially large and persistent human capital effects (Victora et al., 2008; Alderman et al., 2006). Shocks during this window cause stunting (low height-for-age), wasting (low weight-for-height), and micronutrient deficiencies that predict lower cognitive test scores, reduced educational attainment, and diminished adult earnings. Repeated or prolonged shocks compound impacts through cumulative nutritional deficits and development delays (Alderman et al., 2006).

2.4 General Equilibrium and Community Effects

Beyond household-level impacts, climate and disaster shocks generate aggregate effects operating through local labor markets, commodity prices, public finance, and social capital. Commodity prices, particularly for staple foods, spike following widespread droughts or floods that reduce agricultural output, eroding real incomes especially for net food-consuming households (Hallegatte et al., 2016). Public finance pressures intensify as disaster-related expenditures compete with normal budgetary allocations for education and health, potentially crowding out human capital investments or triggering user fees that reduce access for poor households.

These general equilibrium effects amplify household-level impacts and create spillovers across households and regions that complicate causal identification. The standard Stable Unit Treatment Value Assumption (SUTVA) is violated when shocks generate price movements, migration flows, or policy responses that affect non-treated units. Researchers must account for these spillovers through appropriate choice of treatment and control group definitions or by interpreting estimates as reduced-form parameters incorporating both direct and indirect channels.

2.5 Adaptation and Resilience

Households, communities, and governments undertake various adaptive responses to reduce vulnerability to climate and disaster shocks, operating both before shocks occur (ex-ante adaptation) and after shocks strike (ex-post responses). Ex-ante adaptation includes livelihood diversification, construction of resilient infrastructure, implementation of early warning systems, and adoption of drought-resistant crop varieties. Ex-post responses encompass disaster relief, reconstruction of damaged infrastructure, cash transfers, and psychosocial support.

However, adaptation may also include maladaptive responses such as chronic underinvestment in fixed assets and human capital if households perceive shock risks as prohibitively high (Barrett et al., 2008). Adaptation affects the observed treatment effects estimated in empirical studies, as impacts will appear smaller in settings with strong adaptive capacity. Anticipatory behavior may also confound treatment assignment if households adjust fertility timing, migration, or investment decisions based on weather forecasts, violating the exogeneity assumption required for causal identification.

2.6 Theoretical Predictions

The conceptual framework generates several testable predictions. Negative shocks should reduce human capital investments through income and budget constraint mechanisms, with larger effects in poor, credit-constrained households. Supply-side constraints including school closures and teacher displacement should reduce attendance and learning independently of demand effects. Early-life health shocks, particularly those occurring in utero and during the first 1,000 days, should generate persistent effects on cognition and adult productivity through biological programming. General equilibrium effects including price movements and labor market disruptions should amplify household-level impacts. Adaptation and social protection should attenuate observed effects, with heterogeneity across contexts reflecting differences in adaptive capacity and institutional quality. The empirical evidence synthesized in subsequent sections tests these predictions.

More generally, the framework emphasizes that climate and disaster shocks should not be viewed solely as temporary disturbances. Because human capital accumulation is inherently dynamic and path-dependent, disruptions occurring at critical stages of development may generate effects that persist long after the original shock has disappeared. Understanding these cumulative processes is therefore essential for evaluating the long-run economic consequences of climate-related risks.

3 Evidence by Outcome

Causal evidence is organized around four outcome categories. Studies are classified by evidence quality: RCT (randomized controlled trial); QE-strong (quasi-experimental with credible design including difference-in-differences (DiD), event studies, regression discontinuity (RD), or instrumental variables (IV) with plausible exclusion restrictions); QE-weak (panel fixed effects or limited controls); and CS (cross-sectional correlations). Table 1 provides an illustrative summary of representative studies, shock types, outcomes, and design quality discussed throughout this section.

3.1 Schooling Attendance and Enrollment

A substantial literature documents that climate and disaster shocks reduce school attendance in the immediate aftermath, with effect magnitudes and persistence varying by shock type, severity, and context. Jacoby and Skoufias (1997) exploit rainfall variation in India as an instrument for household income and find significant enrollment reductions, with effects concentrated among girls and poorer households consistent with credit constraint mechanisms. Shah and Steinberg (2017) use district-level rainfall variation in India within a difference-in-differences framework and show that droughts reduce school attendance and completed years of schooling, with larger impacts for girls and lower-caste children. Maccini and Yang (2009) demonstrate that adverse rainfall conditions during early life reduce educational attainment measured decades later, particularly for women, suggesting incomplete recovery from temporary shocks during critical developmental windows.

Floods generate sharp but often temporary attendance disruptions, with recovery speed depending on infrastructure reconstruction and household resources. Baez et al. (2010) study Hurricane Mitch in Nicaragua and find enrollment declines of 10–15 percentage points, concentrated among poor households. Heatwaves reduce attendance through heat stress, illness, and competing labor demands. Park et al. (2020) provide evidence that hot examination days reduce test-taking in the United States, an indirect indicator of attendance or cognitive capacity

constraints. Björkman-Nyqvist (2013) find that heat stress during agricultural seasons increases child labor and reduces school participation in Sub-Saharan Africa. Where quantified credibly, short-run attendance effects range from 2 to 10 percentage points for moderate shocks, rising to 10–20 percentage points for severe events, with effects typically dissipating within a few months if schools reopen quickly. Longer closures increase permanent dropout risk, especially near transition grades where re-enrollment costs are high.

Effects exhibit consistent heterogeneity across subpopulations. Girls face larger impacts in contexts with strong gender norms favoring male education, higher opportunity costs from domestic responsibilities, or early marriage risks exacerbated by household economic stress (Jacoby and Skoufias, 1997; Shah and Steinberg, 2017). Poorer households reduce schooling more than wealthy households when shocks hit, reflecting binding credit constraints. Rural populations experience larger disruptions than urban households due to greater climate exposure, weaker infrastructure, and thinner safety nets. Evidence on completed years of schooling is more mixed. Maccini and Yang (2009) find persistent attainment effects of early-life rainfall shocks in Indonesia. Shah and Steinberg (2017) document lasting attainment losses from childhood droughts in India. The strongest designs employ cohort-level variation in shock timing combined with individual or sibling fixed effects.

3.2 Learning, Test Scores, and Cognitive Achievement

Cognitive achievement and test scores measure actual human capital accumulation rather than mere time in school, though evidence on learning impacts is substantially thinner than attendance evidence due to data scarcity. Garg et al. (2020) demonstrate that hotter school years reduce test scores in the United States, with larger effects in schools lacking air conditioning. Park et al. (2020) show that heat exposure on test days lowers performance, consistent with reduced cognitive function under thermal stress. Park et al. (2021) provide further evidence that learning is inhibited by heat exposure both internationally and within the United States. In low- and middle-income countries, Björkman-Nyqvist (2013) find that droughts in Uganda reduce test scores, likely through combined nutrition, health, and increased labor demand channels. Evidence on flood impacts comes from Randell and Gray (2016), showing learning disruptions in Ethiopia, with slower recovery in remote areas lacking resources for remedial education.

Effect magnitudes, where measured credibly, range from 0.05 to 0.20 standard deviations for moderate shocks, rising to 0.30–0.50 standard deviations for severe events with prolonged closures. Effects compound with repeated shocks, as cumulative learning deficits grow when students miss multiple school years or experience chronic nutritional stress. Shah and Steinberg

(2017) document increased grade repetition following droughts in India, while Baez et al. (2010) show dropout spikes after Hurricane Mitch concentrated among adolescents and girls.

The research gap on learning losses versus attendance in LMICs is critical, as attendance may recover quickly while learning deficits persist if not addressed through remedial instruction. Few studies rigorously measure cognitive achievement as opposed to enrollment or years completed, and even fewer track recovery trajectories. This gap reflects both data constraints—limited standardized testing in many LMICs—and methodological challenges including longer follow-up periods required and potential for differential attrition by initial learning level. Evidence from high-income countries, while covering a narrower range of shock types, offers methodological advantages including administrative test score records linked to precise geocoded weather data (Park et al., 2020; Garg et al., 2020). These findings underscore that learning losses from climate shocks are not confined to developing-country contexts.

3.3 Child Health and Cognition as Human Capital Formation

A robust literature establishes that climate and disaster shocks during pregnancy and early childhood generate lasting effects on health and cognition consistent with fetal origins theory. Temperature shocks during pregnancy increase infant mortality in both high- and low-income settings. Deschênes et al. (2009) find that high temperatures during pregnancy raise infant mortality in the United States, while Burgess et al. (2014) show similar effects in India with larger magnitudes among poor households lacking access to cooling or healthcare.

Rainfall shocks during pregnancy and early childhood affect anthropometric outcomes, cognition, and long-run productivity. Maccini and Yang (2009) show that Indonesian women born during poor rainfall years have worse adult health, alongside lower educational attainment and earnings, consistent with early-life nutritional deficits creating persistent human capital gaps. Aguilar and Vicarelli (2011) document that droughts in Mexico reduce birth weight and increase infant mortality. Alderman et al. (2006) and Dercon and Porter (2014) demonstrate that rainfall shocks reduce child height and cognitive test scores across Sub-Saharan Africa, with effect magnitudes increasing with shock severity and duration.

Floods increase diarrheal disease, low birth weight, and neonatal mortality through contaminated water, disrupted healthcare, and maternal stress. Currie and Rossin-Slater (2013) find that hurricanes in Texas increase low birth weight, suggesting stress or air quality channels operating beyond direct physical exposure. Mechanisms linking shocks to fetal and early-life health include maternal malnutrition reducing fetal growth and brain development, maternal stress elevating cortisol and affecting fetal programming, reduced prenatal care utilization when clinics are

damaged, and postnatal nutritional deficits during the first 1,000 days. Evidence on effect magnitudes shows that early-life rainfall shocks reduce adult height by 1–3 centimeters on average. Cognitive effects measured by test scores or skills assessments range from 0.10 to 0.30 standard deviations depending on shock timing and intensity. Critical windows matter substantially, with effects largest for shocks during the first 1,000 days from conception to age two (Victora et al., 2008; Alderman et al., 2006).

3.4 Long-Run Earnings and Labor Market Outcomes

A smaller but growing literature links early-life or school-age climate shocks to adult labor market outcomes. Maccini and Yang (2009) demonstrate that Indonesian women born during poor rainfall years earn 5–10 percent lower wages as adults, with effects mediated by health and educational channels. Dercon and Porter (2014) document that children exposed to droughts in Ethiopia earn lower wages and achieve worse occupational attainment in adulthood. Similar patterns emerge from studies of historical famines, where cohorts exposed in utero or in early childhood show lasting labor market effects including lower earnings and reduced employment. Taken together, these findings suggest that climate-related shocks may influence economic development not only through their direct effects on production and income, but also through their lasting impact on the quantity and quality of human capital available to future generations.

4 Mechanisms and Heterogeneity

4.1 Mechanisms: Evidence and Pathways

The transmission mechanisms linking shocks to human capital outcomes, summarized in Table 2 alongside their observable proxies and representative supporting evidence, operate through several interrelated channels. The income and budget constraint mechanism operates when shocks reduce household resources available for educational and health investments. Jacoby and Skoufias (1997) and Shah and Steinberg (2017) provide direct evidence that income reductions from rainfall shocks decrease schooling, with effects concentrated among credit-constrained households. Beegle et al. (2006) and Edmonds (2005) document child labor increases following agricultural shocks, with corresponding school attendance declines.

School closure mechanisms operate through direct supply constraints when infrastructure is damaged or teachers are unavailable (Baez et al., 2010). Health and disease mechanisms link shock exposure to reduced learning capacity and mortality risk. Jayachandran (2009) and Burgess et al. (2014) provide credible evidence on health pathways from wildfire smoke and

temperature extremes respectively. Nutrition and food security mechanisms operate when shocks spike food prices or reduce availability (Alderman et al., 2006; Aguilar and Vicarelli, 2011). The in-utero and early-life programming mechanism represents a distinct biological channel wherein maternal shocks affect fetal development with persistent consequences (Maccini and Yang, 2009; Almond, 2006). Psychosocial stress mechanisms link shocks to attention deficits, mental health problems, and behavioral issues that impair learning (Currie and Rossin-Slater, 2013). Migration and displacement generate ambiguous effects depending on whether disruption dominates or whether displaced populations gain access to better services (Baez et al., 2017; Beegle et al., 2011). Public finance and social protection mechanisms powerfully moderate shock impacts (Hidrobo et al., 2014).

Key insights from mechanism analysis include the following. Multiple channels operate simultaneously, making it difficult to cleanly separate them without rich intermediate outcome data. Channels differ across shock types, with droughts primarily operating through income and nutrition, floods through disease and infrastructure, heatwaves through physiological stress, and storms through sudden destruction and displacement. Timing critically determines which mechanisms dominate. A comprehensive policy response therefore requires attention to all major pathways simultaneously, particularly in contexts where multiple shocks and multiple mechanisms coincide.

4.2 Heterogeneity Across Populations and Contexts

Poverty and credit constraints generate the most consistent heterogeneity pattern, with impacts concentrated among poor households lacking savings, assets, or credit access (Jacoby and Skoufias, 1997; Shah and Steinberg, 2017; Dehejia and Gatti, 2006). Gender heterogeneity is context-dependent rather than universal. In South Asia and parts of Sub-Saharan Africa, girls face larger schooling losses during shocks driven by cultural norms, lower perceived returns to female education, and early marriage risks exacerbated by household stress (Jacoby and Skoufias, 1997; Shah and Steinberg, 2017). Maccini and Yang (2009) find larger health effects for women, potentially reflecting biological vulnerability in utero or postnatal discrimination in parental investment.

Rural versus urban heterogeneity reflects greater rural exposure through agriculture-dependent livelihoods, weaker infrastructure, lower adaptive capacity, and thinner safety nets. Rapid urbanization in flood-prone coastal zones and informal settlements, however, creates new vulnerabilities that may increasingly rival rural exposure (Beegle et al., 2011). Institutional quality and governance capacity powerfully moderate impacts through timely relief provision,

functioning safety nets, and effective coordination. Kahn (2005) shows that disaster mortality is substantially lower in countries with better institutions, with similar logic applying to human capital where robust education systems and social protection recover faster. Shock severity and repeated exposure generate nonlinear effects, as repeated shocks compound impacts as households deplete savings and assets with each event (Alderman et al., 2006).

5 Identification and Data Considerations

5.1 Identification Strategies and Design Quality

Randomized controlled trials (RCTs) are feasible for evaluating relief policies and adaptation interventions but cannot randomize disaster exposure itself. The climate shock literature therefore relies primarily on quasi-experimental designs exploiting plausibly exogenous variation.

Difference-in-differences (DiD) and event study designs control for time-invariant unobservables and common trends by comparing changes over time between treated and control units. Best practices include graphically showing pre-trends, using robust standard errors clustered at the level of treatment assignment, and addressing staggered adoption complications using recent econometric advances. Instrumental variables (IV) approaches address endogenous exposure when credible instruments exist, such as using weather variation as an instrument for agricultural income. Threats include weak instruments and the challenge of satisfying exclusion restrictions when weather likely affects outcomes through multiple channels. Regression discontinuity (RD) designs provide sharp causal estimates at arbitrary thresholds but require specific institutional features and are rare in this literature. Panel fixed effects control for time-invariant individual or location heterogeneity but do not address time-varying confounders, and reverse causality remains possible if outcomes affect subsequent exposure through migration or settlement decisions.

High-income country contexts often provide methodological advantages that complement LMIC evidence. Administrative data systems in these settings enable precise matching of geocoded weather records to individual-level outcomes over long follow-up horizons. Studies exploiting this infrastructure (Garg et al., 2020; Park et al., 2020) can serve as benchmarks for understanding dose–response relationships that may be extrapolated, with appropriate caution, to settings with weaker data infrastructure.

5.2 Threats to Validity and Mitigation Strategies

Endogenous exposure through migration and settlement patterns arises when households sort based on disaster risk in ways correlated with unobservables. Baez et al. (2017) document large migration responses to disasters. Mitigation approaches include using baseline pre-shock populations as the denominator, tracking migrants through panel surveys, bounding estimates using methods from Lee (2009), or instrumenting for exposure using predetermined geographic features.

Measurement error in shock intensity occurs because climate variables are measured with noise from sparse weather station networks, interpolation errors, and satellite sensor limitations. Classical measurement error attenuates estimates toward zero. Mitigation strategies include using high-resolution gridded climate reanalysis products and reporting robustness to alternative shock definitions.

Spillovers and general equilibrium effects violate the SUTVA assumption when shocks affect non-treated units through price changes, migration, or relief allocation. Mitigation requires defining treatment and control units at scales where spillovers are less likely, or interpreting estimates as reduced-form parameters incorporating both direct and indirect effects.

Policy endogeneity arises when disaster relief targets worst-hit areas, creating omitted variable bias. Mitigation involves modeling relief explicitly as a mediator or moderator, or focusing on pre-relief periods to estimate gross impacts.

Selection into outcome measurement occurs when human capital measures are observed only for survivors or enrolled students. Mitigation strategies include bounding estimates under selection scenarios and carefully tracking attrition in panel surveys.

Spatial and temporal correlation in errors arises because climate shocks affect regions rather than individual units. Best practices include clustering at the treatment assignment level, using spatial heteroskedasticity and autocorrelation consistent (HAC) standard errors when appropriate, and considering randomization inference or wild bootstrap methods when cluster counts are small.

5.3 Data Sources and Measurement

Common climate data sources include gridded rainfall and temperature products such as CHIRPS, CRU, and ERA5 reanalysis. Drought indices like the SPI, the Standardized Precipitation Evapotranspiration Index (SPEI), and satellite-based NDVI capture water stress through different mechanisms. Storm data comes from IBTrACS and HURDAT databases. Disaster event databases including EM-DAT and DesInventar compile reported disasters but vary in coverage

quality.

Outcome data sources include household surveys such as the Demographic and Health Surveys (DHS), Living Standards Measurement Study (LSMS), and Multiple Indicator Cluster Surveys (MICS). International test score databases including TIMSS and PISA support cross-country analyses where sample sizes permit. Key challenges include temporal mismatch when surveys occur annually and shocks must be matched to survey timing, spatial resolution mismatches, retrospective recall error, and missing data in remote or conflict-affected areas.

5.4 Standards for Credible Evidence

Priority is given to studies with plausible exogeneity, transparent identification assumptions, high-quality validated data, and robustness to alternative specifications. RCTs of relief programs and quasi-experimental studies using DiD, event studies, or credible IV constitute the strongest evidence, while panel fixed effects studies require careful scrutiny of time-varying confounders and cross-sectional correlations are descriptive only.

6 Policy and Adaptation

6.1 Social Protection: Cash Transfers and Safety Nets

Conditional and unconditional cash transfers rank among the best-evidenced interventions for buffering climate shocks by relaxing household budget constraints. Fiszbein and Schady (2009) review conditional cash transfer (CCT) programs including Mexico's Progresa/Oportunidades and Brazil's Bolsa Família, documenting robust positive effects on enrollment and health even absent shocks. De Janvry et al. (2006) show that Mexican CCT recipients maintained schooling during droughts while non-recipients withdrew children, demonstrating the protective role of predictable income support. Ethiopia's Productive Safety Net Programme appears to protect education and health during drought episodes (Berhane et al., 2011). Design features matter substantially. Larger transfers, longer duration, and targeting to the poorest households yield bigger protective effects. Cash alone may not suffice when schools are closed or destroyed, or when health services collapse, highlighting the need for complementary supply-side interventions.

6.2 School Feeding and Nutrition Programs

School feeding programs provide in-school meals that incentivize attendance while improving nutrition. During shocks, particularly droughts and food crises, feeding programs become critical. Alderman et al. (2012) review school feeding in LMICs, finding positive attendance effects

and, in some cases, learning gains. Challenges include supply chain dependence, as feeding programs require reliable food availability and logistics that may break down during severe shocks. Programs appear particularly valuable in chronically food-insecure areas prone to climate shocks.

6.3 Resilient Infrastructure and Early Warning Systems

Cyclone warning systems in Bangladesh have dramatically reduced mortality (Haque et al., 2012), though effects on education specifically are less well documented. Disaster preparedness planning at school and district levels may speed recovery, but evaluation evidence remains primarily qualitative.

6.4 Health Interventions and Education Continuity Planning

Post-flood immunization campaigns reduce diarrheal disease and cholera. Micronutrient supplementation with vitamin A and iron during food crises improves child health (Alderman et al., 2006). Formal education continuity planning including pre-positioned materials, teacher training, and remote learning protocols are advocated but unevenly implemented. Radio-based instruction in some African contexts shows promise but needs rigorous evaluation.

6.5 Index Insurance and Forecast-Based Financing

Index insurance pays based on objective triggers like rainfall or temperature rather than assessed losses, reducing moral hazard and speeding payouts. Agricultural insurance pilots in Kenya and Ethiopia face uptake challenges from basis risk, trust deficits, and liquidity constraints, but some studies find positive income smoothing effects (Jensen et al., 2018). Forecast-based financing releases funds when forecasts predict shocks, enabling preemptive action. Both instruments remain promising but under-evaluated for human capital protection (Barrett et al., 2008).

6.6 Synthesis: What Works?

Strong evidence from RCTs or credible quasi-experiments supports cash transfers and school feeding for maintaining schooling and health during shocks, especially for poor households (Fiszbein and Schady, 2009; De Janvry et al., 2006; Alderman et al., 2012; Hidrobo et al., 2014). Promising but less rigorous evidence suggests resilient infrastructure reduces damage and early warning systems save lives and reduce displacement. Health interventions during shocks improve child health, likely protecting learning capacity (Alderman et al., 2006). Education continuity planning and remote learning are logical but poorly evaluated in disaster contexts. Speculative or

unproven interventions include index insurance and forecast-based financing for education protection, cost-effectiveness of "build back better" school policies, and psychosocial support for trauma. The imbalance in evidence—strong on household income support, weak on supply-side and structural interventions—itself constitutes a research gap with direct implications for how ministries of education and finance should allocate scarce budgets in climate-exposed settings.

7 Research Gaps and Future Directions

Five priority research questions are identified that are tractable, policy-relevant, and currently under-explored.

The *first gap* concerns **measuring and mitigating learning losses beyond mere attendance**. The key question is how large and persistent learning losses from climate and disaster shocks are, and what interventions offset them. Attendance may recover quickly while learning deficits persist if not addressed through remedial instruction. Needed research includes standardized assessments administered before and after shocks in affected areas, RCTs evaluating remedial education interventions including extended school years and targeted tutoring, and long-run follow-up assessing persistence of learning losses. Pitfalls to avoid include selection bias by testing only students who return to school, conflating attendance with learning, and short follow-up periods that miss delayed impacts.

The *second gap* addresses **cumulative and repeated shocks**. The key question is how repeated or concurrent shocks—such as multi-year droughts, drought plus conflict, or flood plus pandemic—affect human capital, and whether impacts compound or exhibit diminishing marginal effects. Single-shock studies dominate but many vulnerable populations face multiple shocks, with cumulative effects potentially nonlinear through buffer depletion and resilience erosion (Alderman et al., 2006). Needed research includes panel data tracking individuals across multiple shocks and models of dynamic household responses including savings depletion and coping strategy sequencing. Pitfalls include high attrition in long panels and identification challenges when shocks are correlated.

The *third gap* concerns **cost-effective adaptation in education systems**. The key question is which adaptation investments offer the highest returns for protecting human capital in high-risk settings. Current evidence is mostly qualitative or engineering-focused without human capital outcome measurement. Needed research includes RCTs or natural experiments comparing adaptation approaches, and cost data including upfront investment and maintenance alongside benefit measurement through reduced closures and improved learning. Pitfalls include long time horizons for benefits and ethical issues around randomizing disaster protection.

The *fourth gap* addresses **long-run labor market effects and intergenerational transmission**. The key question is how childhood climate shock exposure translates into adult labor market outcomes and intergenerational mobility in LMICs. Needed research includes longitudinal studies or retrospective cohort designs linking childhood shocks to adult earnings and occupation, and mediation analysis quantifying how much of adult effects operate through education versus health versus other channels. Pitfalls include attrition over 20 or more years, migration making cohorts hard to track, and recall bias in retrospective designs.

The *fifth gap* involves **behavioral adaptation and anticipatory responses**. The key question is how households and governments adapt behavior in anticipation of climate risks, and how this affects human capital investment strategies. As shocks become more frequent or predictable through improved forecasts, anticipatory behavior may change, potentially improving outcomes through precautionary savings and migration, or worsening them through underinvestment in education when future risk appears high. Needed research includes experiments providing forecast information and measuring effects on schooling and health investments, and comparisons across contexts with different forecast accuracy. Pitfalls include distinguishing rational anticipation from behavioral biases and long lags between investment decisions and outcome realization.

Additional important gaps include understanding gender-specific mechanisms; mental health and psychosocial impacts of shocks on learning and development; conflict interactions where climate shocks may trigger or exacerbate conflict, compounding human capital losses; and urban resilience given that most research focuses on rural areas while rapid urbanization in flood-prone and heat-vulnerable cities creates new risks.

8 Summary

Climate-related and disaster shocks pose significant threats to human capital formation, operating through household income shocks, child labor responses, school supply disruptions, health and nutritional channels, and early-life biological programming. The evidence base has grown substantially in recent decades driven by improved data and quasi-experimental methods, but remains uneven across outcomes, contexts, and shock types.

Several clear findings emerge from the synthesis. Short-run disruptions to schooling are well-documented, with droughts, floods, storms, and heatwaves reducing attendance and enrollment, especially for poor households, girls in many contexts, and rural populations. Early-life exposure has particularly persistent effects on health, cognition, and long-run productivity, consistent with fetal origins research documenting lasting consequences of in-utero and first-1,000-days shocks. Learning losses and long-run earnings effects are under-measured relative to attendance dis-

ruptions, but where studied suggest meaningful human capital destruction warranting greater research investment. Impacts are highly heterogeneous, driven by baseline poverty, institutional capacity, gender norms, and adaptation investments. Social protection including cash transfers and school feeding can buffer shocks with strong evidence from RCTs and credible quasi-experiments, while complementary supply-side measures including resilient infrastructure and continuity planning show promise but need more rigorous evaluation. The evidence base is also global in scope: meaningful impacts are documented across both low- and high-income settings, reinforcing the need for adaptation strategies across the full income distribution.

The literature faces methodological challenges including endogenous exposure through migration and settlement patterns, measurement error in shock intensity, spillovers and general equilibrium effects, policy endogeneity when relief is non-randomly allocated, and selection into outcome measurement. The strongest evidence exploits quasi-experimental variation in shock timing and intensity through difference-in-differences, event studies, and credible instrumental variables.

Five research priorities stand out: measuring learning losses and evaluating remedial interventions; understanding cumulative effects of repeated shocks; assessing cost-effective adaptation strategies; linking childhood shocks to long-run labor outcomes and intergenerational transmission; and studying behavioral adaptation and anticipatory responses. Progress requires sustained investment in longitudinal panels, administrative education data, and high-resolution climate data, methodological innovation to credibly evaluate infrastructure and continuity interventions, and interdisciplinary collaboration across economics, public health, climate science, and education research.

From a broader historical perspective, the relationship between environmental shocks and human capital formation is not a new phenomenon. Episodes of famine, climatic instability, disease outbreaks, and food insecurity have repeatedly shaped educational opportunities, health outcomes, and social mobility throughout history. What distinguishes the contemporary period is not the existence of such mechanisms, but the prospect that climate-related shocks may become more frequent, more intense, and more geographically widespread. In this sense, climate change should be understood not only as an environmental challenge, but also as a fundamental challenge to the accumulation, preservation, and transmission of human capital across generations.

As climate change intensifies extreme events, the human capital consequences will grow in magnitude and frequency. Protecting education and health investments in vulnerable populations is critical for sustaining economic growth, reducing inequality, and enabling resilient development.

Cross References

Readers are directed to the following related entries in the *Handbook of Labor, Human Resources and Population Economics*:

- Human Capital and Economic Growth
- Early Childhood Development and Human Capital Formation
- Health and Human Capital
- Education and Economic Development
- Intergenerational Mobility
- Child Labor and Schooling Decisions
- Human Capital and Demographic Change
- Climate Change and Labor Markets
- Migration, Displacement and Human Capital
- Poverty, Vulnerability and Social Protection

Tables

Table 1: Evidence Map (Illustrative Sample)

Table 1: Evidence Map: Climate/Disaster Shocks and Human Capital (Illustrative)

Shock Type	**Outcome**	**Direction & Size**	**Design Quality**	**Context**	**Key Study**
Drought	Enrollment	Negative (5–10 pp)	QE-strong (IV)	India, rural	Jacoby and Skoufias (1997)
Drought	Enrollment, attainment	Negative (larger for girls)	QE-strong (DiD)	India, rural	Shah and Steinberg (2017)
Rainfall (early-life)	Attainment, health, earnings	Negative (persistent)	QE-strong	Indonesia	Maccini and Yang (2009)
Temperature (prenatal)	Infant mortality	Positive	QE-strong	U.S.; India	Deschenes et al. (2009); Burgess et al. (2014)
Temperature (prenatal)	Adult earnings	Negative (0.5% per hot day)	QE-strong	U.S.	Isen et al. (2017)
Heatwave (school year)	Test scores	Negative (0.05–0.10 SD)	QE-strong	U.S.	Garg et al. (2020); Park (2020)
Drought	Test scores	Negative	QE-weak	Uganda	Björkman-Nyqvist (2013)
Drought (early-life)	Height, health	Negative (1–2 cm)	QE-strong	Sub-Saharan Africa	Alderman et al. (2006)
Rainfall (early-life)	Earnings (adult)	Negative (5–10%)	QE-strong	Ethiopia	Dercon and Porter (2014)
Hurricane	Enrollment	Negative (10–15 pp drop)	QE-strong (DiD)	Nicaragua	Baez et al. (2010)

Notes: pp = percentage points; SD = standard deviations. QE-strong = credible quasi-experimental design including difference-in-differences, instrumental variables with plausible ex-

clusion, regression discontinuity, or cohort variation; QE-weak = panel fixed effects or limited controls. This table is illustrative rather than exhaustive. Compiled by the authors specifically for this chapter; it has not been previously published, and no third-party permission is required for its reproduction here.

Table 2: Mechanisms and Observable Proxies

Table 2: Mechanisms Linking Climate/Disaster Shocks to Human Capital

Mechanism	Expected Effect	Observable Proxies	Supporting Evidence
Income/Budget Constraint	↓ Negative (credit constraints bind)	Household income, asset sales, consumption, borrowing	Jacoby and Skoufias (1997); Shah and Steinberg (2017)
Child Labor	↓ Negative (time from school)	Child labor hours, agricultural work, domestic work	Beegle et al. (2006); Edmonds (2005)
School Closures	↓ Negative (missed instruction)	Days/weeks closed, infrastructure damage	Baez et al. (2010)
Health/Disease	↓ Negative (learning capacity, mortality risk)	Disease incidence, healthcare access, stunting	Jayachandran (2009); Burgess et al. (2014)
Nutrition/Food Security	↓ Negative (cognition, energy)	Food prices, caloric intake, micronutrient deficiency	Alderman et al. (2006); Aguilar and Vicarelli (2011)
In-Utero/Early-Life Programming	↓ Negative (persistent)	Birth weight, infant health, prenatal exposure timing	Maccini and Yang (2009); Almond (2006)
Psychosocial Stress	↓ Negative (attention, mental health)	Maternal stress, anxiety/depression measures	Currie and Rossin-Slater (2013); Mani et al. (2013)
Migration/Displ	↔ Ambiguous (disruption vs. access)	Household mobility, displacement status	Baez et al. (2017)
Price Shocks	↓ Negative (if costs rise)	Food prices, school fees, transportation costs	Barrett et al. (2008)

Table 2 continued

Mechanism	Expected Effect	Observable Proxies	Supporting Evidence
Public Finance/Safety Nets	↑ Positive (if relief targets HC)	Cash transfers, school feeding, fee waivers	Hidrobo et al. (2014); Fiszbein and Schady (2009)

Notes: HC = human capital. ↓ = negative effect on human capital outcomes; ↑ = positive/protective effect; ↔ = direction is context-dependent or ambiguous in the literature. Compiled by the authors specifically for this chapter; it has not been previously published, and no third-party permission is required for its reproduction here.

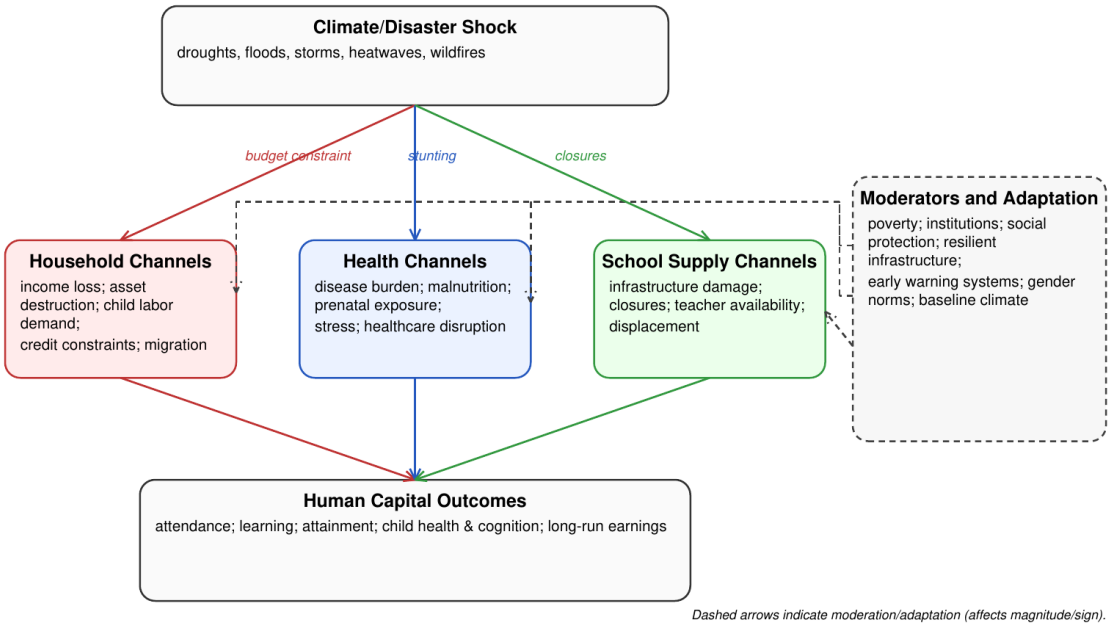

Figure 1: Pathways from Climate/Disaster Shocks to Human Capital. Arrows indicate the direction of causal influence. Dashed arrows denote channels with weaker or more context-dependent empirical support. HC = human capital. Created by the authors for this chapter; not previously published, and no third-party permission is required for its reproduction here.

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