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Fetal Exposure to Abnormal Rainfall Events and Later-Life Outcomes in Colombia

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Abstract:

This paper provides estimates of the long-term impacts of prenatal exposure to rainfall shocks using Colombian data. I find that individuals prenatally exposed to rainfall shocks have fewer years of schooling, display increased rates of illiteracy, are less likely to work in the market, and are more likely to report serious mental and physical illness. This paper then uses historical information on malaria risk and fraction of population depending on farming to analyze the extent to which agricultural income and disease shocks may be the mechanisms driving the results. The patterns I find are generally consistent with these hypotheses

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Keywords: Drought; Heavy precipitation; Early life health; Later-life outcomes

1 Introduction

It is now widely recognized that emissions of greenhouse will alter global climate, causing extreme weather events, such as droughts and floods, to become more frequent. One prominent body of work highlights that climate change may have serious repercussions for children's health and human capital acquisition, especially for children in the developing world. The prenatal programming theory indicates that individuals exposed to an unhealthy environment during a sensitive period of fetal development are likely to suffer from a number of health and developmental difficulties that persist throughout life (Barker, 1997; Seckl, 1998). Since health is both a type of human capital and a contributor to other forms of human capital (Becker, 2007), increasing attention is being paid to the long-run impacts of a variety of early life shocks, including epidemics (Almond, 2006; Venkataramani, 2012; Barreca, 2010), maternal stress (Aizer et al., 2016) and even food availability (Lindeboom et al., 2010; Almond and Mazumder, 2011).¹ Yet, despite this plethora of evidence about the pervasive role of poor conditions in early life, surprisingly little attention has been devoted to the long-run consequences of extreme weather events. Estimates of the welfare consequences of early exposure to weather shocks are crucial for the most efficient design of climate change mitigation policies.

Existing research suggests several channels through which early rainfall shocks can have intergenerational consequences on human capital and welfare. It is well established that heavy precipitation increases the optimal conditions for infectious and parasitic diseases, which could adversely affect the health of pregnant mothers and thus increase the risk of poor health in early life. At the same time, lower yields of subsistence crops and reduced income from cash crops due to water scarcity or excessive precipitation may result in reduced nutrition intake during pregnancy, especially in countries with imperfect credit markets and fewer formal social safety net programs. As a result, poor health among school age children is likely to result in school absenteeism and higher probabilities of dropping out, most notably causing fewer completed schooling (Miguel and Kremer, 2004; Baird et al., 2016). Less educated individuals, in turn, have poorer labor market prospects.²

This paper uses birth cohorts spanning several hundred locations over 40 years (1942-1981) to conduct a systematic evaluation of the relationship between early rainfall shocks and later-life outcomes. There are a few features about Colombia, the focus of this paper, that make it an interesting case in which to study this question. Because Colombia is exposed to both *El Niño* and *La Niña* phenomena, precipitation records vary widely over time and space,

¹See Almond and Currie (2011) for a comprehensive review of literature.

²See Currie (2009) and Cutler and Lleras-Muney (2010).

with some periods characterized by heavy rainfall and others by pervasive droughts. Indeed, Colombia has been considered one of the countries with the highest incidence of extreme events. In 2010, the Global Climate Risk Index placed Colombia in the top 3 countries most effected by loss related to floods and storms (Andalon et al., 2016; Germanwatch, 2011). Moreover, the cohorts this paper analyses were born in a context where a considerable fraction of population was living in rural areas and depended on farming for a living either directly or indirectly. Thus, this paper investigates a context where the aforementioned mechanisms are likely to be relevant.

My identification strategy exploits variation in rainfall records over time within municipalities. I construct a municipality-by-month weather dataset, which then is combined with microdata by using date and place of birth to identify the prevailing rainfall conditions during pregnancy. The empirical approach then compares later-life outcomes of individuals who were prenatally exposed to extreme droughts or heavy rainfall relative to those who experienced less severe rainfall conditions in utero. Therefore, this analysis explores the effects of fetal exposure to extreme rainfall fluctuations relative to the consequences of such exposure after birth or before conception. I control by a full set of municipality-of-birth and month-of-birth \times year-of-birth fixed-effects to account for time invariant characteristics, aggregate shocks, and seasonal factors that might be correlated with the incidence of extreme rainfall events. Hence, this approach exploits arguably random fluctuations in rainfall from municipality-specific deviations in long-term rainfall after controlling for all seasonal factors and common shocks to all municipalities.

I examine several dimensions, including health, education and labor market outcomes, and find strong evidence that prenatal exposure to rainfall shocks leads to poorer adult outcomes. I find that individuals prenatally exposed to adverse rainfall have fewer years of schooling, display increased rates of illiteracy, are less likely to work in the market, and are more likely to report serious mental and physical illness.

I then explore a set of additional heterogeneities that may provide insights on the mechanisms at play. Understanding of specific mechanisms is critical for guiding the targeting of policies. Policy implications when infectious and parasitic diseases are the relevant mechanism may be different from those when the relevant mechanism is reduced agricultural income. I first examine heterogeneities with respect to the fraction of population that is rural. If the agricultural income is in fact an important mechanism, one should see larger effects among cohorts born in areas with a high fraction of population depending on farming and related agricultural activities for their livelihoods. I also examine heterogeneities with respect to malaria risk, a disease related to precipitation conditions that was a major cause of morbidity in Colombia during the period study. I find substantial heterogeneities

across these dimensions. For example, the impacts of prenatal rainfall among cohorts born in the malarious regions more than double that of those cohorts born in areas with lower risk of malaria. By contrast, I find heterogeneities with respect to income that are smaller in magnitude and less consistent across outcomes. Collectively, these results are consistent with the existence of the agricultural income and disease mechanisms.

A small set of recent studies has investigated the relationship between early rainfall shocks and later-life outcomes. Using data from Indonesia, Maccini and Yang (2009) find evidence that exposure to early droughts is associated with poorer self-reported health and less grades of schooling. Dinkelman (2017) shows that early drought exposure raises later-life disability rates in South Africa, with the effects concentrated in physical and mental disabilities. A work by Adhvaryu et al. (2016) examines the extent to which a cash incentive program for school enrollment mitigates the medium-term impacts of early rainfall on education and employment in Mexico. They documented that the adverse effects of rainfall on grade attainment, post-secondary enrollment and employment outcomes are smaller among for children from families who receive conditional cash transfers.

The present study extends the existing literature in at least two important ways. First, this paper uses historical information on municipality characteristics in which individuals were born to distinguish between heterogeneous effects across subgroups, which may help understand the mechanisms of impacts. As plausible as the hypotheses of changes in agricultural income and diseases in utero may be, previous studies tend to assume rather than test them. Second, differently from previous studies, I exploit precise information on date of birth to identify prenatal exposure. The existing literature has made use of the individual's year of birth (rather than year and month of birth) to identify early rainfall exposure. Thus, it is unclear whether the effects are driven by prenatal or postnatal exposure to rainfall. As discussed in detail by Doyle et al. (2009), interventions aimed at investing during the prenatal period can have costs radically different from those focused on the postnatal period. Hence, identifying the timing of the impacts is crucial for guiding the design of policies intended to mitigate the adverse consequences of rainfall shocks. In addition, relying only on individual's year of birth for identifying exposure may be empirically problematic because it may include exposure around time of conception. If different quality parents are more likely to postpone fertility when exposed to extreme rainfall shocks around time of conception, then it may lead to overestimates of the true effects of rainfall shocks on later-life outcomes. Using precise information on date of birth, the present study examines cohorts conceived before a shock occurred and contributes to the literature by exploring the extent to which this issue may be important in practice.

The rest of paper is organized as follows. Section 2 provides information on the data,

while Section 3 introduces the empirical strategy. Section 4 presents the main results and robustness tests. Section 5 explore potential mechanisms of impact. Section 6 concludes.

2 Data

2.1 Weather data

This paper builds a series for temperature and precipitation using data from the Terrestrial Air Temperature and Terrestrial Precipitation: 1900-2010 Gridded Monthly Time Series, version 3.02, respectively (Matsuura and Willmott, 2012). This dataset provides worldwide estimates for weather conditions at the 0.5×0.5 degree latitude/longitude grid. Using an interpolation algorithm, Matsuura and Willmott (2012) compute values for each grid node from several nearby weather stations. Following Rocha and Soares (2015), I construct a municipality-by-month of weather panel. I begin by computing the centroid for each of the municipalities and then located the four closest nodes to build a monthly series as the weighted average of estimates related to these four nodes. I use the inverse of the distance to each node as weight.

Following Adhvaryu et al. (2016), I define “normal rainfall” for a given month if rainfall fell within one standard deviation of historical mean for that calendar month within municipality. Since I am not comparing municipalities, the “normal” rainfall measure should not be taken in an absolute sense. These are simply normal rainfall months for each municipality within the given period. The historical average rainfall is calculated for each municipality and calendar month over the 1900-2010 period. Since early years did not have weather stations, Matsuura and Willmott (2012) impute the data for missing years using a meteorological model. Thus, a natural concern is bias from measurement error. However, I find very similar results when considering the 1942-2010 period to construct both the historical mean and standard deviation. I then measure prenatal rainfall as the fraction of normal rainfall months occurring in the 9 months before birth. For example, if an individual was born in December, then prenatal exposure to normal rainfall is computed as the share of normal rainfall months between April and December.

2.2 Census data

This paper uses microdata from the 2005 Colombia Census, the most recent full population census available. I use a randomly drawn sample available through the Integrated Public Use Microdata Series (IPUMS), a project to harmonize the coding census from several countries (Ruggles and Sobek, 1997; Sobek et al., 2012). Importantly for my analysis, the Census asks

for municipality and exact date of birth.³ This information allows me to match individuals with rainfall conditions of the municipality where they were born to identify the prevailing rainfall conditions in early-life. I focus on adults aged 25-65 at the time we see them in 2005 (cohorts born between 1942 and 1981).

The Census provides information on basic socio-economic and demographic characteristics. I consider several adult outcomes. First, I explore years of schooling and an indicator for illiteracy. Since young individuals are excluded from the analysis, these measures are likely to capture completed schooling. Second, I examine an indicator for having any serious disability and the number of disabilities as measures of health human capital. Individuals who reported having any disability are asked to provide information on the type of disability, so I also construct indicators for individual disability types. These include vision, hearing or speech, mental or physical disability. These disability measures have been widely used in the literature linking early life shocks to later outcomes (Almond, 2006; Almond and Mazumder, 2011; Lin and Liu, 2014). Unfortunately, the 2005 Census does not provide information on income. Hence, I use an indicator for employment status as a proxy for labor market success.

The expanded sample consists of 18,843,493 individuals. Since the analysis exploits the municipality-by-month-by-year variation in rainfall conditions, I collapse the data into municipality-of-birth \times month-of-birth \times year-of-birth - cells and use the conditional means as dependent variables. In the regressions, I weight the observations by the cell size to adjust for precision with which the cell means are estimated. Estimates based on this type of group-means data are asymptotically equivalent to the ones derived from the micro-data counterpart (Donald and Lang, 2007), but the use of group-means data eases the computational burden.

Table 1 shows descriptive statistics for the outcomes of interest. About 6 percent of individuals have at least a disability and the average number of disabilities is 0.07. The most common disability in the data is related to vision. The fraction of individuals suffering from this condition is 3 percent. By contrast, the prevalence of mental disability is relatively lower, with 0.8 percent of individuals reporting a serious mental disability. The mean schooling level is 7.91. About 8 percent of individuals declared that do not know how to read or write, and 56 percent of people have a job.

2.3 Other municipality-level data

To investigate the role of potential mechanisms, I use a rich set of municipality-specific historical data. In particular, using data from the 1973 Census, I compute data on number

³The 2005 Census is the only Colombian Census with information on month and year of birth.

of residents, rural population rate, and per capita income. I use rural population rate as a proxy for the fraction of population depending on farming and related agricultural activities for their livelihoods. I also obtain data on malaria ecology from Bleakley (2010). I use these variables to evaluate the degree to which these aggregate factors magnify or dampen the baseline effects of prenatal rainfall shocks.

3 Empirical Strategy

To measure the relationship between early-life rainfall and later-life outcomes, I use the following specification:

$$\begin{aligned} Outcome_{jmt} = & \alpha + \beta R_{jmt} + \gamma Z_{jmt} + \theta Trend_{tm} \times M_j \\ & + \eta_j + \mu_{mt} + \xi_{jmt} \end{aligned} \tag{1}$$

for cohorts born in municipality j , month m and year t . $Outcome$ is the dependent variable of interest, either an education, health or employment outcome. R is the fraction of normal rainfall months during the 12 months prior to birth. The covariates Z include a set of predetermined individual characteristics, such as sex and race. In all specifications, I control for municipality-specific linear time trends ($Trend_{tm} \times M_j$) to account for factors changing over time that might affect the outcomes of interest.

The models include municipality-of-birth fixed effects (η_j), which absorb any unobservable time-invariant determinants of adult outcomes, including initial conditions, geography, and area-specific risks of diseases. The set of month-of-birth \times year-of-birth fixed effects controls for common time trends such as seasonal fluctuation in later outcomes, macroeconomic conditions and common national policies. All our models use robust standard errors adjusted for clustering at the municipality level to account for serial correlation (Bertrand et al., 2004).

The coefficient β measures the effects of prenatal exposure to rainfall on the adult outcomes of interest. My quasi-experimental design rests on the assumption that the occurrence of extreme rainfall events is uncorrelated with omitted determinants of later-life outcomes. This assumption is plausible insofar as parents are unlikely to anticipate precisely a rainfall shock at a given moment in time and place. By conditioning on the full set of municipality and time fixed effects and local-specific time trends, the analysis uses arguably random fluctuations in rainfall from municipality-specific deviations in long-term rainfall after accounting for all seasonal factors and common shocks to all municipalities.

4 Results

4.1 Main findings

I begin by examining graphically the relationship between prenatal rainfall and the outcomes of interest. I estimate local linear regressions of adult outcomes on fraction prenatal in normal rainfall conditions, conditional on municipality-specific time trends, municipality-of-birth and year-of-birth \times month-of-birth fixed effects. Figures 2-3 plot the respective estimates and 90 percent confidence intervals. Figure 2, panel (c) shows a negative relationship between fraction prenatal in normal precipitation and mental disability. There are not clear patterns for other disability outcomes. By contrast, Figure 3 suggests a statistically significant relationship between prenatal rainfall and socioeconomic outcomes. Individuals who spent more of their prenatal period in normal rainfall conditions have more years of schooling, higher literacy rates, and are more likely to work in the labor market.

While the figures provide compelling evidence, I also formally present the regression results. Table 2 shows the estimates from equation (1). All regression results are based on the full specification that adjusts for municipality-of-birth fixed effects, month-of-birth \times year-of-birth fixed effects, municipality-specific time trends and the set of predetermined individual characteristics. Sample sizes and *R*-squared's of the regressions are shown at the bottom of the table.

Columns (1)-(2) look at an indicator for any serious disability and the number of disabilities, respectively. There is no evidence that early-life rainfall shocks are associated with changes in the prevalence of disabilities, with estimates of the parameter of interest statistically indistinguishable from zero at the conventional levels of significance. However, these aggregate measures of disabilities may mask important form of heterogeneities across disability types. Columns (3)-(6) explore the effects of early rainfall shocks on disability types. Column (3) shows evidence that greater prenatal exposure to normal precipitation reduces mental disability incidence. The estimate of β is -0.0015 (standard error=0.0008), which is statistically significant different from zero at the 10 percent level of significance. This estimate implies that individuals who spent 100 percent of their prenatal period exposed to normal rainfall conditions have mental disability rates 0.15 percentage points lower than those individuals who were never exposed to normal rainfall conditions. Relative to the mean rate of mental disability of 0.79, this is a large effect estimate at 18 percent.

Column (4) suggests a statistically significant effect of prenatal rainfall on physical disability. The point estimate is negative and indicates that greater exposure to normal conditions is associated with lower rates of physical disability. Comparing individuals with zero and complete prenatal exposure to normal rainfall suggests a difference of 0.28 percentage

points in the probability of report any physical disability. Relative to the mean, this estimate suggests a increase of 11 percent.

To better place the disability results in perspective, I compare these estimated effects to the differences in the disability outcomes between less- and more-educated individuals. This seems to be a relevant comparison given the well-established striking correlation between health and education.⁴ In my sample, an increase of one standard deviation in years of education is associated with a increase of 0.48 percentage points in the probability of reporting a serious mental disability.⁵ Relative to this difference, the estimated effect of prenatal normal rainfall is about 30 percent. The same comparison for physical disability reveals a similar relative difference.

Column (7) investigates the relationship between early rainfall and years of schooling. I find evidence that greater prenatal exposure to normal rainfall leads to more years of schooling, with β estimate at 0.1102 (standard error = 0.0559). This is about a 1.5 percent increase relative to the mean years of schooling of 7.9. For comparison, Duflo (2001) finds that a large school construction program leads to an increase of 0.15 years of education in Indonesia. Column (8) presents the results for illiteracy and suggests a statistically significant effect of early rainfall. The rate of illiteracy among individuals experiencing a 100 percent prenatal exposure to normal rainfall is reduced by 0.46 percentage points relative to those who were not exposed to normal rainfall conditions in utero. This is about 5.4 percent at the mean illiteracy rate. Finally, column (9) examines early rainfall impacts on employment. I find that exposure to prenatal normal rainfall results in higher employment rates. The estimated coefficient indicates that individuals who spent 100 percent of their prenatal period experiencing normal rainfall conditions are 1.74 percentage points more likely to work in adulthood.

Instead of using exposure to “normal” rainfall, Table 3 considers separately the effects of prenatal floods and droughts. Flood and drought shocks are defined as ± 1 standard deviations with respect to the historical monthly mean of each municipality. The results suggests negative impacts of both prenatal floods and droughts on later-life outcomes. In general, I find larger effects of prenatal exposure to floods than droughts. For example, the treatment effect of prenatal floods on mental disability is about 10 times larger than that of prenatal droughts. Thus, these results suggest that the observed impacts in Table 2 are largely driven by excessive precipitation.

⁴See Adams et al. (2003) for a good summary of this literature

⁵This estimate is obtained by regressing mental disability on years of schooling, and controls for age, sex, and race.

5 Mechanisms

5.1 Heterogeneous treatment effects

In this section, I explore heterogeneity in treatment effects to help understand the plausible mechanisms at play. The literature generally attributes the effects of prenatal rainfall to agricultural income and diseases. Precipitation is crucial for agricultural productivity, so extreme fluctuations in rainfall can adversely affect the income of rural families that depend on agricultural activities. Reduced income in turn may adversely affect living conditions of pregnant women and thus the quality of the prenatal period. At the same time, infectious diseases such as malaria are transmitted faster in the humid environment created by the excess precipitation (Kabanywanyi et al., 2008). While plausible, previous studies tend to assume rather than test these mechanisms. Understanding the importance of these mechanisms is important for the designing of policy.

To investigate the relative role of agricultural income and disease environment, I regress the outcomes of interest on interactions of prenatal rainfall with a set of municipality-specific variables. This regression is specified as follows:

$$\begin{aligned} Outcome_{jmt} = & \alpha + \beta R_{jmt} + \delta R_{jmt} \times I_j + \gamma Z_{jmt} + \theta Trend_{tm} \times M_j + \\ & \eta_j + \mu_{mt} + \xi_{jmt} \end{aligned} \tag{2}$$

A significance of coefficients on interactions (δ) would point to the presence of differences in the effect of prenatal rainfall on later-life outcomes. If for example one expects agricultural income to be an important factor underlying the results above, then one should observe larger impacts among cohorts born in areas with a high fraction of population depending on agriculture for their living. I use rural population rate in 1973 as a proxy for the proportion of individuals depending on agricultural income. To examine the importance of the disease channel, I examine heterogeneities with respect to a measure of malaria risk. Many cohorts analysed by this paper were born in a period where malaria had not been eradicated and was a major cause of morbidity in Colombia. Furthermore, the risk of malaria varies widely across areas of Colombia, with some regions with very high risk of malaria and others with low or no incidence. Naturally, there could be other important diseases in driving the long-run effects of prenatal rainfall on adult outcomes and they are likely to be highly correlated with malaria incidence. While limitations of the available data do not allow me to disentangle all possible infectious disease mechanisms, I interpret any significant interactions on malaria as evidence of the existence of a disease channel rather than a malaria one.

I also examine heterogeneities with respect to income and population size. Because all

these variables have a high degree of collinearity, examining interactions with income and population size is useful to help understand the relative importance of agricultural income and malaria from economic development. To better compare the importance of each factor, I standardize each factor to have mean 0 and standard deviation 1.

Figures 4-5 show the estimated coefficients on interactions and respective 90 percent confidence interval. The results indicate that the effects of prenatal shocks tend to be larger among cohorts born in municipalities with higher risk of malaria and areas with high fraction of population that is rural. The differences in the treatment effects are striking in some cases. For instance, one increase of one standard deviation in malaria risk more than doubles the impacts of prenatal fraction spent in normal rainfall on years of schooling. The same is true for other outcomes such as mental disability and illiteracy, for which the baseline impacts of prenatal are the strongest and consistent. When heterogeneities with respect income and population size are examined, I do find statistically significant differences, but the magnitude are relatively smaller and in fact less consistent across outcomes than that of malaria risk and rural population rate. This suggests that are disease risk and rural income, and not only economic development, behind these results.

5.2 Postnatal investments

The long-run effects shown above represent the impacts of rainfall throughout a individual's life-cycle, which include parental investments after birth. Existing literature suggests several pathways through which rainfall shocks may affect parental investments. The income effects of rainfall shocks may have direct repercussions on the ability of parents to allocate important resources to their children early after-birth, especially in contexts characterized by credit constraints and other market imperfections. In this case, postnatal investments would reinforce the baseline impacts of prenatal rainfall shocks. Alternatively, income shocks induce by fluctuations in precipitation may affect the opportunity cost of time-intensive investments. For example, if parents anticipate that returns to agricultural activities are low due to unfavorable rainfall conditions, they may be more likely to be at home and devote more time to crucial investments that require large amounts of time, such as travelling to distant facilities for free health services (Miller and Urdinola, 2010). Hence, investments would contribute to compensating the initial adverse effects of rainfall shocks on infant health.

Shifts in child endowments at birth due to prenatal rainfall shocks may also affect household behavior independently of changes in income. A prominent literature both theoretical and empirical suggests that parents' investments respond to variations in birth endowments. An early study by Becker and Tomes (1976) suggests that complementarities in the pro-

duction function of child quality create an incentive for families to devote more resources in highly endowed children. This implies that parental investments reinforce the long-term consequences of poor infant health. Conversely, Behrman et al. (1982) argue parents are likely to undertake compensatory investments in weaker children because of altruism and aversion to inequality. Empirically the evidence has been mixed, with some studies finding evidence for reinforcement (Adhvaryu and Nyshadham, 2016; Datar et al., 2010) and others showing the opposite (Del Bono et al., 2012; Bharadwaj et al., 2013). Hence, it is difficult to infer how prenatal rainfall shocks affect investments through the child endowments channel.

I then use data from the Colombia Demographic Health Survey (DHS) to seek understand the relationship between prenatal rainfall shocks and postnatal investments, driven either by an income effect, parents investing more or less in weaker children, or any other channel. The DHS is a nationally representative survey of women ages 15-49 and contains detailed information on early-life investments for all children under five. I use all the waves (1986, 1990, 1995, 2000, 2004-05, 2009-10) of the DHS and pool them into one dataset. The basic sample consist of about 45,000 children. The inputs I examine are vaccination and breastfeeding. Vaccinations have been shown to be effective in preventing ill health and mortality. Given the limited access to medical treatment in developing countries, vaccinations become an important health inputs. Likewise, breastfeeding plays a central role in nutrition, especially in environments characterized by unsafe drinking water and limited supply of food.⁶ Since the cohorts in the DHS are not the same as in the main results, this analysis should be view as an exploratory exercise.

To assess the role of postnatal investments, I estimate the following specification:

$$Investment_{ijmt} = \alpha + \beta R_{ijmt} + \theta Trend_{tm} \times M_j + \eta_j + \mu_{mt} + \xi_{ijmt} \quad (3)$$

for the child i born in municipality j , month m , and year t . R is the fraction of normal rainfall months during the 12 months prior to birth. The regressions control for municipality-specific linear time trends ($Trend_{tm} \times M_j$), municipality-of-birth fixed effects (η_j), and month-of-birth \times year-of-birth fixed effects (μ_{mt}). In all regressions, I also control for average temperature during the 12 months before birth.

The results are reported in Table 4. Column (1) shows that children with greater exposure to normal rainfall conditions in utero are less likely to have ever been breastfed. Column (2) uses a dummy indicating whether the child was breastfed for more than six months, the minimum length recommended by the World Health Organization (WHO). Using this breastfeeding measure leads to the same qualitative result that normal rainfall in utero reduces the

⁶A large body of work has documented that breastfeeding is predictive of later cognitive outcomes (see, for example, Del Bono et al. (2012)).

likelihood of being breastfed. Columns (3)-(4) look at the duration of breastfeeding by using linear and log-linear regressions.⁷ I find negative and statistically significant effects of prenatal fraction in normal rainfall on the duration of breastfeeding. The magnitudes indicate that the duration of breastfeeding decreases as much as 10 percent when the child is completely exposed to normal rainfall in utero. Irrespective of how breastfeeding is measured, I find a negative effect of prenatal exposure to normal rainfall on this postnatal investment.

In the next set of columns, I look at BCG (*Bacillus Calmette-Guerin*), polio, DPT (diphtheria, pertussis and tetanus combination) and measles vaccinations. I construct dummies indicating whether the child has all the recommended vaccination doses for specific diseases.⁸ I find statistically significant impacts on DPT and polio vaccinations. The results indicate that greater exposure to normal rainfall conditions in utero reduces the probability of being vaccinated for specific diseases. In general, the magnitudes suggest that complete exposure leads to an increase of 6 percent in the probability of having all the recommended vaccination for DPT and polio. Table 5 shows estimates of the effects of prenatal rainfall for each of the three DPT and polio vaccines separately. The results show statistically significant impacts on receipt of individual vaccinations.

Overall, the evidence suggests that prenatal exposure to normal rainfall leads to less health investments in early-life. This suggests that postnatal investments may be contributing in mitigating the long-run adverse consequences of poor neonatal health. The fact that earlier investments such as BCG, and first doses of polio and DPT vaccinations are not affected suggests that parents engage in compensatory investments once child quality is better known. I do not find any significant impacts on measles vaccination, which is administered at 11 months or later, but it may be because that vaccine is typically delivered through large scale immunization campaigns whereas the other vaccines are more likely to be delivered during postnatal care visits. Still, the timing of the impacts on vaccination contrast with the income or opportunity cost mechanisms in driving the investments effects, since they would imply significant impacts on early postnatal investments. While it is beyond the scope of this paper understanding the nature of these investment effects and it is impossible to rule out alternative histories, the evidence suggests that parental responses to birth endowments is the primary source of these findings. In any case, the results of this section suggest that the reduced-form long-term impacts of prenatal rainfall shocks on adult outcomes are likely to represent lower bounds of biological effects.

⁷In the log-linear regressions, I use $\log(\text{duration of breastfeeding} + 1)$ as dependent variable.

⁸In Colombia, the recommended vaccination schedule is: BCG within weeks after birth, polio at two months, four months, and six months; DPT at two months, four months, and six months; measles at 11 months.

6 Conclusion

The health and other consequences of extreme weather events are an increasing salient issue in the public debate about the costs and benefits of climate change mitigation policies. Several scholars highlight that more heavy rainfall and droughts will have serious repercussions for children's development in poorer and more fragile states. Yet, despite its importance in the public debate, there is even little research to date documenting the long-run effects of rainfall shocks on human capital and welfare. This paper uses Colombian data to gain new insights into the effects of early rainfall shocks on later-life welfare. I show that prenatal exposure to normal rainfall conditions result in more years of schooling, reduced rates of illiteracy, lower unemployment rate, and reduced rates of disabilities.

To gain insights into the mechanisms underlying these results, I explore heterogeneities in treatment effects across an array of geographical disaggregations. Rainfall shocks are a major source of income volatility for families depending on farming for a living, so one would expect to see larger effects among cohorts born in areas with a fraction of population depending on agriculture. The results are generally consistent with this hypothesis. I also find strong heterogeneities with respect to malaria risk, with stronger effects among cohorts born in malarious regions. Furthermore, the effects are smaller among more recent cohorts, when malaria was eradicated and a higher fraction of population were living in urban areas and did not depend on farm related activities. By contrast, there are weaker heterogeneities when examined income or population size, suggesting that changes in agricultural income and disease prevalence may be in fact the mechanisms underlying the long-run effects of rainfall shocks.

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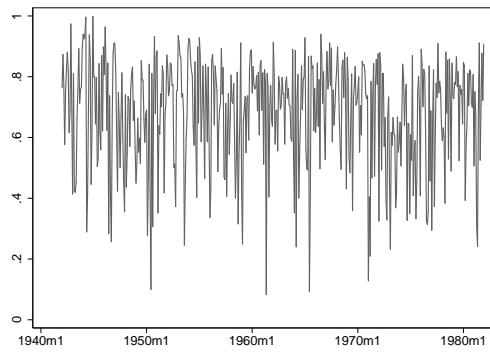
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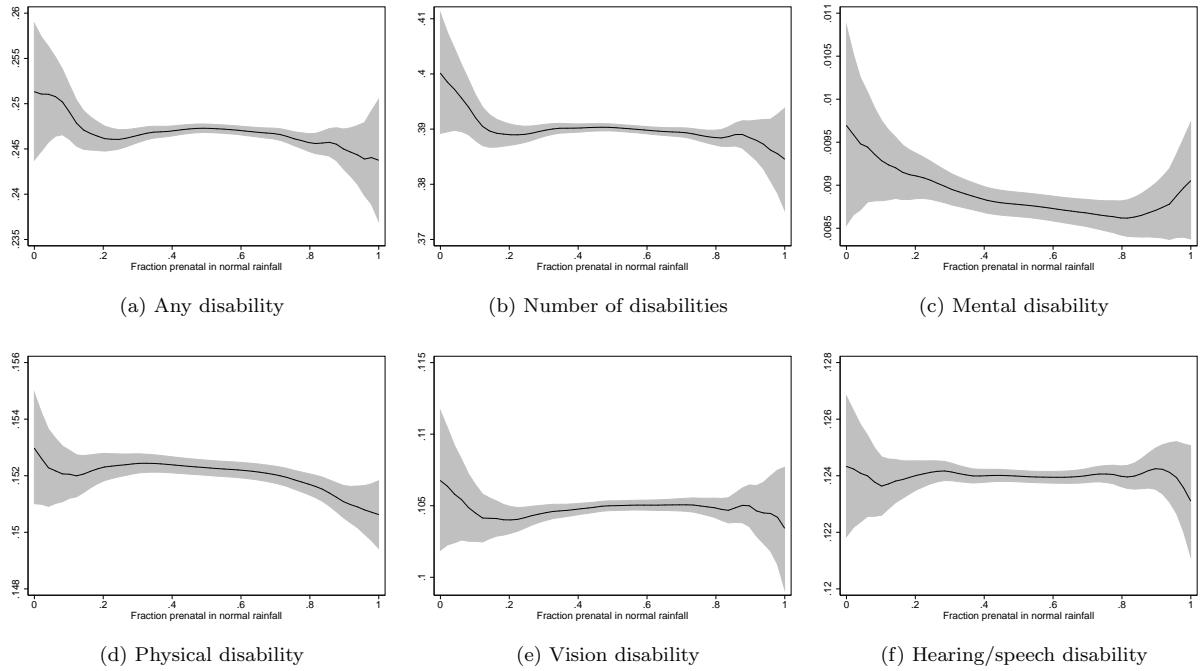
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Figure 1: Normal rainfall across time and place



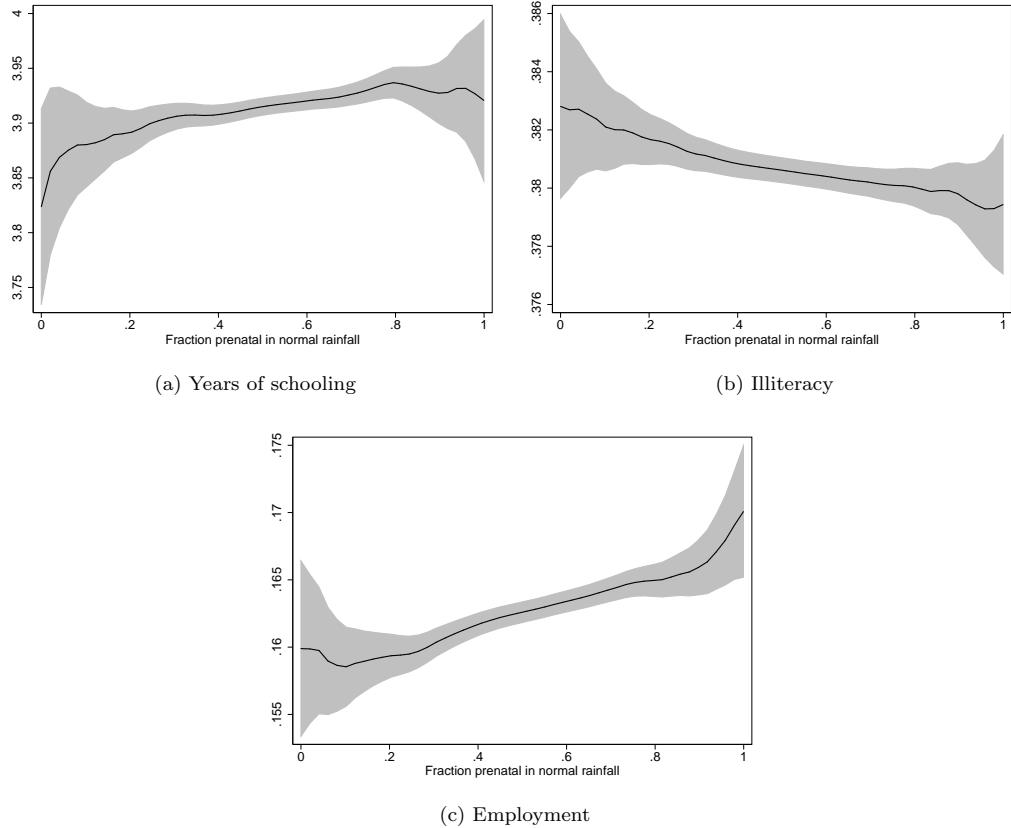
Notes. Figure 1 presents the percentage of municipalities with normal rainfall conditions in each month. Author's calculation based on data from the Terrestrial Air Temperature and Terrestrial Precipitation: 1900-2010 Gridded Monthly Time Series, Version 3.02.

Figure 2: Effects of prenatal rainfall on disabilities



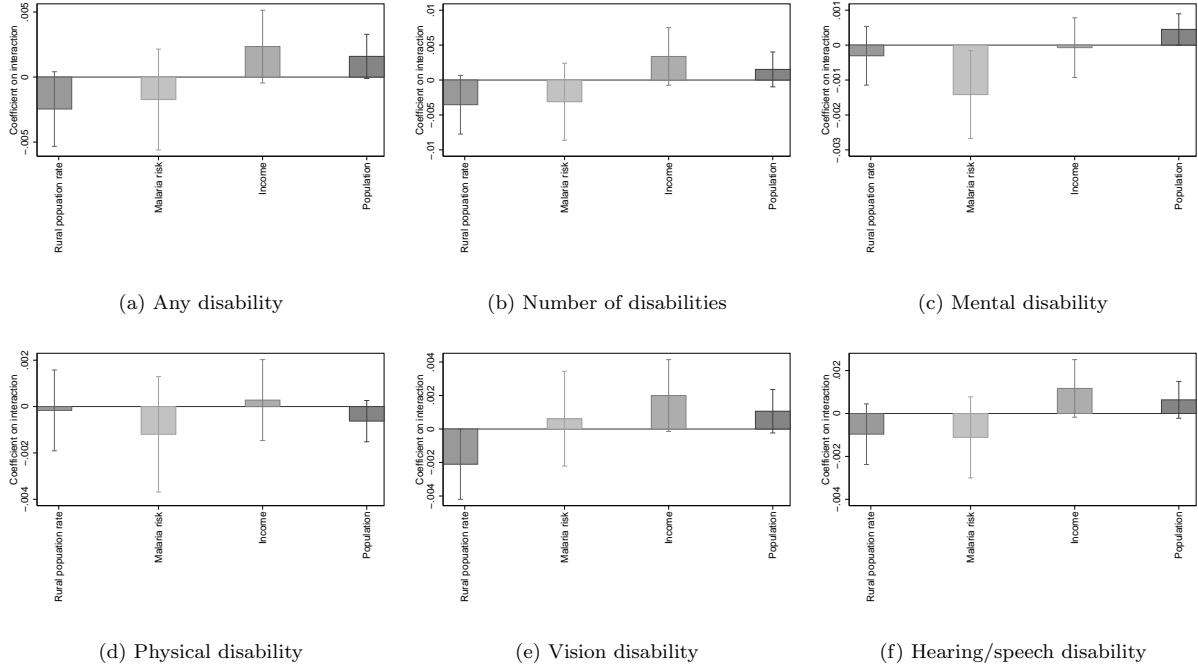
Notes. Local regressions of outcomes on fraction prenatal in normal rainfall. To produce these plots, the outcomes and the prenatal rainfall exposure are both regressed on all other explanatory variables in equation (1). The residual terms from the outcome regression is then locally regressed on the residual from the prenatal rainfall regression using a locally weighted polynomial regression with Epanechnikov kernel functions. 90% confidence intervals are based on errors that are not clustered as in our main specifications.

Figure 3: Effects of prenatal rainfall on socioeconomic outcomes



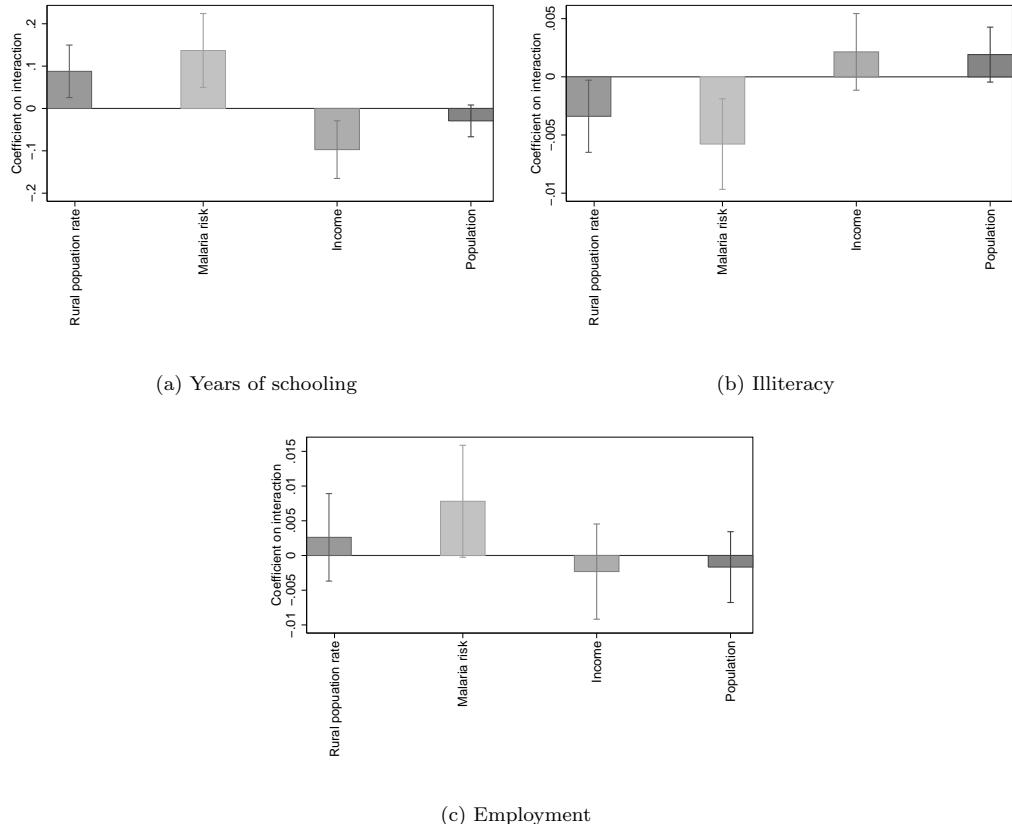
Notes. Local regressions of outcomes on fraction prenatal in normal rainfall. To produce these plots, the outcomes and the prenatal rainfall exposure are both regressed on all other explanatory variables in equation (1). The residual terms from the outcome regression is then locally regressed on the residual from the prenatal rainfall regression using a locally weighted polynomial regression with Epanechnikov kernel functions. 90% confidence intervals are based on errors that are not clustered as in our main specifications.

Figure 4: Effects of prenatal rainfall on disabilities - heterogeneities



Notes. Results from regressions of each outcome on fraction prenatal rainfall and interaction with each municipality-specific variable. All regressions control for specific-municipality linear time trends, municipality-of-birth fixed effects, month-of-birth \times year-of-birth fixed effects, sex and race. Rural population rate, income and population at the municipality level are computed from the 1973 Census. Malaria risk at the municipality level is obtained from Bleakley (2010). For ease of comparison, each municipality-specific variable are normalized to have mean 0 and standard deviation 1. Regressions for each municipality-specific variable are run in sequence including one variable as a main effect and interacted regressors at a time. The figure reports the coefficients on the interactions with respective 90 percent confidence intervals. Regressions for each municipality-specific variable are run in sequence including one variable as a main effect and interacted regressors at a time. Robust standard errors are adjusted for clustering at the municipality level.

Figure 5: Effects of prenatal rainfall on socioeconomic outcomes - heterogeneities



Notes. Results from regressions of each outcome on fraction prenatal rainfall and interaction with each municipality-specific variable. All regressions control for specific-municipality linear time trends, municipality-of-birth fixed effects, month-of-birth \times year-of-birth fixed effects, sex and race. Rural population rate, income and population at the municipality level are computed from the 1973 Census. Malaria risk at the municipality level is obtained from Bleakley (2010). For ease of comparison, each municipality-specific variable are normalized to have mean 0 and standard deviation 1. The figure reports the coefficients on the interactions with respective 90 percent confidence intervals. Regressions for each municipality-specific variable are run in sequence including one variable as a main effect and interacted regressors at a time. Robust standard errors are adjusted for clustering at the municipality level.

Table 1: The effects of early rainfall shocks on later-life outcomes

	Mean	Standard deviation	Min	Max
Any disability	0.0619	0.1231	0	1
Number of disabilities	0.0759	0.1668	0	4
Mental disability	0.0079	0.0402	0	1
Physical disability	0.0244	0.0771	0	1
Vision disability	0.0332	0.0915	0	1
Hearing/speech disability	0.0121	0.0534	0	1
Years of schooling	7.9115	3.0374	0	17
Illiteracy	0.0846	0.1833	0	1
Employment	0.5632	0.2617	0	1
Fraction prenatal in normal rainfall	0.6790	0.16611	0	1
Fraction prenatal in floods	0.1421	0.1357	0	1
Fraction prenatal in droughts	0.1703	0.1478	0	1

Notes. The data are collapsed to municipality-of-birth \times month-of-birth \times year-of-birth level. Sample restricted to 2005 Census data on individuals born between 1942 and 1981.

Table 2: The effects of early rainfall shocks on later-life outcomes

	Any disability	Number of disabilities	Mental disability	Physical disability	vision disability	hearing/speech disability	Years of schooling	Illiteracy	Employment
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Prenatal normal rainfall	-0.0017 [0.0027]	-0.0031 [0.0038]	-0.0015 [0.0008]*	-0.0028 [0.0015]*	0.0014 [0.0020]	-0.0002 [0.0013]	0.1102 [0.0559]**	-0.0046 [0.0026]*	0.0174 [0.0057]**
N	236062	236062	236062	236062	236062	236062	235426	236057	235461
R-sq	0.106	0.093	0.016	0.054	0.085	0.031	0.53	0.297	0.313

Notes. Prenatal normal rainfall is the fraction of months during the 12 months before birth that the *normal* rainfall indicator equal one. The data are collapsed to municipality-of-birth \times month-of-birth \times year-of-birth level. All regressions control for municipality-of-birth fixed effects, month-of-birth \times year-of-birth fixed effects, municipality-specific linear time trends, average temperature in 12 months before birth, sex and race. The regressions weights the observations by the cell size to adjust for precision with which the cell means are estimated. Sample restricted to 2005 Census data on individuals born between 1942 and 1981. Robust standard errors clustered at the municipality level are presented in brackets. Significance: * $p < 0.10$ ** $p < 0.05$, *** $p < 0.01$.

Table 3: The effects of early floods and droughts on later-life outcomes

	Any disability	Number of disabilities	Mental disability	Physical disability	vision disability	hearing/speech disability	Years of schooling	Illiteracy	Employment
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Floods	0.0037 [0.0032]	0.0064 [0.0046]	0.003 [0.0011]***	0.0047 [0.0021]**	-0.0008 [0.0025]	-0.0006 [0.0014]	-0.1183 [0.0616]*	0.0077 [0.0030]**	-0.0216 [0.0076]***
Droughts	0.0000 [0.0034]	0.0003 [0.0045]	0.0003 [0.0011]	0.0011 [0.0018]	-0.002 [0.0024]	0.0008 [0.0018]	-0.1032 [0.0745]	0.0021 [0.0032]	-0.0149 [0.0057]***
N	236062	236062	236007	236007	236007	236007	235426	236062	236062
R-sq	0.106	0.093	0.016	0.054	0.085	0.031	0.53	0.297	0.311

Notes. Floods and Droughts represent the fraction of months during the 12 months before birth that the *flood* and *drought* indicators equal one, respectively. The data are collapsed to municipality-of-birth × month-of-birth × year-of-birth level. All regressions control for municipality-of-birth fixed effects, month-of-birth × year-of-birth effects, municipality-specific linear time trends, average temperature in 12 months before birth, sex and race. The regressions weights the observations by the cell size to adjust for precision with which the cell means are estimated. Sample restricted to 2005 Census data on individuals born between 1942 and 1981. Robust standard errors clustered at the municipality level are presented in brackets. Significance: * p < 0.10 ** p < 0.05, *** p < 0.01.

Table 4: The effects of early rainfall shocks on postnatal investments

	Was child ever breastfed?	Breastfed for more than six months	# months breastfed	Ln(# months breastfed + 1)	BCG	Polio	DPT	Measles
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Prenatal normal rainfall	-0.0219 [0.0110]**	-0.0964 [0.0230]***	-1.1383 [0.4515]**	-0.1093 [0.0419]***	-0.0069 [0.0125]	-0.0498 [0.0201]**	-0.0481 [0.0231]**	-0.0325 [0.0210]
Mean of dep. Var	0.929	0.615	12.01	2.308	0.942	0.671	0.737	0.706
N	45209	42709	41997	41997	45800	45799	45798	45759
R-sq	0.052	0.21	0.221	0.262	0.092	0.229	0.295	0.536

Notes. Estimation based on all the waves of the DHS (1986,1990, 1995, 2000, 2004-05, 2009-10). The sample consist of children under five. Prenatal normal rainfall is the fraction of months during the 12 months before birth that the *normal* rainfall indicator equal one. Dependent variable in column (1) is dummy variable indicating whether the child was ever breastfed. Dependent variable in column (2) is a dummy variable indicating whether the child was breastfed for more than six months. Columns (3)-(4) represent the duration of breastfeeding by using linear and log-linear regressions, respectively. Dependent variables in columns (5)-(8) are dummies indicating whether the child has all the recommended vaccination doses for specific diseases. All regressions control for municipality-of-birth fixed effects, month-of-birth \times year-of-birth fixed effects, municipality-specific linear time trends, and average temperature in 12 months before birth. Robust standard errors clustered at the municipality level are presented in brackets. Significance: * p < 0.10 ** p < 0.05, *** p < 0.01.

Table 5: The effects of early rainfall shocks on postnatal investments- specific vaccines

	Polio 1 (1)	Polio 2 (2)	Polio 3 (3)	DPT 1 (4)	DPT 2 (5)	DPT 3 (6)
Prenatal normal rainfall	-0.0143 [0.0158]	-0.0356 [0.0192]*	-0.0515 [0.0205]**	0.0111 [0.0161]	-0.0324 [0.0201]	-0.0534 [0.0227]**
Mean of dep. Var	0.889	0.811	0.674	0.916	0.824	0.741
N	45799	45779	45779	45798	45773	45773
R-sq	0.184	0.262	0.231	0.226	0.272	0.3

Notes. Estimation based on all the waves of the DHS (1986, 1990, 1995, 2000, 2004-05, 2009-10). The sample consist of children under five. Prenatal normal rainfall is the fraction of months during the 12 months before birth that the *normal* rainfall indicator equal one. Dependent variables in each column are dummies indicating whether the child has all the recommended polio or DPT vaccination dose. All regressions control for municipality-of-birth fixed effects, month-of-birth \times year-of-birth fixed effects, municipality-specific linear time trends, and average temperature in 12 months before birth. Robust standard errors clustered at the municipality level are presented in brackets. Significance: * $p < 0.10$ ** $p < 0.05$, *** $p < 0.01$.