Assessing Heterogeneity in the Child Growth Impacts of In-Utero Rainfall Shocks in Rural Rwanda

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Assessing Heterogeneity in the Child Growth Impacts of In-Utero Rainfall Shocks in Rural Rwanda

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Abstract

In this paper, we show how rainfall shocks in different cropping periods in Rwanda can lead to heterogeneous child growth impacts that would be missed in an annual measure. Using high-resolution rainfall data, we find that above historical average rainfall in-utero during land preparation and planting or mid-season leads to improved child growth outcomes; above historical average rainfall in-utero during harvest has the opposite effect. These offsetting impacts cause the estimate of the annual in-utero rainfall effect to attenuate towards zero. Our findings are robust to redefinition of the cropping periods and the inclusion of rainfall in other periods. This heterogeneity helps explain mixed findings on the relationship between in-utero rainfall and health among studies that use annual or growing season rainfall measures.

Keywords: child growth, rainfall, in-utero shocks, cropping cycle, Rwanda

JEL codes: I15, I18, J13, Q54

Introduction

The in-utero period of a child’s life is critical for his or her development with long-term implications for human capital accumulation (Barker 1998; Almond, Currie, and Duque 2017).

Exposure to poor environmental conditions during this period has been linked to a wide array of negative consequences. For example, Rocha and Soares (2015) find that negative rainfall shocks

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1 This paper is based on the data collected with funding from the International Potato Center (CIP) under the project titled SUSTAIN: Scaling Up Sweetpotato through Agriculture and Nutrition, grant agreement number 8/GRANT/12/MOZAMBIQUE between CIP and the U.K. Department for International Development (DFID). We are grateful to Incisive Africa, CIP, Imbaraga, and YWCA for their support in all the fieldwork and data collection activities. Thanks also go to all the farmers and their family members for participating in the survey. We appreciate helpful comments and suggestions received from Andrew Dillon, Chris Ahlin, Leah Lakdawala, Eduardo Nakasone, and participants of the MSU Development Economics Seminar on an earlier version of this paper. Views expressed in this paper are the authors’ alone and should not be attributed to Michigan State University, Incisive Africa, the International Potato Center or DFID.
in the year before birth result in lower birth weights and increased infant mortality. The negative consequences of in-utero shocks need not be limited to infancy nor do they require extreme events. In their recent meta-analysis, Almond, Currie, and Duque (2017) emphasize that even moderate early life shocks can have long-term negative consequences.

The existence of heterogeneous effects in response to in-utero shocks is of particular interest to practitioners, as knowledge of these differences can assist in targeting the most vulnerable children. The effects of these in-utero shocks may be heterogeneous according to the characteristics of the child and the ability of the household to respond. For instance, Aizer, Stroud, and Buka (2016) find that children exposed to higher cortisol levels while in-utero receive less education than their siblings in the first seven years of life, and the magnitude of this education reduction is higher for children of mothers with less human capital.

We study the implications of rainfall shocks while in-utero for children’s growth in rural Rwanda. In rural Rwanda, as in many rural developing country contexts, agriculture is the principal source of livelihood. The vast majority of the Rwandan agricultural sector is dependent on rainfall fluctuations. As rural Rwandan households rely primarily on rainfed agriculture, rainfall outcomes are a key source of exogenous variability in household incomes and hence nutrition availability.

Past studies of rainfall shocks in similar agricultural contexts have identified three main mechanisms in which rainfall can affect child growth. The primary mechanism is the effect of rainfall on crop production. Too much or too little rainfall can negatively affect yields and lower

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2 In 2012, the agricultural sector accounted for more than three quarters of employment in Rwanda (World Bank 2017)
3 Based on the three-year average over the 2011-2013 period, less than one percent of all arable land in Rwanda was equipped for irrigation (FAO 2017)
nutrition availability (Maccini and Yang 2009; Leight, Glewwe, and Park 2015; Rocha and Soares 2015). We also consider the possibility of other pathways.

A second mechanism in which rainfall outcomes in-utero may impact child growth is through its impact on the mother’s labor supply decision (Maccini and Yang 2009; Leight, Glewwe, and Park 2015; Rocha and Soares 2015). For example, if more rainfall than expected occurs during key weeding periods of the cropping season, then this may increase labor demand during this period and result in an increase in the mother’s labor supply. The additional strain on the mother during pregnancy caused by this increase in labor supply may transfer to the child and negatively impact his or her health endowment (Leight, Glewwe, and Park 2015).

Finally, a third mechanism in which rainfall outcomes in-utero may influence child health is through the disease environment. More rainfall than average may facilitate the spread of water-borne diseases, particularly in areas with poor sanitation infrastructure (Rocha and Soares 2015).

While the latter two mechanisms are potentially important in impacting children’s health, we focus here on the effect on yield, and our findings are consistent with doing so. Importantly, the yield response to rainfall fluctuations may vary according to the timing of the cropping period (Leight, Glewwe, and Park 2015). For example, maize yields can be particularly sensitive to water deficits during the mid-season flowering and grain-filling stages. Less rainfall during the harvest period, however, can improve yields as this reduces grain water content (Barron et al. 2003).

As the intra-year relationship between rainfall and agricultural productivity need not be constant, the relationship between rainfall experienced in-utero and child growth may also vary according to the cropping period. Therefore, we split the year into three periods: land preparation
and planting, mid-season, and harvest. As Rwanda has two major and one minor agricultural season per year, these cropping periods occur at multiple points in the year and are not chronological.

These differentiated season effects of rainfall shocks have differing implications for each of the pathways discussed above. Above average rainfall during land preparation and planting is likely to increase yields while also worsening the disease environment. Similarly, above average rainfall in the mid-season may have these same impacts while also increasing mother’s labor supply. More rainfall than average in harvest period, however, may have the opposite effect on yields relative to the other two periods.

The main contribution of this study to the existing literature is to disentangle the growth effects of rainfall outcomes by cropping season. This strategy captures potential changes in the marginal effect of rainfall by crop development stage, which would be subsumed in more aggregate measures. If the direction of the effect of rainfall shocks on child growth differs according to the cropping period, then the aggregation of rainfall outcomes into a single measure will attenuate the estimated effects.

We find that rainfall shocks in Rwanda have different implications for children’s development paths according to the cropping periods in which they occur. At planting or mid-season, above average historical rainfall has a positive relationship with child growth, with the strongest relationship occurring mid-season. Late in the cropping seasons, however, we find the opposite relationship; increases in rainfall during harvest reduce child growth. These findings imply that more aggregate measures of rainfall shocks may conceal acute differences in the relationship between rainfall and child growth.
The remainder of the paper proceeds as follows. Section I reviews existing literature on the relationship between rainfall and health. Section II discusses the crop yield response to rainfall as it relates to rural Rwanda. Section III lays out the theoretical framework, rainfall variables, and hypotheses. Section IV describes the empirical strategy. Section V discusses the data sources and summary statistics. Section VI presents the empirical results. Section VII concludes.

I. Rainfall and Health

Many prior studies define rainfall shocks based on yearly rainfall (e.g., Maccini and Yang 2009; Kim 2010; Burgess et al. 2011; Rocha and Soares 2015; Comfort 2016; Abiona 2017) or growing season rainfall (e.g., Skoufias, Vinha, and Conroy 2011; Kudamatsu, Persson, and Stromberg 2012; Shively 2017).

We show that using such aggregate measures of rainfall shocks summarized over the course of a year or growing season masks much of the heterogeneity in the impact of rainfall outcomes. For instance, Leight, Glewwe, and Park (2015) find that, although increases in annual rainfall have a significantly positive effect on grain yields in Gansu Province, China, this measure conceals key intra-year differences by cropping period; the same regression with rainfall split by the planting and harvest periods shows that increased rainfall in the former significantly increased yields while increases in rainfall in the latter significantly reduced them. Instead of aggregate annual or growing season rainfall measures, we examine the cropping period in which rainfall deviations occur.

Although studies based on annual or growing season rainfall often find a positive relationship between rainfall and health outcomes (e.g., Maccini and Yang 2009; Burgess et al.
2011; Rocha and Soares 2015; Comfort 2016; Abiona 2017), others suggest a more mixed relationship. Two meta-analyses combining DHS data on African countries find both positive and negative effects of rainfall on mortality (Kim 2010; Comfort 2016). In Mexico, rainfall one standard deviation below average during the wet season reduced HAZ for a subsample of children in the north region, while increasing HAZ for a subsample of children in the center and south regions (Skoufias, Vinha, and Conroy 2011).

Mixed findings on the effect of rainfall on health is not surprising. The underlying relationship is complex, shaped by an interplay of mechanisms that vary according to local context, health outcomes explored, timeframe between the rainfall and health outcome, etc. A significant portion of these mixed findings, however, may also be driven by the use of rainfall indicators which assume intra-year or intra-season homogeneity in the rainfall effect.

One response to the mixed findings on the rainfall-health relationship is a strand of the literature that seeks to assess this relationship using non-rainfall measures. Early work in Rwanda analyzed a crop failure in 1988-1989 that occurred for a particular cohort of children in one region of the country. Girls born in the region during the famine had reduced growth rates compared to girls born in the same region at a different time or girls born at the same time but in a different region. No effect was found for boys (Akresh, Verwimp, and Bundervoet 2011). Similarly, in a panel analysis of children in Zimbabwe, children 12-24 months old during a 1994-1995 food shortage were 1.5 to 2 cm shorter on average than children who reached that age in a non-food shortage year (Hodginott and Kinsey 2001). Among communities in Ethiopia that were asked to directly report the months when food was relatively scarce, children exposed to more food-scarce months in-utero had significantly lower heights at age eight (Miller 2017).
Rainfall-based measures, however, have some advantages over non-rainfall based indicators. Rainfall data can assess the impact of small deviations without extreme events or self-reporting of food scarcity. As rainfall data increases in resolution and availability, rainfall measures can be increasingly tailored to specific household circumstances. The rainfall data used in this study is at the 0.05 degree resolution, allowing daily rainfall to be estimated at the household level. As rainfall data and rainfall-based measures improve, rainfall-based measures become increasingly useful in teasing out complex relationships between nutrition availability and health.

This study is part of a growing literature that recognizes that aggregate measures may mask heterogeneity in the rainfall-health relationship and explores this relationship using intra-season rainfall variables. In a study of children in Indonesia, rainfall was captured in three variables: monthly average, average positive monthly deviation from the historical mean, and average negative monthly deviation from the historical mean (Cornwell and Inder 2015). Although this specification allows for intra-season heterogeneity, it forces all positive and all negative deviations to have the same-signed effect regardless of the cropping period during which the rainfall occurred. In the rural subsample, only increases in monthly average rainfall significantly increased child HAZ (Cornwell and Inder 2015). A study in Mexico allowed harvest period rainfall to have a separate health effect by focusing solely on rainfall during the maize harvest months of September and October. In contrast to a positive rainfall-health relationship, they find that exposure to harvest rainfall more than 0.7 standard deviations above average significantly reduced child heights and increase stunting (Aguilar and Vicarelli 2011). Our study expands on previous work by specifying cropping-period specific rainfall shocks at planting, mid-season, and harvest that vary by household and child birthday.
II. Crop Yield Response to Rainfall

The crop-yield response to water varies over the course of the growing season (Doorenbos and Kassam 1979; Brown 2008; Steduto et al. 2012). For most crops, yield sensitivity to water requirements is relatively low in early and late growth periods and relatively high during flowering and yield formation. For example, the yield response of beans, an important food crop in Rwanda, to water deficit is four to five times larger during flowering and pod filling than during its vegetative and ripening periods. Yield for maize, another major food crop in Rwanda, is also relatively sensitive to water stress during flowering (Doorenbos and Kassam 1979).

The relationship between rainfall and yield is not always positive. Extreme rainfall can lead to waterlogging and aeration stress. As in crop stress from insufficient rainfall, aeration stress from excess rainfall can lead to crop yield reductions (Steduto et al. 2012).

Even in the absence of extreme rainfall events, there may be periods when less rainfall is beneficial. A period of little rainfall at harvest can improve maize yield by reducing grain water content (Barron et al. 2003). Comparably, for dry beans, a period of no rain 20 to 25 days before harvest is ideal (Doorenbos and Kassam 1979).

The difference in yield sensitivity to water requirements by crop development stage means that two seasons with the same total rainfall can have very different yield outcomes depending on how rainfall was distributed within the season (Brown 2008; HarvestChoice 2010). Thus, rainfall shock measures based on aggregating annual or growing season rainfall may miss important intra-seasonal variation.
To allow for intra-season cropping period differences in crop yield response in rural Rwanda, we divide each of Rwanda’s agricultural seasons into three periods: land preparation and planting, mid-season, and harvest. As shown in Figure 1, Rwanda’s first major agricultural season, which extends from February to July, is split into: land preparation and planting (February and March), mid-season (April and May), and harvest (June and July). Similarly, we split Rwanda’s other major agricultural season, which extends from August to January, into land preparation and planting (August and September), mid-season (October and November), and harvest (December and January).

[Figure 1 here]

Although exact timing of crop development stages will vary by plot, crop, and year, dividing each agricultural season into three common periods captures the key general differences in crop yield response: the land preparation and planting period when most crops are beginning their growth, the mid-season period when most crops are in their critical growth stages and are relatively more sensitive to water stress, and the harvest period when most crops are mature and some may benefit from a tapering off of rainfall.

In viewing the year in this way, it becomes possible to separate each month by its major cropping period. Based on the Rwandan cropping calendar, we assign each month to one of the three periods as follows: land preparation and planting (February, March, and August), mid-
season (April, May, October, and November), and harvest (January, June, July, September, and December). This specification is based primarily on the two major agricultural seasons.\footnote{The one exception to this is the minor season harvest in September, which we include in the harvest period as it occurs just before the onset of the year’s major lean season. We estimate a robustness specification that re-assigns September based on the major season cropping period.}

Using this specification, we can now analyze how the relationship between in-utero rainfall and child growth may vary according to the cropping period in which the rainfall occurs.

III. Theoretical Framework

In this paper, we analyze height-for-age z-score (HAZ) as an objective measure of child health. Self-reported assessments of health are prone to measurement error and this error may be correlated with health status (e.g., more health conscious parents may report more accurately and health consciousness is likely to positively affect a child's long-term health). In contrast to self-reported measures of wellbeing, the components of HAZ (height, age, and gender) are directly observable. Furthermore, as HAZ measures each child's height in relation to the distribution of children of the same age and gender, it provides an objective means of comparison and a clear measure of malnutrition. For example, the World Health Organization (WHO) defines stunting as a HAZ below minus two standard deviations (WHO 1997).

As height is a long-term measure of health, there are natural dynamics in the production process for child height. Strauss and Thomas (1998) and Maccini and Yang (2009) provide useful simple reduced forms for dynamic health production functions. Adapting their health production functions to the context of HAZ, we model a child's HAZ at time $t$ as:

$$ HAZ_t = f(H_0, X, N_{t-k}, ..., N_1, B_{t-k}, ..., B_1, R_{t-k}, ... R_1) $$

(1)
where time zero is the in-utero period of a child’s life which we define as the one year period before birth\(^5\), \(H_0\) is the height endowment at birth, \(X\) are time invariant demographic characteristics such as gender and ethnicity, \(N_{t-k},...,N_k\) are the flow of health inputs such as food intake (quantity) and dietary diversity (quality), \(B_{t-k},...,B_k\) are the flow of (potentially) time-varying infrastructure characteristics such as proximity of medical care and sanitation, and \(R_{t-k},...,R_k\) are the flow of other environmental conditions that may affect height for age such as the disease environment. Due to the long-term nature of height, there is an inherent lag in the effect of inputs on height (e.g., eating a good meal today will not influence a child's current height, but may have an effect on his or her future height).

A child’s initial height endowment is itself a function of initial conditions:

\[
H_0 = g(G, R_0, B_0)
\]  

(2)

where \(G\) are genetic characteristics such as parents' heights, \(R_0\) are the environmental conditions in-utero, and \(B_0\) are the infrastructure characteristics in-utero.

In this analysis, we are interested in estimating the following:

\[
\frac{\partial HAZ_t}{\partial H_0} \frac{\partial H_0}{\partial R_0}
\]  

(3)

This partial derivative measures the marginal effect of a change in environmental conditions while in-utero on a child’s current level of growth.

Seasonal heterogeneity would imply that the marginal effect given in equation (3) is not constant across the cropping year. In order to assess this potential heterogeneity, we allow the

\(^5\) The additional three months preceding pregnancy are included as a child’s health endowment can be influenced by the mother’s health pre-conception (Rocha and Soares 2015).
marginal effect given in equation (3) to differ by Rwanda’s cropping periods. Denoting the rainfall shocks in the land preparation and planting, mid-season, and harvest periods as \( R_0^1, R_0^2, \) and \( R_0^3 \) respectively, we can now conceptualize a separate marginal effect for each in-utero cropping period:

\[
\frac{\partial HAZ_t}{\partial H_0} \frac{\partial H_0}{\partial R_0^i} \forall i = 1,2,3 \tag{4}
\]

where: \( R_0^i \) is the deviation of the log of total rainfall in period \( i \) that the child experienced in-utero from the log of the historical average for that period. The equation for \( R_0^i \) is given by:

\[
R_0^i = \ln \left( \sum_{t=T-12}^{T-1} z_{it} * r_{ht} \right) - \ln (\bar{r}_{ih}) \ \forall i = 1,2,3 \tag{5}
\]

where \( T \) is the birth month of a child in household \( h \), \( z_{it} \) is an indicator variable equal to one if month \( t \) is included in cropping period \( i \) and zero otherwise, \( r_{ht} \) is the monthly rainfall (mm) that occurred within a 5 kilometer radius of household \( h \) in month \( t \), and \( \bar{r}_{ih} \) is household \( h \)'s long-run yearly average rainfall for cropping period \( i \) over the 1981-2017 time period.

For example, for a child born in October 2014, the harvest period rainfall would be the sum of the child’s household’s rainfall in December of 2013 and January, June, July, and September of 2014. This summation represents the total rainfall the child experienced in-utero during this cropping period. The in-utero shock measure is then the natural log of the average harvest period rainfall for the child’s household in all years from 1981-2017 subtracted from the natural log of the in-utero summation. This same process is repeated for the land preparation and planting and mid-season periods.
Due to differences in the three major underlying mechanisms (yield, mother’s labor supply, and the disease environment), we hypothesize that the signs and magnitudes of the rainfall shock effects on $H_0$ will differ by cropping period.

The crop-yield effect of rainfall may have offsetting effects by cropping period. In the land preparation and planting and mid-season periods, positive rainfall deviations are likely to improve crop yields. The ceteris paribus effect of this increase in crop yield will be to increase $H_0$. In the harvest period, however, positive rainfall deviations may have the opposite effect on crop yields as the additional rainfall may spoil crops (Barron et al. 2003; Leight, Glewwe, and Park 2015). Thus, the ceteris paribus effect of the decrease in crop yield from positive rainfall shocks in the harvest period will be to decrease $H_0$.

Rainfall deviations by cropping period may also have differing effects on the mother’s labor supply decision. In each period, there will be an indirect effect on a mother’s labor supply decision due to the change in harvest labor requirements. For example, a positive yield effect from positive rainfall shocks in the land preparation and planting period will increase harvest labor requirements. We abstract away from the indirect harvest labor effects in each period as we expect the yield effect to dominate. That is, the positive (negative) endowment effect from a yield increase (decrease) will offset any potential negative (positive) endowment effect from a mother supplying more (less) labor at harvest.

Therefore, the main period in which we expect the mother’s labor supply decision to impact child growth would be in response to rainfall shocks in the mid-season. Positive mid-season rainfall shocks are likely to promote weed growth, increasing labor requirements. If the mother increases her labor supply in response to this increase in weeding labor demand, the
additional strain on the child in-utero is likely to have a negative ceteris paribus effect on $H_0$ (Leight, Glewwe, and Park 2015). In contrast, a positive rainfall shock during the land preparation and planting or harvest periods is not likely to affect farm labor requirements other than through the yield effect.

In contrast to the other two mechanisms, the effect of rainfall on the disease environment is not likely to have different effects by cropping period. Regardless of the cropping period, a positive rainfall shock may worsen the disease environment by facilitating the transmission of water-borne diseases (Rocha and Soares 2015). The worsening of the disease environment due to a positive rainfall shock is expected to have a negative ceteris paribus effect on $H_0$.

[Table 1 here]

Table 1 provides a summary of the expected ceteris paribus endowment effects from each of the three main underlying mechanisms in each cropping period. Although we cannot identify the underlying mechanisms, this conceptualization assists in understanding the expected heterogeneity in the marginal effects. Furthermore, it provides us with a simple foundation for hypothesis tests on the directions of the overall marginal effects given in equation (4).

As the land preparation and planting and mid-season periods have offsetting mechanisms, the signs of their overall effects can provide insight into the dominant effect. For example, a positive mid-season effect would suggest that the yield effect dominates the negative mother’s labor supply and disease environment effects.

We expect rainfall’s effect on agricultural yields to be the primary driver of the effects on child growth as yield has the most direct link to nutrition availability. Therefore, the land
preparation and planting and mid-season effects are expected to be positive. Contrastingy, we hypothesize that the in-utero harvest period rainfall shock will be negative, as above average rainfall during this period may be detrimental to harvested output.

IV. Data

The household data used in this study come from a two round panel survey of households from eight districts across three provinces (Northern, Southern, and Eastern) in Rwanda. The surveys were conducted in 2014 and 2017. This unique dataset focuses on pregnant women and children under five years old. While not nationally representative, the sampling frame is a rural subset of three regions where concerns of food security and child malnutrition were identified as important issues.

The 2014 survey round used a three-stage cluster sampling method where the primary, secondary, and tertiary sampling units were the sector, village, and household respectively. A census was conducted in each of the 252 selected villages to collect basic information of all the households. Only households with a pregnant woman or child under five were eligible to be sampled for the survey (Peters et al. 2015).

The survey instrument was comprehensive, covering a wide array of household and individual characteristics. Along with each child’s weight, height, and gender, the survey also collected detailed child-specific information on nutrition and health.

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6 The survey was conducted as part of an impact evaluation of the International Potato Center’s Scaling Up Sweet Potato Through Agriculture and Nutrition (CIP-SUSTAIN) project.

7 The sampling frame was created with the support of YWCA and Imbaraga, two NGOs based in these areas that work on women’s and children’s health and food security issues.
The subsample of children for this analysis is children that were less than five in the first or second survey round. For this analysis, we use the anthropometric information that was collected for all children less than five in each sampled household.

Summary statistics for key variables are provided in Table 2. The mean and median HAZ in our sample are -1.57 and -1.64 respectively indicating that most of the children are below average height for age. This is not surprising given the rural, developing country context and highlights the relevance of this research for the study area. The rate of stunting in our sample is 39%, well above the expected rate of 2.3% in a healthy population (WHO 1997).

The rainfall data comes from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS). This publicly available dataset combines 0.05 degree satellite data with in-station data to provide daily rainfall estimates from January 1st 1981 to near present day (Funk et al. 2015).

For this analysis, the household’s current GPS location is used as the child’s primary location of residence in-utero. We estimate the average rainfall within five kilometers of each household with GPS coordinates for each day from January 1st, 1981 to December 31st, 2017. A five-kilometer radius captures the vast majority of household plots, as more than 85% of all plots were reported as being within an hour’s walk from the household’s dwelling. For the households in the sample with missing GPS coordinates, we estimate the average rainfall of all households with GPS in the same village for each day.

Table 2 lists summary statistics for the rainfall shock measures defined in equation 5. The average in-utero land preparation and planting, mid-season, and harvest rainfall shocks are 0.03,

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8 If the same child was under five and measured in both rounds, the second round measurement is used.
9 Children with HAZ more than six standard deviations in absolute value are removed from the sample as HAZ outside of this range are considered unreasonable and likely to be an outcome of measurement error (WHO 2011).
-0.016, and 0.023 respectively. When multiplied by 100, each measure can be approximately interpreted as the percent deviation above or below the historical average for the respective period.

[Table 2 here]

V. Empirical Strategy

Our main empirical specification is given by the following:

\[
HAZ_{ihvd} = R_{ih} \alpha + X_i \beta + c_v + t_d \gamma + \omega_i + u_{ihvd}
\]  

(6)

where \( HAZ_{ihvd} \) is the height-for-age z-score (HAZ) for child \( i \) in household \( h \) of village \( v \) and district \( d \), \( R_{ih} \) are the log-deviations in in-utero cropping period rainfall based on each child’s birthday and household GPS location, \( X_i \) are child-specific controls (gender, age, age squared, and month of birth fixed effects), \( \omega_i \) is a survey round indicator, and \( u_{ihvd} \) is the idiosyncratic error. As identified effects of in-utero rainfall on child growth are likely to be larger for younger (recently born) children than older children, the coefficients in \( R_{ih} \) are interacted with child age in months. All standard errors are clustered by village to account for spatial correlation.

By including a broad set of controls in our main specification, we seek to differentiate any in-utero rainfall effects from other spatial and temporal child growth determinants that may be correlated with rainfall outcomes. In particular, this identification strategy seeks to isolate the effects of in-utero rainfall deviations on child growth from the average conditions of children in similar circumstances and localities.

There are several econometric challenges in identifying the HAZ production function given in equation (1). Most of the health inputs a child receives will be subsumed in the error term. For example, it is not feasible to observe a child's entire diet over the course of his or her
lifetime. Since the observed health inputs are likely correlated with the unobserved health inputs, any included health inputs will be endogenously determined resulting in biased coefficient estimates in a standard OLS estimator. Similarly, we are unlikely to observe all the relevant factors in $X$, $G$, and $B$ that influence height. We address this econometric challenge using fixed effects and location-specific time trends.

The birth month fixed effects are included to account for child growth outcomes that vary according to birth timing in relation to the cropping seasons. For instance, children born during lean months are likely to have different child growth outcomes than children born in post-harvest months.

The village fixed effects, $c_v$, control for village location and other time constant village-level unobservables that may influence child growth and be correlated with rainfall deviations. For example, certain villages may be located in more mountainous terrain with little access to healthcare.

The district specific time trends, $t_d$, control for development paths that are heterogeneous by the child’s district. For instance, Rwanda’s districts are likely to develop at different rates and the average growth path of children will vary according to the level of development in the area of birth (Maccini and Yang 2009).

Another related potential estimation problem is serial correlation in log deviation in rainfall. If rainfall outcomes are serially correlated, then our estimated marginal effects could be driven by the effect of rainfall outcomes in other periods. We test for this via a robustness regression that includes additional rainfall shocks before a child’s in-utero period and find that
the in-utero period effects are robust to the inclusion of these shocks (Maccini and Yang 2009; Rocha and Soares 2015).10

VI. Results

Table 3 presents our main results. The column 1 regression tests the HAZ effect of the deviation of log total rainfall in the 12 months before birth from the historical average. The point estimate is positive, but not statistically significant from zero. As this sample of rural Rwandan households relies on rainfall for crop production, this suggests that, while the net annual rainfall effect may be positive, the wide confidence interval also indicates we cannot rule out that there may be no such effect. Another reason for these large standard errors may be that this aggregate, annual measure of rainfall is suppressing intra-year, seasonal heterogeneity in how rainfall at various times of the year would impact yields, and therefore also children’s health outcomes.

[Table 3 here]

When the in-utero rainfall effect is allowed to vary according to the cropping period in which it occurs, the rainfall shocks reveal intra-year differences in their impacts on child growth. As shown in column 2 in Table 3, above average in-utero rainfall in the land preparation and planting or mid-season periods has significantly positive effects on expected child growth outcomes. Relative to the land preparation and planting period, the magnitude of the effect on child growth is also qualitatively larger in the mid-season period, when crop yields are most sensitive to water stress, although this difference is not statistically significant.

10 Our specification does not control for unobserved household-level heterogeneity in child growth outcomes, such as family heritage and the household environment. We estimate a robustness regression with household fixed effects. This specification is restricted to the subsample of households with anthropometric measurements for at least two children under five. Results are qualitatively similar, but low in power due to the small sample size.
In contrast to the other cropping periods, rainfall deviations during key harvest months have the opposite effect on child health. Experiencing above average in-utero harvest rainfall has significantly negative effects on expected child growth outcomes.

These findings suggest that the annual measure is attenuated towards zero due to offsetting intra-seasonal effects by cropping period.

Furthermore, the significantly positive mid-season coefficient suggests that the positive yield effect dominates any negative effects of increased mother’s labor supply in response to increased farm labor requirements or of a worsened disease environment.

The magnitudes of these statistically significant cropping period coefficients have practical significance for the expected child growth outcomes in this subsample of children. A one standard deviation increase in in-utero rainfall during the land preparation and planting or mid-season periods is associated with a 0.27 standard deviation and 0.38 standard deviation increase in HAZ respectively. These effects represent 17% and 24% increases at the sample mean HAZ of -1.57. In the harvest period, a one standard deviation increase in rainfall reduces expected HAZ by 0.31 standard deviations, a decrease of 20% from the sample mean.

We also find statistically significant differences in the magnitudes of the cropping effects by child age cohorts. The in-utero rainfall effects are largest for infants, declining as children age. This decline is separate from the general decline in HAZ with age, which we also identify. These findings suggest that households may be able to compensate for the growth effects of in-utero rainfall even if they cannot fully offset the HAZ decline with age that is typical of the developing country context (Groppo and Kraehnert 2016).

These results are robust to redefinition of the cropping periods. As shown in Figure 1, a minor season harvest and major season land preparation and planting period both occur in
September. This is a key month, as it occurs just before the start of the major lean season. To test the sensitivity of the results to September’s cropping period assignment, we reassign September from the harvest period to the land preparation and planting period. The results are presented in column 3 in Table 3. This change has no statistical or practical effect on the mid-season and harvest period coefficients. The land preparation period coefficient increases in statistical and practical significance, but is still statistically indistinguishable from the mid-season coefficient.

Another concern with the main results is the possibility of serial correlation in rainfall outcomes driving the estimated effects. We test for this by controlling for the rainfall measures and their interactions for the 13-24 month period before birth. Column 4 in Table 3 presents the results for the annual rainfall regression. The in-utero annual rainfall measure decreases in magnitude and remains statistically insignificant.

As shown in column 5 in Table 3, the estimated cropping period effects do not appear to be driven by serial correlation in rainfall. When controlling for the same rainfall shocks in another year, the mid-season and harvest period rainfall effects remain statistically and practically similar to the base regression. The land preparation and planting coefficient remains qualitatively similar. None of the estimated 13-24 month rainfall coefficients for the land preparation and planting, mid-season, and harvest periods or their interactions with child age are statistically significant.

VII. Conclusion

This paper analyzes the effects of in-utero rainfall shocks in different cropping periods on child growth in rural Rwanda. We find that above (below) average in-utero rainfall in the land preparation and planting or mid-season periods significantly increases (decreases) expected child
height-for-age z-scores (HAZ). Contrastingly, above (below) average in-utero rainfall in the harvest period significantly decreases (increases) expected child HAZ.

Our findings show intra-seasonal heterogeneity in in-utero rainfall effects that attenuates the estimate of the annual in-utero rainfall effect towards zero. This helps explain the mixed findings of studies analyzing the relationship between rainfall and child health using annual or growing season rainfall measures.

These findings are consistent with variations in the crop yield effects of rainfall by crop development stage. Crops are generally more sensitive to water requirements during the mid-season flowering and yield formation periods relative to other development stages (Doorenbos and Kassam 1979). Similarly, the yield effect for rainfall is not always positive. For important Rwandan food crops such as dry beans and maize, reduced rainfall at harvest can improve yields by reducing moisture content (Doorenbos and Kassam 1979; Barron et al. 2003).

The estimated cropping period effects are robust to alternative definitions of the cropping periods, as well as the inclusion of rainfall measures from other periods to account for serially correlated rainfall.

This paper is subject to several limitations, such as the possibility of simultaneity caused by children with higher height-for-age being valued differently. The direction of this simultaneity is unknown as it depends on whether parents mitigate or reinforce differences in endowments. For example, Leight (2017) found that parents in Gansu Province, China mitigated endowment differences by investing more in the education of their children with relatively lower height-for-age. In the case of scarce health inputs in the rural Rwandan context, however, taller children may show more promise and therefore receive a higher relative share of health inputs
than shorter children (or vice versa). Future research is needed to understand such dynamics in parents’ response to negative (or positive) in-utero shocks to children.

Another limitation is our measurement of in-utero rainfall, which is only partially correlated with the actual rainfall experienced by the child in-utero. This classical measurement error will tend to attenuate our estimated coefficients (Wooldridge 2010). Maccini and Yang (2009) reduce attenuation by instrumenting the observed rainfall at the nearest weather station to each child with the observed rainfall at the next closest weather station(s). As this approach is not feasible with our rainfall data, which relies on a combination of satellite and weather station data, our empirical strategy will tend to underestimate the true in-utero rainfall effects.

Furthermore, our estimated cropping periods are constant across space and time. Actual cropping periods will vary with household cropping decisions and with the onset of rains. Here, we abstract away from these differences in order to estimate general cropping period effects that are not endogenous to household’s planting decisions. Future research is needed to better understand the dynamics between such decisions, rainfall, and child health outcomes.
References


Figure 1: Rwanda’s Season Calendar in a Typical Year

Legend: Land Prep. and Planting  |  Mid-Season  |  Harvest

Figure adapted from Famine Early Warning Systems Network (2017). The shade of the month indicates the cropping period assigned to it.
<table>
<thead>
<tr>
<th>Cropping Period:</th>
<th>Mechanism:</th>
<th>Hypothesized Overall Marginal Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield</td>
<td>Mother's Labor Supply</td>
</tr>
<tr>
<td>Land Preparation &amp; Planting</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Mid-Season</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Harvest</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
## Table 2: Descriptive Statistics

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height-for-Age Z-Score (HAZ)</td>
<td>-1.572</td>
<td>1.598</td>
<td>-5.980</td>
<td>5.610</td>
<td>-1.640</td>
</tr>
<tr>
<td>Deviation of log <strong>total</strong> rainfall in the 12 months before birth from historical average</td>
<td>0.017</td>
<td>0.106</td>
<td>-0.277</td>
<td>0.374</td>
<td>0.004</td>
</tr>
<tr>
<td>Deviation of log <strong>land preparation and planting period</strong> rainfall in the 12 months before birth from historical average</td>
<td>0.030</td>
<td>0.169</td>
<td>-0.368</td>
<td>0.481</td>
<td>0.016</td>
</tr>
<tr>
<td>Deviation of log <strong>mid-season</strong> rainfall in the 12 months before birth from historical average</td>
<td>-0.016</td>
<td>0.171</td>
<td>-0.395</td>
<td>0.531</td>
<td>-0.025</td>
</tr>
<tr>
<td>Deviation of log <strong>harvest period</strong> rainfall in the 12 months before birth from historical average</td>
<td>0.023</td>
<td>0.204</td>
<td>-0.606</td>
<td>0.480</td>
<td>0.049</td>
</tr>
<tr>
<td>Deviation of log <strong>land preparation and planting period (including September)</strong> rainfall in the 12 months before birth from historical average</td>
<td>0.060</td>
<td>0.143</td>
<td>-0.346</td>
<td>0.435</td>
<td>0.047</td>
</tr>
<tr>
<td>Deviation of log <strong>harvest period (excluding September)</strong> rainfall in the 12 months before birth from historical average</td>
<td>-0.027</td>
<td>0.237</td>
<td>-0.738</td>
<td>0.473</td>
<td>0.010</td>
</tr>
<tr>
<td>Child’s age in months</td>
<td>33.692</td>
<td>15.550</td>
<td>0</td>
<td>59</td>
<td>36</td>
</tr>
<tr>
<td>Child is female (1=yes)</td>
<td>0.499</td>
<td>0.500</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Survey Round Indicator (1=data from 2017)</td>
<td>0.551</td>
<td>0.497</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Child was born in January (1=yes)</td>
<td>0.100</td>
<td>0.299</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Child was born in February (1=yes)</td>
<td>0.082</td>
<td>0.275</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Child was born in March (1=yes)</td>
<td>0.089</td>
<td>0.285</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Child was born in April (1=yes)</td>
<td>0.085</td>
<td>0.279</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Child was born in May (1=yes)</td>
<td>0.092</td>
<td>0.290</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Child was born in June (1=yes)</td>
<td>0.085</td>
<td>0.278</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Child was born in July (1=yes)</td>
<td>0.081</td>
<td>0.273</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Child was born in August (1=yes)</td>
<td>0.079</td>
<td>0.269</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Child was born in September (1=yes)</td>
<td>0.068</td>
<td>0.251</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Child was born in October (1=yes)</td>
<td>0.072</td>
<td>0.258</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Child was born in November (1=yes)</td>
<td>0.074</td>
<td>0.262</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Child was born in December (1=yes)</td>
<td>0.094</td>
<td>0.292</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

Notes: 3,093 observations. Rainfall data from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS). Original data is daily, 0.05 degree resolution, from 1981-2017 (Funk et al. 2015). Child characteristics are from the 2014 and 2017 SUSTAIN survey (Peters et al. 2015). See data section for explanation of variables.
### Table 3: In-Utero Rainfall Effects on Child Growth (Height-for-Age Z-Score)

<table>
<thead>
<tr>
<th>Variables</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviation of log total rainfall in the 12 months before birth from historical average</td>
<td>1.546</td>
<td>0.960</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1.168)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deviation of log land prep. and planting period rainfall in the 12 months before birth from historical average</td>
<td>1.592**</td>
<td>2.560***</td>
<td>1.417</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.795)</td>
<td>(0.818)</td>
<td>(0.873)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deviation of log mid-season rainfall in the 12 months before birth from historical average</td>
<td>2.256***</td>
<td>2.033***</td>
<td>2.173***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.712)</td>
<td>(0.690)</td>
<td>(0.799)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deviation of log harvest period rainfall in the 12 months before birth from historical average</td>
<td>-1.539**</td>
<td>-1.556***</td>
<td>-1.903**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.705)</td>
<td>(0.500)</td>
<td>(0.795)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deviation of log total rainfall X child age in months</td>
<td>-0.016</td>
<td>-0.002</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.029)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deviation of log land prep. and planting pd. rainfall X child age in months</td>
<td>-0.037**</td>
<td>-0.049**</td>
<td>-0.031</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.017)</td>
<td>(0.020)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deviation of log mid-season rainfall X child age in months</td>
<td>-0.052***</td>
<td>-0.044***</td>
<td>-0.056***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.017)</td>
<td>(0.017)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deviation of log harvest period rainfall X child age in months</td>
<td>0.054***</td>
<td>0.047***</td>
<td>0.067***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(0.018)</td>
<td>(0.013)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Child is female (1=yes)</td>
<td>0.180***</td>
<td>0.187***</td>
<td>0.185***</td>
<td>0.186***</td>
<td>0.191***</td>
</tr>
<tr>
<td>(0.058)</td>
<td>(0.057)</td>
<td>(0.058)</td>
<td>(0.058)</td>
<td>(0.058)</td>
<td></td>
</tr>
<tr>
<td>Child’s age in months</td>
<td>-0.136***</td>
<td>-0.154***</td>
<td>-0.128***</td>
<td>-0.142***</td>
<td>-0.160***</td>
</tr>
<tr>
<td>(0.041)</td>
<td>(0.041)</td>
<td>(0.041)</td>
<td>(0.041)</td>
<td>(0.042)</td>
<td></td>
</tr>
<tr>
<td>Child’s age in months squared</td>
<td>0.001***</td>
<td>0.001***</td>
<td>0.001***</td>
<td>0.001***</td>
<td>0.001***</td>
</tr>
<tr>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>3,093</td>
<td>3,093</td>
<td>3,093</td>
<td>3,093</td>
<td>3,093</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.086</td>
<td>0.096</td>
<td>0.096</td>
<td>0.089</td>
<td>0.099</td>
</tr>
<tr>
<td>Number of villages</td>
<td>251</td>
<td>251</td>
<td>251</td>
<td>251</td>
<td>251</td>
</tr>
</tbody>
</table>

Robust standard errors clustered at the village level in parentheses. Significance: *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is height-for-age z-score. All regressions include birth-month fixed effects, district-specific time trends, village fixed effects, a survey round indicator, and an overall constant. Column (3) re-assigns September from the harvest period to the land preparation and planting period. Column (4) controls for the deviation in annual rainfall for the 13-24 months before birth and its interaction with child age. Column (5) controls for the three cropping period rainfall deviations for the 13-24 months before birth and their interactions with child age. See data section for a full explanation of variables.