Environment and Development Economics (2022), **27**, 20–39
doi:10.1017/S1355770X20000571

RESEARCH ARTICLE

Malnutrition pathway for the impact of in utero drought shock on child growth indicators in rural households

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(Submitted 10 November 2019; revised 05 July 2020; accepted 29 November 2020; first published online 8 March 2021)

Abstract

This paper evaluates the short-term health effects of in utero drought shock using repeated cross-section household data on Malawi. The main finding reveals that the effects of in utero harvest variability caused by rainfall shocks on child growth indices are driven by the deleterious effects of negative rainfall deviations, namely droughts. Negative rainfall deviation during the agricultural season prior to the gestational period of a child leads to a 21.8 per cent average local level reduction in age-standardized height scores, with the counterpart positive rainfall deviation having no apparent effect. The paper also uses harvest and consumption patterns to establish an important link between early-life malnutrition and growth serving as a precursor for the fetal period programming hypothesis in the literature. The direct impact of embryonic period shocks on growth provides supportive evidence on potential interaction between nutritional and environmental pathways.

Keywords: child growth; drought; in utero; nutrition

JEL classification: I12; I15

1. Introduction

1.1 Background

An extensive body of literature provides supporting evidence for the persistent effects of early life shocks – such as famine, disease outbreak and natural disaster – on long-term socioeconomic outcomes (Almond, 2006; Almond *et al.*, 2009; Almond and Currie, 2011; Gould *et al.*, 2011; Lehmann and Wadsworth, 2011; Sotomayor, 2013; Flores and Kalwij, 2014; Justino *et al.*, 2014; Caruso and Miller, 2015; Deuchert and Felfe, 2015; De Vreyer *et al.*, 2015). Another strand of literature provides evidence for medium- to long-term consequences of early life nutritional intake on human capital development, such as cognitive development, schooling outcomes, academic performance, labor market proficiency and socioeconomic outcomes; which include life achievements and satisfaction (Yamauchi, 2008; Alderman *et al*., 2009; Maccini and Yang, 2009; Maluccio *et al*., 2009; Neelsen and Stratmann, 2011; Ampaabeng and Tan, 2013; Dercon and Porter, 2014; Thai and Falaris, 2014; Bertoni, 2015). In this context, the short-term and long-term nutritional effects of growth gradients are characterized by early life health variables for children aged 0 to 59 months using standardized weight and height scores. These include standardized weight-for-height (WHZ), weight-for-age (WAZ) and height-for-age (HAZ) scores.

Covariate shocks in the sub-Saharan Africa (SSA) region are pervasive owing to the adoption of rain-fed agricultural practices for crop cultivation in this region, compared to developed societies where mechanized farming is widely accessible. While informal insurance mechanisms exist in SSA countries, the literature emphasizes that sale of assets and livestock are inefficient and suboptimal for consumption smoothing in periods of covariate shocks (Fafchamps *et al*., 1998; De Weerdt and Dercon, 2006; Kazianga and Udry, 2006; Islam and Maitra, 2012). Given this background, this paper assesses the impact of in utero rainfall shocks on children's growth outcomes in rural Malawi. It focuses on these because there is literature showing that these have persistent effects (see Hoddinott and Kinsey, 2001; Yamano *et al*., 2005; Alderman *et al*., 2006; Maccini and Yang, 2009; Neelsen and Stratmann, 2011; Ampaabeng and Tan, 2013; Dercon and Porter, 2014; Bertoni, 2015).

This paper focuses on substantiating an important human capital conceptual framework related to short-term effects of in utero climate shocks and contributes to an extensive body of research in developing countries. Previous research includes evidence from India (Banerjee and Maharaj, 2020); Jamaica (Beuermann and Pecha, 2020) and the Andean region (Molina and Saldarriaga, 2017). In this paper, we complement the existing literature by providing evidence from the SSA region. Results from the paper contribute to the growing evidence of the vulnerability of rural households to exogenous weather patterns imposing short- to long-term costs on the welfare of individuals. Whilst the short-term effects may persist due to a lack of sustainable safety net programs for agricultural households, the indirect long-term effects of exposure to early life shocks seem to be similarly prevalent. The focus on the nutrition pathway provides tractability of proposals regarding a policy intervention framework to tackle exposure to extreme weather events in the early stages of life. This will particularly ensure a focus of attention on addressing malnutrition faced by pregnant women and babies in developing countries during droughts.

1.2 Conceptual framework

The fetal origin hypothesis within the critical programming framework underpins the intergenerational transmission of shock impacts. A considerable body of empirical evidence demonstrates the persistent nature of impacts from gestation events, whereby disease or socioeconomic outcomes are associated with a period of gestation and continue to affect an individual for a very long time after birth. Another set of evidence confirms the latency of effects, wherein effects manifest in the form of chronic health conditions or, subsequently, birth outcomes in later life. However, the inherent genetic programming component of the impacts of early life shocks has received only minor attention. This is usually related to an activation of specific genetic responses to historical-critical period events including environmental shocks and captured by direct weather shocks in the lead up to the pre-pregnancy period. This element of the dynamics of early life events can be captured early enough by evaluating the impacts of the prenatal environment on child health outcomes.

The short- to long-term impacts of the early life events after a child's delivery are interconnected between gestational development progress and contemporaneous early life events. The vital body organs of a child are formed within the first 1,000 days of life. Perfect formation of the organs during infancy is fundamental for successful milestones in the subsequent stages of life. Defective formation may lead to disability or emergence of distorted socioeconomic outcomes within the medium- to long-term. However, this does not constitute part of the intergenerational transmission component of the impact of early-life events associated with the gestation period. Events occurring during the gestation period are important in consideration of the intergenerational pathway for the impacts of early life events and isolating the pathways may help with designing intervention programs for pregnant women. Shocks within the gestation and other early life periods can be divided into nutrition on the one hand; and disease environment, extreme weather events, natural disasters and infrastructural decadence among others on the other hand. While most of these factors are interrelated, it is important to disentangle the role of each for policy intervention purposes. In this regard, it may be important to disentangle the factors connecting the trajectory of children's health to weather, in order to effectively deploy resources.

Early life weather events/shocks contribute to the fetal/childhood developmental pathways from food/nutrition, disease and direct environmental viewpoints. These are mutually non-exclusive weather conditions and could range from before to immediately after birth. The nutrition pathway for the impact of weather shocks is mainly captured indirectly. This is interpreted as low harvest realizations during the period of pregnancy which is characterized by deviation of seasonal local rainfall pattern from the historical average of the same locality. In the current setting, the deviation or extreme rainfall shocks in the immediate past agricultural season are a proxy for harvests.[1] This approach is considered in a reduced form methodology to characterize the food security/nutrition of mothers during pregnancy. This approach is complemented by the association of rainfall pattern and household food consumption composition to clearly link health stunting to food security/nutrition.

In rural areas of low-income countries, the disease environment is closely linked to variability in weather events due to unsustainable and weak institutional frameworks and inefficient regulatory bodies. For instance, flood events increase the possibility of blocked drainage, subsequently leading to mosquito infestation that could trigger malaria. Also, a flood could lead to a dirty and muddy environment causing dirty water flows into streams[2] that could lead to severe diarrheal illnesses such as cholera. Another dimension of a direct environmental hypothesis is the harsh weather which is equivalent to investigating the impacts of the natural disaster on birth outcomes in the literature (Currie and Rossin-Slater, 2013). This pathway can be isolated using extreme temperature shocks, namely heat waves and/or cold waves during the gestation period.

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[1] The variation in the rainfall pattern simultaneously captures household to community level harvests. This may help to capture variations in seasonal food security and income. Where applicable, the instrumental variable approach may be specified to capture exogenous variation of each of the variables to plausibly measure a causal impact.

[2] The local stream remains the main source of household drinking water for many rural households in low-income countries.

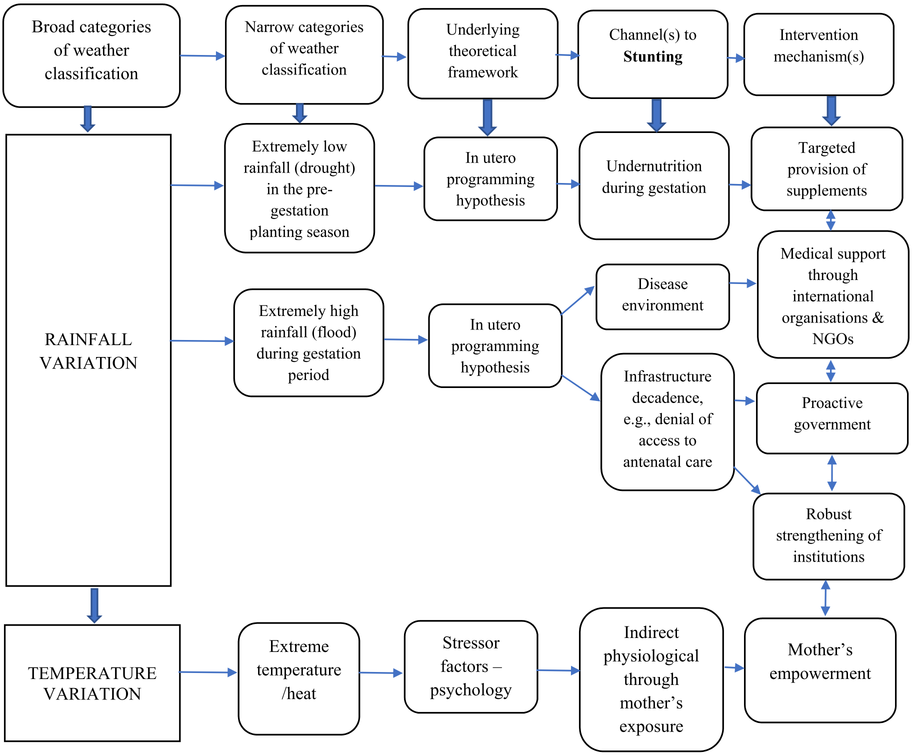

Figure 1. Pathways on the effect of weather shocks on stunting.

Lastly, another intergenerational pathway can be modelled through mothers' human capital prior to gestation on child health outcomes. This underlines the programmed physiological mechanism of weather shocks. Separate models are required for in utero shocks of babies and mothers' pre-pregnancy nutrition to appropriately disentangle the impact of babies' in utero shocks in the overall critical programming model. Figure 1 provides a summary of the weather shock pathways on child stunting outcomes.

Baseline results for linear rainfall deviation show that a -0.2 log-point in utero harvest shock results in a decrease of 8.2 per cent in HAZ, while increasing the average likelihood of moderate and severe stunting by 8.7 and 13.2 per cent, respectively. The effects of seasonal harvest in utero shocks are attributed to negative rainfall deviation (drought), while positive rainfall deviation (flood) coefficient estimates are small and weakly significant.

The remainder of the paper is organized as follows. Section 2 describes the household data and summarizes the main variables while section 3 unveils the empirical strategy for evaluating the impact of in utero shock on infant welfare, as indicated by various measures. Section 4 presents the main results and highlights potential pathways while section 5 discusses the results and provides concluding remarks.

2. Data and summary statistics

We use three rounds of the Malawi Integrated Household Survey (IHS), later named the Malawi Living Standard Measurement Study-Integrated Survey on Agriculture

(LSMS-ISA), conducted by the World Bank. The rounds cover the survey years 2004, 2010 and 2013 which are pooled together to obtain repeated cross-section data. The household-level data is then matched to rainfall data on terrestrial precipitation. The number of observations matched with rainfall data from the aforementioned household surveys are 11,280 households (49,066 individuals), 3,246 households (15,582 individuals), and 4,000 households (20,076 individuals), for the three years, respectively. We utilize the panel structure of the data from years 2010 and 2013 for supplementary results in the paper. Our study leverages an important component of the Malawi household surveys, which reveals the locality of birth of the individuals interviewed. We determine the place of birth of children as the mother's location during pregnancy from the individual level data. We combine this data with the information on date of birth of children to precisely measure exposure to shocks and focus our analysis on mothers who have never migrated from their place of birth. Given the above details, our estimation approach is based upon a minor assumption that mother's place of permanent residence is the place of gestation and place of birth of the children. This is consistent with a stable living environment for the period of pregnancy. Previous research (Comfort, 2016) provides a caveat to the reported results similar to the assumption of this paper by matching gestation shocks to events within 9 months prior to the month of birth of children. We construct rainfall shocks for the agricultural harvests available to a mother during pregnancy, according to the locality of her residency, in order to examine the in utero specific impact of nutritional shocks on childhood growth trajectory.

2.1 Weather data

We use terrestrial precipitation data provided by the University of Delaware (UDel) Center for Climatic Research to construct local rainfall shocks. UDel's rainfall data are monthly precipitation estimates on a 0.5° by 0.5° grid covering terrestrial areas across the globe for the period 1900–2017 (version 5.01).[3] Although the data repository is available at the UDel Center for Climatic Research, the compilation is credited to Matsuura and Willmott (2017). Our main source of collation of locality rainfall estimates is the GPS coordinates provided for each local community in the LSMS-ISA data. We match each respective community to the four nearest weather stations for estimates of historical rainfall data in order to obtain rainfall data for the years spanning 1900 and 2017.[4]

2.2 Constructing rainfall deviation and shocks

Rainfall deviation is measured as the deviation of the local rainfall from a combination of both historical and projected seasonal rainfall average in the locality. We combine 10-year seasonal historical rainfall before the year of birth of each child with future rainfall projections until seasonal rainfall for the year 2017. Rainfall deviation (shocks) computed this way reflects unanticipated weather events where it will be nearly impossible for households to pre-empt rainfall variations within the medium to long term. The monthly rainfall measures are aggregated for each community on the basis of agricultural season, which is November to October of the following year. Similar to Maccini

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[3] Recent papers that have used the UDel rainfall data for the purpose of empirical investigation include Chaurey (2015) and Rocha and Soares (2015).

[4] Further details about the formation of the precipitation measure by birth month and locality of birth are available from the author upon request.

and Yang (2009), Björkman-Nyqvist (2013) and Rocha and Soares (2015), amongst others, rainfall deviation is constructed as the natural logarithm of the current agricultural season minus the historical average for the same locality,

$$\text{Rainfall Deviation}_{ct} = \ln \text{Rainfall}_{ct} - \ln \ \overline{\text{Rainfall}}_c, \tag{1}$$

where Rainfall_{ct} indicates the seasonal precipitation for the current agricultural season within the locality for community c, and $\overline{\text{Rainfall}_c}$ is the average historical seasonal precipitation of the community over previous and future seasonal periods. Thus, Rainfall Deviation_{ct} is defined as the deviation between the natural logarithm of the total precipitation in the 12 months of the agricultural season of focus and the natural logarithm of the corresponding norm seasonal precipitation at the community level. This approach to locality precipitation dynamics essentially denotes a percentage deviation from mean value and is measured in log-points deviation (Maccini and Yang, 2009).

We construct the disaggregated measures for the variations in precipitation measures for localities in the following way:

$$\begin{aligned}&\text{Negative Rainfall Deviation}_{ct}\\ &\quad = \left\{\begin{array}{c}\text{Absolute measure of the difference if rainfall deviation within a}\\ \text{locality is lower than the norm,}\\ \text{0 if rainfall within locality is higher than the norm}\end{array}\right\}\end{aligned} \tag{2}$$

$$\begin{aligned}&\text{Positive Rainfall Deviation}_{ct}\\ &\quad = \left\{\begin{array}{c}\text{Actual difference if rainfall deviation within a}\\ \text{locality is higher than the norm,}\\ \text{0 if rainfall within locality is lower than the norm}\end{array}\right\}\end{aligned} \tag{3}$$

2.3 Summary statistics: child growth measures and household characteristics

Our analysis focuses on agricultural households within rural Malawi. The summary statistics in table 1, section A can be compared to the international reference group, which has an expected mean Z-score of 0 for all normalized growth indices. In general, Z-scores two standard deviations below the reference are associated with retardation in the case of HAZ,[5] and this is referred to as stunting. The standardized distribution of HAZ for children between 6 and 59 months of age in our sample is displayed in figure 2. This graphical illustration presents a clearer picture of the stunting distribution.[6] This distribution is highly skewed to the left, implying that growth retardation is prevalent among children of this category in rural Malawi. Section A further provides the stunting associated with focus observations of 6,484 children by gender and age in months. Approximately 39 per cent of children in this sample are stunted, i.e.. their HAZ scores are below −2 standard deviations.

The gender composition of stunting across children aged 6 to 59 months for boys and girls represent 42 to 36 per cent respectively. This subtle differential $\iota\nu$ stunting ratios may not necessarily reflect differential exposition to nutrition shocks in early life. This is because additional factors responsible for retardation in growth have not been

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[5] HAZ is obtained using a STATA command developed by Leroy (2011).

[6] See figures A1 and A2 in the online appendix for corresponding distributions for boys and girls.

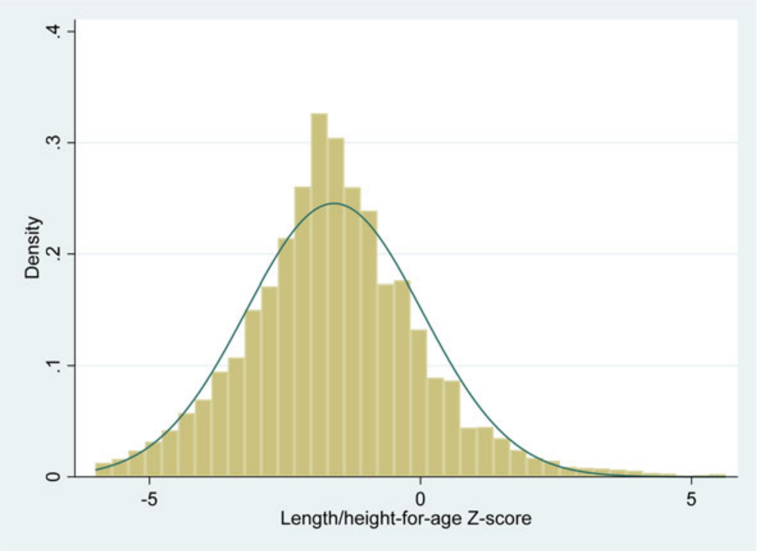

Figure 2. Height-for-age Z scores distribution for children in Malawi (2004–2013).

Table 1. Summary statistics for children aged 6–59 months and shock composition

Variables	Mean	Std. Dev.	Observations
Section A: Children stunting indicator			
All	0.392	0.488	6,484
Gender			
Boys	0.421	0.494	3,205
Girls	0.363	0.481	3,279
Age in months			
6–12	0.173	0.379	750
13–24	0.383	0.486	1,443
25–36	0.486	0.500	1,347
37–48	0.429	0.495	1,598
49–59	0.384	0.487	1,346
Section B: Locality Shocks			
Rainfall deviation	0.036	0.198	6,484
Negative rainfall deviation	0.065	0.099	6,484
Positive rainfall deviation	0.101	0.128	6,484

Notes: Observations are restricted to households that participated in farm cultivation in the previous agricultural season and were living in rural areas of Malawi during the survey periods. Rainfall deviation, Negative rainfall deviation and Positive rainfall deviation are equivalent mean values for the variables constructed in equations (1)–(3) respectively.

captured in the summary statistics. Children between the ages of 6 to 12 months are the least stunted group in our sample. A possible explanation for this pattern is the time lag required for the realization of the effect of nutrition shock on health outcomes. This group is followed by children aged 13 to 24 months, while those between 49 to 59 months indicate the reference point[7] for stunted children in our sample. The most prevalent groups of stunted children fall within their third and fourth years in reverse order. The reason for a further decline in the stunting ratio within the fifth year is an important question in relation to the dynamics of early life shocks and short-term health outcomes.

Section B of table 1 presents the summary statistics for locality rainfall shocks. This reveals that there is an average of 0.04 log point deviation from the aggregate norm rainfall across the localities in the study. Regarding disaggregation of rainfall shocks, an average of 6.5 and 10.1 per cent account for negative and positive rainfall deviations respectively across the communities.

3. Empirical strategy

The existing body of literature uses reduced form specification to convey the impacts of shocks on children's health status using anthropometric indices (Hidrobo, 2014; Rabassa *et al.*, 2014; Thai and Falaris, 2014). We model the impact of in utero shocks using rainfall deviation in a similar context.[8] Equation (4) presents the reduced form specification for the impact of rainfall deviation on HAZ and stunting indicators. Our main identification strategy exploits variations in rainfall deviation within the context of harvest as an important determinant of nutrition within a locality. We also include the birth order indicator for each child aged 6 to 59 months within a household and control for household adaptation strategies adopted to cushion the impact of shocks in utero on children's health outcomes.

3.1 Linear rainfall deviation

$$\text{Child Growth}_{ict} = \alpha_c + \gamma_t + \phi_a + \varphi_{k-1}\text{Rainfall Deviation}_{c,k-1} + X_i'\theta_x + Z_{ct}'\theta_z + \varepsilon_{ict}, \tag{4}$$

where Child Growth$_{ict}$ represents HAZ for children aged 6 to 59 months for an observation i in community c for a survey round t. The subscript t only indicates the survey year in which a child was measured rather than the measurement of the same child in different surveys (repeated cross-section). In addition to HAZ, moderate and severe stunting are also treated as outcome variables in equation (4). Rainfall Deviation$_{c,k-1}$ represents the percentage deviation of rainfall from the norm in community c for the agricultural season prior to the year of birth k. Note that rainfall deviations are measured to coincide with in utero period harvests for each individual. Hence, we extrapolate the effects of rainfall shock with the primary focus on the in utero harvest dynamics and how these relate to the outcome variables. α_c in equation (4) is the community fixed effect and γ_t is the

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[7] Children between 49 to 59 months present a median for the stunting distribution among the five age groups captured in our analysis.

[8] We restrict our framework to only rainfall deviations (shocks) affecting period of gestation which invariably affects in utero nutrition for the fetus. This framework is different from that in Thai and Falaris (2014) where early life shocks for three consecutive agricultural seasons are considered.

interview season based on the year of interview fixed effect.[9] Also, the cohort fixed effect ϕ_a is used in our model to account for the effect of responsive patterns from inter-age group in our model. φ_{k-1} is the parameter of interest on our focus variable, in utero community rainfall variation (Rainfall $\text{Deviation}_{c,k-1}$). φ_{k-1} measures the rainfall dynamics of the last agricultural season before a child's birth. This measure determines the nutrition available to the mother during pregnancy, which is believed to underscore the fetal programming conditions. This may have potential effects on both the short-term and adulthood outcomes of an individual.

Seasonal temperature at the community level is used to control for the role of heat on fetal health, which may impact the child's growth in the short term and even his or her welfare in adulthood (Hancock *et al.*, 2007; Wilde *et al.*, 2014; Barreca *et al.*, 2015; Isen *et al.*, 2017). Temperature has a linear relationship in the preferred specification. X and Z consist of a vector of individual, household and community-level covariates, which are adopted as controls. In addition to household controls, we include other adaptation resources available to households in the past twelve months. These include free food items, particularly maize, free supplements, asset valuation, credit or loans and access to agricultural extension support within this period. The community-level controls also include the availability of Savings and Credit Cooperative Organisations (SACCO) within the locality to help capture village-level support. The error term (ε_{ict}) accounts for unobserved time-variant community characteristics not captured by the trend and unobserved individual characteristics. Insofar as the variables in the error term are orthogonal to an individual child's exposure to harvest shock during pregnancy, the estimates of the effect of rainfall shock on child outcomes will be unbiased. The error term of the model is assumed to be identically and independently distributed (iid) across communities but correlated within a community; hence, standard errors are clustered by community. Our identification strategy is based on the differential impact of the exposure of children to in utero shock across communities. Similar to Hidrobo (2014), we use birth order indicators in households with multiple births and fetus-specific exposure to the exogenous shock during the in utero period in our regression framework.

3.2 Low and high rainfall shocks

Equation (5) exploits the differential impacts of negative and positive in utero rainfall shock measures constructed in equations (2) and (3) on the anthropometric outcomes of children.

$$\begin{aligned}\text{Child Growth}_{ict} = \alpha_c + \gamma_t + \phi_a + N_{k-1}\text{Negative Rainfall Deviation}_{c,k-1} \\ + P_{k-1}\text{ Positive Rainfall Deviation}_{c,k-1} + X_i'\theta_x + Z_{ct}'\theta_z + \varepsilon_{ict}, \quad (5)\end{aligned}$$

where coefficients N_{k-1} and P_{k-1} represent the differential impacts of seasonal rainfall deviations, representing drought and flood shocks, on child anthropometric growth outcomes.

Using pooled cross-section data, identification occurs through children of similar age across communities, which may constitute shock-exposed and non-exposed cohorts. In other words, groups that may be exposed to either low or high rainfall shocks in the

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[9] It is important to note that a variation in month of interview by year fixed effect is alternated during the estimation process with no apparent difference to the estimates of the preferred model.

disaggregated framework. This identification strategy is synonymous with the differential exposure to months of crisis in alignment with the month of birth (see Hidrobo (2014) for further details). The identifying assumption for φ_{k-1}, N_{k-1} or P_{k-1} to be unbiased is that, in the absence of a shock, the average outcome across communities whose children are born the same number of months apart would be the same.

4. Results

4.1 Main results

4.1.1 The effect of linear in utero rainfall deviation on HAZ

The main regression results suggest that harvest deviation during pregnancy may have a significant impact on a child's growth trajectory between the ages of 6 and 59 months. This is revealed in the reduced form coefficient estimates of the growth patterns from exposure to rainfall deviation before birth, reported in tables 2 and 3 for HAZ and the stunting variables, respectively. Columns 1–8 of table 2 report the effect of in utero *rainfall-determined* harvests on the growth trajectories of children within the community by systematically controlling for outlined covariates and fixed effects.

We focus our attention on table 2, column 8 (hereafter referred to as the baseline specification) which includes temperature, community fixed effects, month-of-birth fixed effects, interview season by year fixed effects and cohort fixed effects in addition to household and community-level controls. The in utero rainfall estimate for our baseline specification is 0.656. This indicates that a −0.2 log-point rainfall shock prior to a harvest during pregnancy decreases the child's standardized height score by approximately 0.13 standard deviations at the community-level average height. Within the context of the mean HAZ score of our sample, the corresponding effect is an 8.2 per cent decrease in the standardized height of children in the locality.[10]

4.1.2 Stunting results

The results in table 3 suggest that the in utero harvest effects of health performance are deeper by having a substantial impact on the proportion of stunted children at the community level, similar to Giles and Satriawan's (2015) findings. Rainfall deviation in our reference model in column 8 presents a −0.170 estimate for the moderate stunting indicator (significant at the 1 per cent level). This indicates that a −0.20 log-point locality rainfall shock leads to a reduced harvest during the time of pregnancy which ultimately increases the average likelihood of moderate stunting by 3.4 percentage points. In comparison with the baseline mean stunting ratio of 0.392 in our sample, this estimate indicates an 8.7 per cent increase in the likelihood of stunting. In the same vein, rainfall deviation coefficient estimates for severe stunting in the preferred model of section B of table 3 result in an estimate of −0.115. While this is slightly lower than the impact on moderate stunting, the overall effect is still large. A −0.20 log-point locality rainfall shock leads to a reduced harvest which increases the average likelihood of the severe stunting ratio by 2.3 percentage points. Given that the mean severe stunting ratio in our sample is 0.174, the in utero rainfall shock estimate results in a 13.2 per cent increase in the severe stunting rate. The results in tables 2 and 3 could, taken at face value, be literarily interpreted as representing similar effects across negative and positive precipitation shocks. Disaggregating negative and positive rainfall deviations reveals that while

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[10] The effect is statistically significant at the 1 per cent level and fairly large compared to other estimates in related literature including Hidrobo (2014), Rabassa *et al.* (2014) and Thai and Falaris (2014).

Table 2. The impact of in utero harvest variability due to linear rainfall deviation on height-for-age z-scores for children in Malawi

	Dependent variable: HAZ							
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Linear rainfall deviation	0.563*** (0.113)	0.701*** (0.113)	0.699*** (0.114)	0.681*** (0.115)	0.678*** (0.114)	0.679*** (0.115)	0.642*** (0.117)	0.656*** (0.116)
Temperature								0.065*** (0.025)
Constant	−1.616*** (0.004)	−1.858*** (0.073)	−2.622*** (0.487)	−2.452*** (0.482)	−1.622*** (0.560)	−2.585*** (0.512)	−2.620*** (0.511)	−4.273*** (0.805)
R^2	0.266	0.279	0.286	0.289	0.297	0.289	0.290	0.293
Community FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	Yes	Yes	Yes	–	–	–	–
Month of Birth FE	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Interview Month × Year FE	No	No	No	No	Yes	No	No	No
Interview Season × Year FE	No	No	No	No	No	Yes	Yes	Yes
Cohort FE	No	No	No	No	No	No	Yes	Yes
Community controls	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Household and adaptation controls	No	No	No	Yes	Yes	Yes	Yes	Yes
Observations	6,484	6,484	6,484	6,484	6,484	6,484	6,484	6,484

Notes: This table presents coefficient estimates for the impact of a linear in utero agricultural season's rainfall deviation on HAZ for 6,484 observations. All estimations focus on households that participated in farm cultivation in the previous agricultural season and were living in rural areas of Malawi during the survey periods. This is consistent with the literature on the impact of weather shocks on welfare outcomes in developing countries. Rainfall deviation is constructed as the deviation of the natural log of the community rainfall measure during the pregnancy stage of a child's life from the corresponding average locality level rainfall measure from both historical and future perspectives. Yearly precipitation measures refer to the agricultural season's rainfall for a locality, measured as the total precipitation for wet and dry seasons, corresponding to November-April and May-October respectively. All estimations include birth order dummies and are clustered at the community level, with a total of 590 communities. Community-level controls include indicator variables for access to roads, measured by year-round road usability, and quality of road infrastructure, measured by ease of road passage, the presence of a daily market within the community, the presence of a weekly market within the community, the presence of a phone call center within the community, the presence of chemist within the community, the presence of a government-affiliated health clinic within the community, the availability of a medical practitioner in the government medical center, sales of subsidized bed nets within the community, the presence of a bank or SACCO within the community, a representative at the parliament from the community, and school quality. Other community-level controls include average number of months roads are usable for buses and lorries in a year, number of teachers in government primary schools, number of teachers in government secondary schools, numbers of pupils in government primary schools, number of pupils in government secondary schools, number of private primary schools, number of private secondary schools, distance to community health clinic, community industry, and the number of churches and mosques. Household controls include wealth in terms of household non-agricultural assets in Malawi Kwacha and household demographic characteristics, such as household size, gender of the head of household, average household age, and the education and occupational categories of the head of household. In addition to household controls, we include other adaptation resources available to households in the past twelve months. These include free food items, particularly maize, free supplements, asset valuation, credit or loans and access to agricultural extension support within this period. Individual controls mainly consist of individual demographic characteristics, namely child's age and gender. Robust standard errors (clustered at the community level) are reported in parentheses. *** represents significance at the 1% level.

Table 3. The impact of in utero harvest variability due to linear rainfall deviation on stunting in children in Malawi

	Dependent variables: child stunting indicators							
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Section A: Moderate stunting								
Linear rainfall deviation	−0.146*** (0.037)	−0.161*** (0.036)	−0.163*** (0.036)	−0.156*** (0.036)	−0.155*** (0.036)	−0.156*** (0.036)	−0.167*** (0.037)	−0.170*** (0.037)
Temperature								−0.014* (0.008)
Constant	0.397*** (0.001)	0.453*** (0.022)	0.561*** (0.139)	0.454*** (0.138)	0.302* (0.164)	0.490*** (0.149)	0.479*** (0.150)	0.839*** (0.247)
R^2	0.224	0.228	0.235	0.239	0.245	0.239	0.241	0.244
Section B: Severe stunting								
Linear rainfall deviation	−0.104*** (0.031)	−0.105*** (0.031)	−0.107*** (0.031)	−0.105*** (0.031)	−0.103*** (0.031)	−0.105*** (0.031)	−0.113*** (0.032)	−0.115*** (0.032)
Temperature								−0.010 (0.007)
Constant	0.178*** (0.001)	0.205*** (0.017)	0.340*** (0.089)	0.308*** (0.092)	0.185 (0.118)	0.326*** (0.102)	0.319*** (0.103)	0.573*** (0.191)
R^2	0.184	0.187	0.192	0.194	0.198	0.195	0.195	0.198
Community FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	Yes	Yes	Yes	–	–	–	–
Month of Birth FE	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

(*continued*)

Table 3. Continued

	Dependent variables: child stunting indicators							
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Interview Month × Year FE	No	No	No	No	Yes	No	No	No
Interview Season × Year FE	No	No	No	No	No	Yes	Yes	Yes
Cohort FE	No	No	No	No	No	No	No	Yes
Community controls	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Household and adaptation controls	No	No	No	Yes	Yes	Yes	Yes	Yes
Observations	6,484	6,484	6,484	6,484	6,484	6,484	6,484	6,484

Notes: This table presents linear probability model coefficient estimates of the effect of in utero rainfall shock on moderate and severe child growth stunting indices in sections A and B respectively for 6,484 observations. Moderate stunting and severe stunting refer to the ratio of children with HAZ below −2 and −3 standard deviations respectively. All estimations include birth order dummies and are clustered at the community level, with a total of 590 communities. See the notes for table 2 for additional details and a list of the community and household control variables. Robust standard errors (clustered at the community level) are reported in parentheses. ***,* represent significance at the 1% and 10% levels respectively.

Table 4. The impact of in utero harvest variability due to negative and positive rainfall deviations on HAZ-scores and stunting for children in Malawi

	HAZ	Stunting	Severe stunting
Variables	(1)	(2)	(3)
Negative rainfall deviation	−1.732*** (0.381)	0.233** (0.100)	0.132* (0.077)
Positive rainfall deviation	−0.044 (0.251)	−0.129* (0.073)	−0.103* (0.060)
Temperature	0.065*** (0.025)	−0.014* (0.008)	−0.010 (0.007)
Constant	−4.115*** (0.810)	0.830*** (0.248)	0.570*** (0.191)
R^2	0.294	0.244	0.198
Observations	6,484	6,484	6,484

Notes: This table presents coefficient estimates for the impact of in utero harvest variability due to low and high rainfall shocks on HAZ and stunting indices for 6,484 observations. Negative rainfall deviation is measured as absolute value of the difference between the seasonal precipitation level and the norm if the seasonal rainfall level is lower than the norm; zero otherwise. On the other hand, Positive rainfall deviation is measured as the actual rainfall difference to the norm if the seasonal rainfall level is higher than the norm; zero otherwise. Each column is a separate regression of the preferred model of tables 2 and 3, presented above, including temperature and controls. The regressions also include the community fixed effect, the month of birth fixed effect, the interview season by year fixed effect, cohort fixed effect and birth order dummies. See the notes to table 2 for additional details and a list of community and household control variables. Robust standard errors (clustered at the community level) are reported in parentheses. ***,* represent significance at the 1% and 10% levels respectively.

negative deviations result in a negative impact, positive deviations do not necessarily result in a positive impact (table 4).

4.1.3 Disaggregated rainfall shocks

Coefficient estimates of negative and positive rainfall deviations in table 4, representing drought and flood shocks, reveal an asymmetric pattern with respect to the two major components of the effect of harvest variability due to rainfall shock on child growth trajectories. Our results suggest a stronger impact for drought shock on average child growth measures in the short term, while flood shock has a considerably weaker effect. While drought coefficient estimates persist for separately estimated models across gender where girls are more impacted than boys, the flood estimates become weaker and statistically insignificant (see online appendix table A1). Incidences of in utero period harvest reductions caused by low rainfall shock decrease HAZ by 1.732 standard deviations (which is significant at 1 per cent). This estimate translates into an average 21.8 per cent decrease in HAZ when a small harvest caused by low rainfall shock occurred during pregnancy, without any corresponding effect for a large harvest caused by high rainfall shock. A similar pattern is observed for stunting outcomes. In sum, as is clear from the apparent reinforcement of low rainfall shock in our coefficient estimates, these results can be interpreted as meaning that the rainfall shock effect previously reported in tables 2 and 3 are mainly driven by drought shocks. Due to concerns about potential endogeneity regarding reported results in tables 2–4, we use panel data for the years 2010 to 2013[11] to provide complementary results. This panel consists of 1,292 households. Table

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[11] LSMS-ISA survey rounds for years 2010 and 2013 include follow-up of the same households and individuals.

A2 (online appendix) provides coefficient estimates of the impact of rainfall patterns on HAZ using household fixed effect and other controls highlighted in table 2. The results in table A2 present the disproportionate impact of negative rainfall deviation which corroborates the pattern previously reported in table 4.

4.2 Potential pathways for the impact of rainfall patterns on child growth

4.2.1 Nutrition

While any of the aforementioned channels in section 1 may be responsible for long-term welfare outcomes, HAZ has been predominantly linked to the nutritional pathway.[12] However one cannot overlook the disease environment at the time of birth. A clear departure of the current study from the literature is to showcase the nutrition pathway as a link between rainfall and child growth. In addition to this, we estimate a model using birth-specific precipitation patterns to investigate a direct environmental linkage of rainfall shocks to the short-term growth trajectory indices of children in rural Malawi.

We exploit the agricultural data provided for rural household units in Malawi's LSMS-ISA survey to provide robust evidence to corroborate the nutrition pathway story indicated in tables 2–4. We combine datasets from both household and agricultural questionnaires to empirically prove the argument of this paper by showing a robust association between rainfall deviation and household-level harvest/food security measures. Table A3 in the online appendix shows that there is a statistically significant positive association between household-level harvests and above average rainfall measure. Although the table consistently shows a positive statistically significant association between high rainfall and agricultural harvests, the coefficient estimates remain larger for the low rainfall components in both panels A and B which report results for repeated cross-section and panel data respectively. Likewise, table A4 (online appendix) shows a negative relationship between food consumption score[13] (from reduced agricultural harvests) and low rainfall, and a positive relationship between food consumption score (from excess agricultural harvests) and high rainfall. These patterns are consistent with a priori theoretical expectation of the association between rainfall variation/shocks and harvests/food security measures in the literature.

4.2.2 Other environmental pathways

So far, the results outlined in section 4.1 indicate that the nexus between weather and child health is nutrition. Additional pathways for the impact of in utero shocks on child growth measures could also be purely environmental in nature. This includes water scarcity and the disease environment. To explore this potential linkage, we explore an individual's month-of-birth in relation to their gestation period and trimester level

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[12] HAZ is an integral part of anthropometric indices used to measure nutritional health status of children by the World Health Organisation.

[13] Food consumption score is computed following the World Food Program (WFP) guidelines and aims to capture both dietary diversity and food frequency; it is the weighted sum of the number of days the household ate foods from eight food groups in the last week. The score is calculated based on the sum of weighted number of days in the last week the household ate food from eight food groups: (2 × number of days of cereals, grains, maize grain/flour, millet, sorghum, flour, bread and pasta, roots, tubers, and plantains) + (3 × number of days of nuts and pulses) + (number of days of vegetables) + (4 × number of days of meat, fish, other meat, and eggs) + (number of days of fruits) + (4 × number of days of milk products) + (0.5 × number of days of fats and oils) + (0.5 × number of days of sugar, sugar products, and honey). Spices and condiments are excluded. It has a maximum value of 126.

Table 5. The impact of time of birth-referenced rainfall deviation on HAZ and stunting in Malawi

	HAZ	Stunting	Severe stunting
Variables	(1)	(2)	(3)
Rainfall deviation			
0–12 months before birth	0.130 (0.138)	0.112*** (0.040)	−0.005 (0.034)
Temperature	0.052** (0.026)	−0.019** (0.008)	−0.008 (0.007)
Constant	−3.986*** (0.827)	0.951*** (0.252)	0.545*** (0.192)
R^2	0.289	0.242	0.195
Observations	6,484	6,484	6,484

Notes: This table presents estimates of rainfall deviation with reference to the exact month of birth of a child. This is different from the use of patterns of harvest variability due to rainfall for shock computations in our main results. Deviations are constructed as log-deviation from the norm, exactly as constructed in Rocha and Soares (2015). Each column is a separate regression of the preferred model of tables 2 and 3, presented above, including temperature and controls. The regressions also include the community fixed effect, the year fixed effect, the interview season by year fixed effect and cohort fixed effect. See tables 2 and 4 above for a list of controls and more notes. Robust standard errors (clustered at the community level) are reported in parentheses. ***,** represent significance at the 1% and 5% levels respectively.

rainfall deviation of children to unravel the non-nutritional effects of rainfall shocks on child growth progression in rural Malawi. While our objective differs, this approach aligns with a prominent focus in the literature on examining the impact of in utero shocks on childbirth outcomes and infant mortality rates (Rocha and Soares, 2015). We follow Rocha and Soares (2015) in the construction of accumulated rainfall deviation from the historical rainfall pattern in the same months and the same locality prior to an individual's birth. It is important to emphasize that this measure of rainfall deviation cannot be linked to nutrition, as it is devoid of the harvest mechanisms within each village. As such, Rocha and Soares (2015) link the impact of shock on birth weight and infant mortality in their study to water scarcity in the semiarid Brazilian municipalities.

Tables 5 and 6 report estimates of time-of-birth referenced and trimester-level rainfall impacts on the growth trajectories of children within a locality. The results in table 5 reveal no persistent evidence in support of a direct impact of year of birth rainfall shocks on the standardized height indices of children in our sample. However, trimester-bound results in table 6 provide robust evidence in support of impacts within the *embryonic* stage of gestation that is not available for both *fetal* and *perinatal* stages. These heterogeneous results complement considerable evidence with respect to the fragile nature of the fetus during the formative months and the need to guide against shock exposure in that period. The proximity of the effects to harvest seasons also symbolizes potential interaction between the environmental and nutrition pathways that is yet to be highlighted in the literature.

4.3 Scope for future research

One limitation of our study is the possibility of confounding omitted factors. While rainfall shocks may affect the fetus during gestation as a result of the harvests from previous agricultural seasons, other omitted factors at the time of pregnancy may play an important role in the nutritional status of mothers exposed to shocks within the rural area. We include some controls in our regression to account for household adaptation factors

Table 6. The impact of trimester-level rainfall deviations on HAZ and stunting in Malawi

	HAZ	Moderate Stunting	Severe Stunting
Variables	(1)	(2)	(3)
First trimester (embryonic)	0.073*** (0.028)	−0.025*** (0.008)	−0.017** (0.007)
Second trimester (fetal)	0.005 (0.026)	−0.002 (0.008)	−0.008 (0.006)
Third trimester (perinatal)	0.021 (0.029)	−0.011 (0.008)	−0.006 (0.007)
Temperature	0.047* (0.026)	−0.009 (0.008)	−0.004 (0.007)
Constant	−3.644*** (0.851)	0.632** (0.257)	0.392* (0.204)
R^2	0.292	0.244	0.198
Observations	6,410	6,410	6,410

Notes: This table presents coefficient estimates for the impact of trimester level rainfall shock on the growth trajectories of 6,410 children between the ages of 6 and 59 months. Each column is a separate regression of the preferred model of tables 2 and 3, presented above, including temperature and controls. The regressions also include the community fixed effect, the year fixed effect, the interview season by year fixed effect and cohort fixed effect. See tables 2 and 4 for a list of controls and more notes. Robust standard errors (clustered at the community level) are reported in parentheses. ***,**,* represent significance at the 1%, 5% and 10% levels respectively.

and intervention programs. Nevertheless, other factors that specifically enhance or distort mothers' welfare, not directly factored into our econometric specification, may bias our results. Other exogenous factors include food prices in the communities which may have a direct effect on a household's food consumption patterns, thereby affecting pregnant women. Our findings would be more compelling if food pricing dynamics during the pregnancy period could be factored into our models. However, the lack of adequate data limits the scope of this paper in fully identifying pricing across communities. Whilst there are some limitations of the study, results highlighted in sections 4.1 and 4.2 provide a strong indication of the impact of nutrition shock on early life health outcomes.

In general, the results highlight the need for intervention. Short-term cushions such as emergency aid or social security measures can mitigate the damages during the 'critical' stage of development, providing long-term benefits. Short-term fluctuations in weather during gestation can have long lasting health effects on children. This damage can be greatly reduced by providing future intervention programs that cushion the negative impacts of adverse shocks in SSA.

5. Discussion and conclusion

This paper examines the dynamics of in utero harvest variability due to weather shocks on the nutritional growth trajectories of children in rural Malawi. The article contributes to the literature in two major ways. First, the study adopts a disaggregated rainfall shock framework, in contrast to the linear rainfall shock specifications used in the existing literature for evaluating both the short-term and long-term effects of weather shocks (Maccini and Yang, 2009; Rabassa *et al.*, 2014; Thai and Falaris, 2014). Second, the paper pays particular attention to establishing the nutritional pathway in addition to identifying additional pathways linking in utero shocks to child growth trajectories, using an evidence-based approach. Using both repeated cross-section and panel data structures from World Bank household surveys in Malawi, we find that in utero harvest variability linked to rainfall shocks affects age standardized height scores and the associated faltering indices of children aged 6 to 59 months. More importantly, our disaggregated shock specification reveals that the effect is driven by low rainfall shock.

Our baseline results presented in tables 2 and 3 show that negative (positive) rainfall deviation decreases (increases) children's standardized height scores. That is, reduced harvest during the in utero period, caused by a −0.2 log-point rainfall shock, results in an average decrease of 8.2 per cent in children's standardized height scores. Correspondingly, the relative impacts of in utero harvest variability due to linear rainfall shock on moderate and severe stunting rates are 8.7 and 13.2 per cent, respectively. The disaggregated rainfall shock specification on standardized height scores and stunting indicators shows that the effect of in utero small harvest due to low rainfall shock incidence is dominant, whereas high rainfall shocks resulting in large harvests during pregnancy have no apparent effect on child growth measures. An incidence of low rainfall shock decreases HAZ by roughly 21.8 per cent, with no corresponding effect for an incidence of high rainfall shock. This asymmetric pattern is replicated for moderate and severe stunting where high rainfall coefficients are weakly significant.

Historical rainfall regimes in Malawi have witnessed disproportionately more droughts than floods in the past. Hence, our findings may be viewed in consideration of predominantly low rainfall relative to high rainfall weather variation in Malawi. Also, drought shocks may have a relatively greater impact on welfare outcomes than flood shocks in rural Malawi. This may be due to the fact that irrigation systems for mitigating the impact of drought can be quite expensive to manage and technical to handle. In contrast, excessive rainfall may not necessarily diminish agricultural output in this environment. The asymmetric nature of our results with respect to the impact of in utero low rainfall shocks reinforces the agricultural dependence nature of rural households for nutrition. In the same vein, the role of flooding with regard to agricultural productivity for rural households is unclear, as it mostly leads to displacement and is more common in urban areas.

Another perspective of the contribution of this paper is on the welfare effects of in utero nutritional deficiencies (Wu *et al*., 2004; Zhu *et al*., 2006; Abu-Saad and Fraser, 2010). Policy action in this area would help support women during pregnancy, also potentially helping to address the high rate of maternal mortality through the same framework (Comfort, 2016). More importantly, the childhood and adulthood welfare outcomes of fetuses and newborns can be protected by ensuring that pregnant women take in sufficient nutrition for the children's sustainable growth and long-term welfare protection. This evidence complements numerous other results documented in the literature for the achievement of an effective development strategy after the sustainable development goals (SDGs) era for rural households in the developing countries. This is possible through direct and targeted intervention programs from international agencies, non-governmental organizations (NGOs) and corporate organizations where the local governments may lack appropriate response mechanisms.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1355770X20000571.

Acknowledgements. I would like to thank Martin Foureaux Koppensteiner for his comments. I am grateful to James Rockey and Juan Rud for their suggestions on the initial drafts of the paper. I thank Charles Chakanza (National Statistical Office of Malawi) for the prompt approval of access to Malawi Integrated

Household Survey (IHS) data by the World Bank when it was requested prior to making the data available in the public domain. I express my profound gratitude to the editors of this journal and three anonymous referees for providing helpful comments that undoubtedly improved the quality of the paper during the peer review process. The usual disclaimer applies.

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Cite this article: Abiona O (2022). Malnutrition pathway for the impact of in utero drought shock on child growth indicators in rural households. *Environment and Development Economics* **27**, 20–39. https://doi.org/10.1017/S1355770X20000571