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Maternal Undernutrition in Adolescence and Child Human Capital Development Over the Life Course: Evidence from an International Cohort Study

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Adolescence has been highlighted as a period when environments are critical for the human capital development of women, and thus of their children, but evidence on this from low- and middle-income countries is scarce. We estimate the effect of mother's adolescent undernutrition on offspring growth and development from infancy through adolescence using data from an international cohort study in Ethiopia, India, Peru and Vietnam, and instrumental variables estimation that employs rainfall shocks during mother's adolescence as instruments for mother's nutritional status. We find a positive and significant effect of mother's adolescent nutritional status on child height-for-age in infancy that persists through to adolescence, and evidence that this may manifest mainly through a biological channel. Our results also support a significant impact of rainfall shocks during mother's early adolescence on mother's adult height and child growth from infancy to adolescence. We find no significant effect of mother's adolescent nutritional status and rainfall shocks during mother's adolescence on child achievement tests scores, however.

I. INTRODUCTION

Economic literature on the process of human capital formation through the life cycle highlights the existence of critical and sensitive periods when investments and environments are particularly effective in fostering the acquisition of skills (Cunha and Heckman 2007; Heckman 2007). The identification of these periods is therefore important for the design of interventions that promote human capital. Although early life has been highlighted as a critical period for the development of human capital, relatively little is still known on the extent to which compensation at a later stage of life can remedy earlier deficits (Rutter 1998; Almond and Currie 2011).

In low- and middle-income countries, child undernutrition, usually indicated by poor growth also known as stunting, is very prevalent and is considered as one of the major threats to human capital development (Grantham-McGregor *et al*. 2007; Prendergast and Humphrey 2014). Studies from both the biomedical and economics literatures suggest that growth failure is largely determined during the first 1000 days since conception, with limited potential for catch-up growth thereafter. This leads to an intergenerational cycle of poor growth and development, where women who were stunted in childhood remain stunted as adults and tend to have stunted offspring (Martorell and Zogrone 2012; Currie and Vogl 2013).

Some have argued that adolescence, a period when growth velocity is high, presents an opportunity for catch-up growth and remediation of early nutritional deficits, particularly for girls (Case and Paxson 2008; Georgiadis and Penny 2017). Although there is some supporting evidence (Steckel 1987; Prentice *et al*. 2013), this claim is not yet well-established (Van den Berg *et al*. 2014; Das *et al*. 2017), and little is known about the long-run and intergenerational implications of maternal nutrition during adolescence (Akresh *et al*. 2012, 2017).

This is important as in low- and middle-income countries, undernutrition in adolescence is one of the most prevalent and primary risks to the survival, health and development of young women (WHO 2012; Das *et al*. 2017), with potential implications for the growth and development of the next generation (Black *et al*. 2013). Moreover, existing studies have the following limitations. First, they produce evidence on the implications for offspring's health outcomes, but not for offspring's cognitive development. Second, they do not produce evidence on the extent to which impacts persist over the offspring's life course, which is important to understand the extent to which the responsiveness of child outcomes to interventions is constrained by earlier maternal circumstances (Martorell and Zogrone 2012). And third, they document correlations between maternal undernutrition and child outcomes—and not causal effects—that cannot produce clear implications for policy.

This paper addresses these limitations and makes three contributions to the existing literature. Our first contribution is that we estimate the effect of maternal undernutrition in adolescence on offspring growth and cognitive achievement from infancy to adolescence using data from an international cohort study in Ethiopia, India, Peru and Vietnam. Our empirical strategy addresses bias in estimation arising from the endogeneity of mother's nutritional status through instrumental variables employing rainfall shocks during mother's adolescence as instruments for mother's adolescent nutritional status. To our knowledge, this is the first study identifying the effects of maternal undernutrition in adolescence on different dimensions of the offspring's human capital, including health and cognitive skills, and how these evolve over the offspring's life course from early childhood through middle adolescence.

Our second contribution is that we investigate potential channels through which the effect of maternal adolescent undernutrition on child growth and development manifests. Finally, our third contribution is that we examine the impact of rainfall shocks during the mother's adolescent years on maternal adult height and child growth, and cognitive achievement from infancy to middle adolescence. This allows us to provide additional new evidence of the long-run and intergenerational impacts of environmental insults during adolescence, an area that has received little attention in the literature, as existing studies focus on the impacts of shocks during early childhood (Maccini and Yang 2009; Currie and Vogl 2013).

We find a positive and significant effect of maternal adolescent nutritional status, as measured by height, on child nutritional status at age 1 year that persists through to age 15 years. Our analysis further suggests that this effect may operate primarily through a biological channel, reflecting a direct intergenerational transmission of undernutrition, and persists mainly because child growth in early years strongly predicts growth in subsequent years. We also find a significant negative effect of rainfall shocks during the period when mothers were between 12 and 13 years old on maternal adult height across countries. This could be explained by the fact that higher rainfall is associated with an increase in the prevalence of infectious diseases; this reduces absorption of nutrients by the body over a period that may coincide with the timing of peak height velocity during the pubertal growth spurt in low-income settings (Eckert *et al*. 2009; Das *et al*. 2017). Moreover, we find that these shocks have a negative and significant effect on child nutritional status over the life course, particularly in Peru and Vietnam. Our analysis also suggests that this effect does not manifest through altering parental investments or socioeconomic status, and operates through early child growth. Nevertheless, we do not find a significant effect of maternal nutritional status and rainfall shocks during mother's early adolescence on child cognitive achievement test scores.

Overall, our findings have important policy implications and suggest that interventions that aim to improve the nutritional status of girls during early adolescence may contribute to breaking the intergenerational cycle of undernutrition in low- and middle-income countries.

The remainder of the paper is organized as follows. Section I presents our empirical model and estimation strategy. Section II discusses the data and presents descriptive statistics of the variables used in our analysis. Section III presents the estimation results, and Section IV concludes.

I Empirical Model and Estimation Strategy

We estimate the effect of maternal undernutrition in adolescence on child human capital outcomes at different ages from infancy to adolescence using the specification

$$HC_{ia} = \beta_0 + \beta_1 MN_i + \boldsymbol{\beta}'_2 \boldsymbol{CH_i} + \alpha_i + \varepsilon_{ia}, \tag{1}$$

where HC_{ia} is a measure of child i's human capital at age a, that is, nutritional status, measured by child's height-for-age Z-score, or cognitive achievement, measured by an achievement test score; MN_i stands for child i's maternal nutritional status in adolescence; $\boldsymbol{CH_i}$ denotes a vector of maternal characteristics and other factors influencing child human capital that are determined prior to mother's adolescence; α_i denotes unobserved child-specific time-invariant factors; and ε_{ia} is an error capturing the influence of unobserved factors that vary with child's age on child's human capital.

Equation (1) is a conditional demand for child human capital, where conditioning is on mother's adolescent nutritional status that is endogenous in the decision-making problem (Glewwe and Miguel 2008; Georgiadis 2017).[1] Following Glewwe and Miguel (2008), equation (1) can be used to estimate the total effect of mother's nutritional status in adolescence on child human capital. This reflects a direct (biological) effect, manifesting through the child human capital production function, and an indirect (behavioural) effect, operating through the level and quality/productivity of other inputs to the child human capital production function that may be influenced by mother's nutritional status. The direct effect of mother's adolescent nutritional status on child health reflects that mother's nutritional status during adolescence may be crucial for her nutritional status during pregnancy and lactation that biologically determines child nutritional status during this prenatal and postnatal period as well as in subsequent periods (Martorell and Zogrone 2012). Moreover, given the link between child nutrition and brain development in early life, this may further support a direct effect of maternal nutrition on child cognitive development (Prendergast and Humphrey 2014; Glewwe *et al*. 2001). Indirect effects of mother's undernutrition in adolescence on child human capital may manifest through lower level and quality of investments in child human capital. This may be due to mother's lower human capital (Strauss and Thomas 1998; Schick and Steckel 2015) that is associated with lower labour productivity and income, as well as parenting skills (Furstenberg *et al*. 1989; Francesconi 2008).

Estimating equation (1) by OLS is expected to yield biased and inconsistent estimates of the effect of interest. This is because MN_i, which partly reflects the maternal health endowment, is expected to be correlated with child health and cognitive endowments, subsumed in α_i, as well as with unobserved time-varying determinants of child human capital realised prior to mother's adolescence, subsumed in ε_{ia}. Another source of bias in the OLS estimator of β_1 in equation (1) may also arise from measurement error in maternal adolescent nutritional status, normally captured by adolescent growth (change in height), which is expected to partly reflect genetic variation unrelated to nutrition. The latter is expected to be correlated with genetic variation in child height-for-age, the standard measure of child health and nutritional status used in the literature (Glewwe and Miguel 2008).[2] This makes it difficult to infer the extent to which the OLS estimate of β_1 reflects an intergenerational transmission of undernutrition and the extent to which it reflects an intergenerational genetic transmission of height.

We address the above estimation problems through instrumental variables (IV) using rainfall shocks during mother's adolescence as instruments for mother's adolescent nutritional status. Rainfall shocks, defined as deviations from locality long-run trends, are expected to be valid instruments for maternal adolescent nutritional status, as they are expected to be uncorrelated with child endowment in α_i, and with unobserved factors determined prior to mother's adolescence, subsumed in ε_{ia}, because they are unanticipated prior to adolescence. They are also expected to be uncorrelated with measurement error in maternal and child nutritional status arising from genetic variation in maternal and child height, respectively.

Rainfall shocks during mother's adolescence are also expected to address bias arising from another source of measurement error present in our case, as due to data availability (see the next section for details), we use maternal adult height as an indicator of mother's nutritional status in adolescence. In particular, maternal adult height can be expressed as the sum of height at the beginning of adolescence and growth during adolescence.[3] The latter is the actual measure of adolescent nutritional status and the former is similar to measurement error, which is expected to be uncorrelated with rainfall shocks in adolescence.

Rainfall shocks during adolescence are hypothesized to impact nutrition and growth through two channels. The first is a disease channel, as higher than average precipitation leads to an increase in the incidence of diarrheal diseases and results in lower absorption of nutrients by the body and growth faltering (Ramani *et al.* 2017; Thiam *et al.* 2017). The second is an income channel, which is expected to be relevant mainly in rural contexts, as somewhat higher than average rainfall is strongly linked to agricultural productivity and income (Skoufias and Vinha 2012; Dell *et al.* 2014). This channel is expected to lead to a positive relationship between rainfall shocks and human growth (Skoufias and Vinha 2012).

If the income channel is the main channel through which the impact of rainfall shocks on growth manifests, then the exclusion restriction required for identification may be violated, as rainfall shocks may impact child human capital through channels other than maternal nutrition. We investigate this as part of our analysis presented in Section III.

We also complement IV estimation with an alternative strategy, which allows us to gauge the effect of maternal growth in adolescence and child human capital, and is based on OLS estimation of the reduced-form relationship linking rainfall shocks and child outcomes (Angrist and Krueger 1999). On the one hand, this approach offers indirect evidence of the relationship between maternal adolescent undernutrition and child human capital, but on the other hand, it is not plagued by several of the limitations of IV, including potential violation of the exclusion restriction, weak instruments, and misleading inferences due to low power (Angrist and Krueger 1999; Young 2020).

We investigate the channels via which maternal undernutrition impacts child outcomes through performing mediation analysis by extending equation (1) to include (direct or indirect) measures of parental investments observed after adolescence and prior to the measurement of child outcomes. Comparison of coefficient estimates of MN_i between models with and without mediators allows us to infer the extent to which the impact of maternal undernutrition in adolescence on child human capital manifests through a behavioural channel. We note, however, that this exercise can only be suggestive of causal channels, as it does not address the endogeneity of mediators, which is very challenging considering the number of mediators examined. Thus results of our mediation analysis should be interpreted with caution.

II Data and Descriptive Statistics

The data used in our analysis are from Young Lives, an international cohort study of childhood poverty in Ethiopia, India (the states of Andhra Pradesh and Telangana), Peru and Vietnam. Young Lives has followed over time around 2000 children in each country born in 2001/2, collecting information through five surveys in 2002, 2006, 2009, 2012 and 2015, when children were around 1, 5, 8, 12 and 15 years old, respectively.[4]

The study collects rich information on a range of child characteristics and outcomes as well as characteristics of the primary caregiver, who in most cases is the child's biological mother, and the locality in which the child's household resides (for details, see Barnett *et al.* 2013; Crookston *et al.* 2013).

Nutritional status for children at different ages was measured by height-for-age Z-scores (HAZ scores) calculated using the 2006 WHO standard for children younger than 5 years old (WHO 2007) and the 2007 WHO reference for children older than 5 years (de Onis *et al.* 2007). Supine length at age 1 year, and heights at ages 5, 8, 12 and 15 years were measured to 1 mm using standardized length boards and stadiometers. As discussed in the previous section, maternal nutritional status was measured using maternal height in cm, which was collected once, in 2006 (Round 2), when all mothers were adults (between 21 and 48 years old).

Descriptive statistics of child HAZ scores and maternal adult height across countries and for the pooled sample are presented in Table 1. The table also presents descriptive statistics for other child and parental characteristics used in our analysis, either as controls, such as child age and gender, or as mediators, such as measures of parental human capital and socioeconomic status and investments on child health.[5]

The sample for which descriptive statistics are reported includes children with non-missing HAZ scores or non-missing test scores at all rounds. Extreme values of child HAZ scores (greater than 6 in absolute value) (de Onis *et al.* 2007) at any age are also treated as missing. In order to maximize the estimation sample, we imputed missing values of mediating variables (prevalence 0.004% to 9%)—there were no missing values for the control variables—and we included dummies for imputed values in estimated specifications.

Table 1 suggests that child HAZ scores have improved slightly except of India and that mother's average height is the highest in Ethiopia and the lowest in Peru.

Cognitive development of younger cohort children was assessed at ages 5, 8, 12 and 15 years using quantitative achievement tests. Tests included the quantitative component of the Cognitive Developmental Assessment (CDA) at age 5 years and a mathematics test at ages 8, 12 and 15 years. The quantitative component of the CDA aims to assess a child's understanding of notions such as few, most, half, many, equal, a pair, etc. In particular, it requires children to indicate which one of a set of pictures fits the description in each of 15 statements, such as 'Point to the plate that has few cupcakes' (Cueto *et al.* 2009). The mathematics test includes 29 items[6] on counting, number

TABLE 1
DESCRIPTIVE STATISTICS OF OUTCOMES AND CHARACTERISTICS OF YOUNGER COHORT CHILDREN AND THEIR MOTHERS

	Ethiopia	India	Peru	Vietnam	All countries
Mother's adult height (cm)	158.76	151.45	149.98	152.16	152.98
	(6.20)	(6.11)	(5.45)	(5.90)	(6.77)
Child HAZ 1y	−1.49	−1.29	−1.27	−1.13	−1.29
	(1.83)	(1.48)	(1.27)	(1.24)	(1.47)
Child HAZ 5y	−1.44	−1.65	−1.53	−1.36	−1.49
	(1.11)	(0.99)	(1.10)	(1.02)	(1.06)
Child HAZ 8y	−1.19	−1.44	−1.15	−1.11	−1.22
	(1.12)	(1.04)	(1.03)	(1.06)	(1.07)
Child HAZ 12y	−1.45	−1.44	−1.03	−1.05	−1.24
	(0.99)	(1.03)	(1.09)	(1.15)	(1.09)
Child HAZ 15y	−1.35	−1.46	−1.15	−1.02	−1.24
	(1.11)	(0.97)	(0.88)	(0.89)	(0.98)
Proportion of correct answers in CDA test 5y	0.59	0.67	0.70	0.70	0.66
	(0.21)	(0.18)	(0.18)	(0.18)	(0.19)
Proportion of correct answers in maths test 8y	0.23	0.42	0.49	0.66	0.45
	(0.19)	(0.22)	(0.20)	(0.21)	(0.26)
Proportion of correct answers in maths test 12y	0.39	0.46	0.56	0.51	0.48
	(0.22)	(0.23)	(0.19)	(0.18)	(0.22)
Proportion of correct answers in maths test 15y	0.35	0.36	0.43	0.48	0.40
	(0.17)	(0.17)	(0.18)	(0.22)	(0.20)
Male	0.53	0.54	0.50	0.51	0.52
	(0.50)	(0.50)	(0.50)	(0.50)	(0.50)
Age of child (months) in Round 1	11.68	11.82	11.53	11.67	11.68
	(3.57)	(3.48)	(3.52)	(3.16)	(3.43)
Household wealth index 1y	0.21	0.41	0.43	0.43	0.37
	(0.17)	(0.20)	(0.24)	(0.21)	(0.23)
Mother's schooling (years)	2.89	3.65	7.85	6.76	5.29
	(3.76)	(4.42)	(4.38)	(4.01)	(4.64)
Father's schooling (years)	4.85	5.59	9.08	7.59	6.78
	(4.20)	(5.03)	(3.82)	(3.94)	(4.59)
Urban location 1y	0.39	0.24	0.74	0.18	0.38
	(0.49)	(0.43)	(0.44)	(0.39)	(0.49)
Expenditure on child's health in last 12 mth 5y	64.63	402.36	82.61	230.36	197.75
	(46.67)	(297.83)	(53.84)	(145.56)	(218.68)
Child's dietary diversity score in last 24 h 5y	4.81	5.79	7.86	6.84	6.32
	(1.59)	(1.55)	(1.59)	(2.00)	(2.04)
No. of meals consumed by child in last 24 h 5y	4.38	5.00	4.85	4.64	4.72
	(0.84)	(1.09)	(1.01)	(1.16)	(1.06)
Rainfall shock mother's 10y (cm)	0.10	−0.27	−0.39	5.58	1.29
	(11.36)	(13.88)	(14.57)	(33.06)	(20.47)
Rainfall shock mother's 11y	−0.25	−0.53	0.29	0.99	0.13
	(11.09)	(15.03)	(15.66)	(28.07)	(18.71)
Rainfall shock mother's 12y	−0.23	−0.18	−0.56	−0.18	−0.29
	(11.60)	(15.39)	(15.12)	(28.07)	(18.74)
Rainfall shock mother's 13y	0.54	−0.99	0.21	0.28	0.01
	(11.56)	(15.26)	(15.01)	(28.68)	(18.93)

TABLE 1
CONTINUED

	Ethiopia	India	Peru	Vietnam	All countries
Rainfall shock mother's 14y	−0.09	0.03	0.35	−0.76	−0.12
	(12.57)	(16.49)	(16.68)	(28.25)	(19.52)
Rainfall shock mother's 15y	−0.31	−1.04	0.83	−0.69	−0.31
	(11.01)	(13.72)	(17.42)	(29.62)	(19.43)
Rainfall shock mother's 16y	0.18	−0.02	0.21	−2.35	−0.51
	(10.32)	(14.98)	(16.95)	(30.66)	(19.90)
Rainfall shock mother's 17y	0.30	0.46	0.31	−1.89	−0.22
	(11.22)	(14.52)	(16.57)	(31.41)	(20.15)
Rainfall shock mother's 18y	−0.05	−0.11	0.63	−1.22	−0.20
	(10.02)	(14.59)	(16.07)	(32.33)	(20.26)
Rainfall shock mother's 19y	0.52	0.04	0.17	−1.12	−0.11
	(11.16)	(14.83)	(15.53)	(32.14)	(20.27)
Number of observations	1781	1869	1794	1879	7323

Notes
Statistics are means with standard deviations in parentheses. The sample is restricted to children with non-missing or no extreme values in HAZ scores (greater than 6 in absolute value) in all rounds or non-missing test scores in all rounds. Expenditure on child's health in the last 12 months is measured in country currency and includes expenditure on medical consultation, treatment and medication. The dietary diversity score is the number of different food groups consumed by the child in the last 24 hours, out of 17 groups in total. Rainfall shocks at each period are deviations from the community and season combined average and year-specific average, calculated by aggregating, over the period, the residuals from a regression of the level of distance-weighted monthly total precipitation on combined community and calendar month fixed effects and year fixed effects for the period between 1950 and 2014 using the Global Climate Database of the University of Delaware (Willmott and Matsuura 2012). Community rainfall shocks are measured in centimetres.

discrimination, knowledge of numbers, and basic operations with numbers. Extensive analysis of the psychometric characteristics of these tests indicated high reliability and validity of test items (Cueto and León 2012; Cueto *et al.* 2009). All tests were administered in the language with which the child felt most comfortable. Table 1 shows systematic differences in performance in quantitative achievement tests across countries.

Rainfall shocks during mother's adolescence were calculated by matching precipitation data from the Global Climate Database of the University of Delaware (Willmott and Matsuura 2012) in the period 1950–2014 to the communities in which mothers were residing during their adolescent years. This used information on mother's year of birth and history of locations available in the Young Lives data. Mother's year of birth was identified using repeated information on mother's age in completed years and information on the date of the interview across rounds, which allows us to minimize measurement error arising from age misreporting.

The University of Delaware data include information on monthly total precipitation and have spatial resolution of 0.5×0.5 degrees that corresponds roughly to grids that are 35 miles across at the equator (for detailed discussions, see Auffhammer *et al.* 2013; Dell *et al.* 2014). We calculated monthly deviations of rainfall from the locality/season and year average by obtaining the residuals from a regression of the monthly level of precipitation on dummies of interactions of locality and calendar month and dummies for year. In this way, we purged rainfall variation from locality and seasonality combined fixed effects and year fixed effects that may be also correlated with mother and child outcomes. These residuals were then aggregated to produce rainfall deviations/shocks for each calendar year in mother's adolescence, defined as the period between ages 10 and 19 years inclusive, consistent with international definitions (WHO 2012; Campisi *et al.* 2018).

This allows us to calculate rainfall shocks during an age range of mother's adolescence spanning one year and not at a particular age. For example, measuring rainfall deviation from the locality average in the calendar year when a mother completed 12 years, provides a measure of the rainfall shock in a period during which the mother was between 11 and 12 years old. For simplicity, in the analysis that follows, we will refer to the rainfall shock in the calendar year when the mother turns 12 years old, as the shock at 12 years.

Rainfall shocks averages and standard deviations, measured in cm, from the 10th to the 19th years of mother's life and across countries, are presented in Table 1. In most cases, averages are close to zero because shocks are calculated as deviations from the locality and year mean.

III RESULTS

Maternal adolescent nutritional status and child outcomes

This subsection presents results from the estimation of equation (1), expressing the relationship between maternal nutritional status in adolescence, as measured by adult height, and child human capital, as measured by HAZ scores and quantitative achievement test scores. All estimated specifications control for child age at the time when the child outcome was measured, and child gender as well as maternal ethnicity, the only outcome determined prior to mother's adolescence on which there is information in the data.[7] Clustered standard errors are reported in all cases, either at the sentinel site level—when the main independent variable of interest is mother's height that takes into account the sampling design[8]—or at the level of the community in which the mother was residing prior to adolescence—when the main independent variable is the rainfall shock that takes into account that rainfall varies across communities. However, in the latter case, we also present results based on robust standard errors in the Online Appendix (Tables A3–A5) as a check of the robustness of our inferences.

Table 2 reports OLS estimation results for equation (1), where the dependent variable is child HAZ score at different ages, by country and for the pooled countries sample. Estimates indicate a significant and positive association between maternal adult height and child HAZ score that persists across ages.

Table 3 presents OLS estimates of the impact of rainfall shocks at different years of mother's adolescence on mother's adult height by country and for the pooled countries sample. These are estimates of the first-stage relationship required to assess the reliability of two-stage least squares (TSLS) estimation of equation (1). Results suggest that rainfall in mother's 13th year is the only shock that has a significant effect on adult height across countries—the rainfall coefficient is only marginally insignificant in India—and in the pooled countries sample. The effect is positive in Ethiopia, consistent with the income channel linking rainfall shocks and human growth, and negative in the other countries and in the pooled sample, consistent with the disease channel. The same holds for effects of rainfall shocks in other periods. Another difference across countries is that shocks in late adolescence have a significant effect on adult height only in Ethiopia.

TABLE 2
OLS ESTIMATES OF ASSOCIATIONS OF MATERNAL ADULT HEIGHT WITH CHILD HAZ SCORES FROM AGES 1 YEAR TO 15 YEARS

	HAZ 1y	HAZ 5y	HAZ 8y	HAZ 12y	HAZ 15y
Ethiopia					
Mother's adult height	0.034***	0.047***	0.040***	0.035***	0.044***
	(0.011)	(0.006)	(0.004)	(0.004)	(0.005)
Male	−0.389***	−0.102*	−0.145***	0.024	−0.822***
	(0.098)	(0.051)	(0.050)	(0.065)	(0.078)
Child's age	−0.122***	−0.018**	−0.001	−0.006	0.016**
	(0.018)	(0.008)	(0.005)	(0.006)	(0.007)
R-squared	0.117	0.093	0.068	0.069	0.219
Observations	1622	1622	1622	1622	1622
India					
Mother's adult height	0.053***	0.044***	0.044***	0.045***	0.049***
	(0.006)	(0.004)	(0.004)	(0.005)	(0.004)
Male	−0.181***	−0.116**	−0.072	0.015	0.010
	(0.058)	(0.044)	(0.046)	(0.046)	(0.050)
Child's age	−0.085***	0.006	−0.003	−0.005	0.001
	(0.011)	(0.008)	(0.008)	(0.007)	(0.007)
R-squared	0.111	0.101	0.111	0.107	0.130
Observations	1803	1803	1803	1803	1803
Peru					
Mother's adult height	0.069***	0.079***	0.080***	0.078***	0.070***
	(0.007)	(0.005)	(0.004)	(0.005)	(0.003)
Male	−0.165**	0.050	0.020	0.085*	0.280***
	(0.064)	(0.044)	(0.043)	(0.045)	(0.058)
Child's age	−0.083***	0.051***	−0.003	−0.015*	−0.010
	(0.007)	(0.011)	(0.007)	(0.008)	(0.008)
R-squared	0.187	0.273	0.227	0.195	0.237
Observations	1751	1751	1751	1751	1751
Vietnam					
Mother's adult height	0.048***	0.055***	0.051***	0.050***	0.054***
	(0.005)	(0.004)	(0.005)	(0.005)	(0.004)
Male	−0.155**	0.023	−0.039	0.050	0.087*
	(0.057)	(0.042)	(0.045)	(0.058)	(0.045)
Child's age	−0.109***	−0.002	−0.013	−0.012	−0.006
	(0.013)	(0.009)	(0.008)	(0.007)	(0.006)
R-squared	0.249	0.236	0.205	0.220	0.220
Observations	1829	1829	1829	1829	1829
All countries					
Mother's adult height	0.051***	0.056***	0.053***	0.051***	0.052***
	(0.004)	(0.003)	(0.003)	(0.003)	(0.002)
Male	−0.219***	−0.037	−0.061**	0.039	−0.097*
	(0.036)	(0.024)	(0.023)	(0.026)	(0.053)
Child's age	−0.099***	0.017***	−0.005	−0.011***	−0.001
	(0.007)	(0.006)	(0.004)	(0.004)	(0.004)
R-squared	0.149	0.165	0.153	0.173	0.176
Observations	7005	7005	7005	7005	7005

Notes
Standard errors clustered at the sentinel site are in parentheses. Child's age is measured in months at the time when the HAZ score measure is collected. All specifications control for mother's ethnicity, but estimates are not reported.
***, **, * indicate significant at 1%, 5%, 10%, respectively.

TABLE 3
OLS ESTIMATES OF THE IMPACT OF RAINFALL SHOCKS AT DIFFERENT PERIODS OF MOTHER'S ADOLESCENCE ON MATERNAL ADULT HEIGHT

	Ethiopia	India	Peru	Vietnam	All countries
Rainfall shock 10y	0.0003	−0.0069	−0.0247*	−0.0078	−0.0061
	(0.0160)	(0.0126)	(0.0136)	(0.0056)	(0.0040)
	[1.000]	[1.000]	[0.693]	[1.000]	[1.000]
	{0.985}	{0.496}	{0.006}***	{0.055}*	{0.055}*
Rainfall shock 11y	−0.0261	−0.0086	−0.0124	0.0123**	0.0010
	(0.0174)	(0.0110)	(0.0116)	(0.0054)	(0.0040)
	[1.000]	[1.000]	[1.000]	[0.244]	[1.000]
	{0.061}*	{0.356}	{0.126}	{0.013}***	{0.769}
Rainfall shock 12y	−0.0048	−0.0124	−0.0148	−0.0003	−0.0055
	(0.0148)	(0.0106)	(0.0116)	(0.0048)	(0.0038)
	[1.000]	[1.000]	[1.000]	[1.000]	[1.000]
	{0.730}	{0.204}	{0.083}*	{0.940}	{0.137}
Rainfall shock 13y	0.0278**	−0.0190	−0.0306***	−0.0099**	−0.0127***
	(0.0126)	(0.0123)	(0.0117)	(0.0048)	(0.0038)
	[0.287]	[1.000]	[0.091]*	[0.390]	[0.008]***
	{0.029}**	{0.038}**	{0.000}***	{0.033}**	{0.002}***
Rainfall shock 14y	0.0418**	−0.0289***	0.0020	−0.0057	−0.0081**
	(0.0170)	(0.0103)	(0.0085)	(0.0048)	(0.0035)
	[0.150]	[0.05]**	[1.000]	[1.000]	[0.219]
	{0.000}***	{0.001}***	{0.813}	{0.243}	{0.027}**
Rainfall shock 15y	0.0522***	−0.0048	−0.0009	−0.0003	−0.0003
	(0.0148)	(0.0117)	(0.0103)	(0.0043)	(0.0034)
	[0.005]***	[1.000]	[1.000]	[1.000]	[1.000]
	{0.000}***	{0.639}	{0.901}	{0.946}	{0.928}
Rainfall shock 16y	0.0454**	−0.0007	0.0164*	−0.0091**	−0.0029
	(0.0179)	(0.0101)	(0.0089)	(0.0044)	(0.0033)
	[0.121]	[1.000]	[0.653]	[0.386]	[1.000]
	{0.001}***	{0.934}	{0.029}**	{0.031}**	{0.396}
Rainfall shock 17y	0.0048***	0.0013	0.0010	−0.0007	−0.0003
	(0.0016)	(0.0011)	(0.0009)	(0.0005)	(0.0003)
	[0.008]***	[1.000]	[1.000]	[1.000]	[1.000]
	{0.000}***	{0.161}	{0.186}	{0.111}	{0.383}
Rainfall shock 18y	0.0378**	−0.0002	0.0009	0.0049	−0.0007
	(0.0150)	(0.0112)	(0.0078)	(0.0035)	(0.0033)
	[0.130]	[1.000]	[1.000]	[1.000]	[1.000]
	{0.015}**	{0.979}	{0.919}	{0.210}	{0.828}
Rainfall shock 19y	0.0316**	0.0021	0.0092	−0.0053	−0.0019
	(0.0130)	(0.0131)	(0.0095)	(0.0045)	(0.0035)
	[0.161]	[1.000]	[1.000]	[1.000]	[1.000]
	{0.022}**	{0.802}	{0.265}	{0.213}	{0.603}
R-squared	0.032	0.038	0.040	0.076	0.245
Kleibergen–Paap *F*-statistic	2.90	1.01	2.03	2.43	2.88
Observations	1622	1803	1751	1829	7005

Notes
Standard errors clustered at the community in which the mother was residing in the calendar year in which she turned 10 years old are in parentheses; Bonferroni multiple testing corrected *p*-values are in square brackets; *p*-values computed through 1000 random permutations of the values of rainfall shocks at each period of mother's life are in curly brackets. Controls are included in all specifications for child's age in Round 1, child's gender and mother's ethnicity, but coefficients are not reported.
***, **, * indicate significant at 1%, 5%, 10%, respectively.

We perform a range of tests to investigate the robustness of these patterns. First, we use Bonferroni corrected p-values that adjust for multiple testing, as specifications estimating the relationship between rainfall shocks in adolescence and maternal adult height consider 10 different shocks. Bonferroni corrected p-values for tests of significance of the effects of the different rainfall shocks are reported in square brackets below the coefficient estimates in Table 3. These show that adjusting for multiple testing does not affect the significance of the effect of the rainfall shock in mother's 13th year of life on mother's adult height in Peru and in the pooled sample.

Second, we check the reliability of conventional tests of significance of individual rainfall shocks coefficients by computing p-values using permutation tests (Fisher 1935; Young 2019), implemented through reshuffling each rainfall shock across years and communities. These tests reinforce the pattern identified by conventional significance tests that rainfall shocks during the mother's 13th year have a significant effect on her adult height across all countries.

A potential explanation of the significant impact of the rainfall shock during the mother's 13th year of life—or to be more precise, during the period when mothers were between 12 and 13 years old—on mother's adult height is that this year may coincide with the period of peak height velocity during the pubertal growth spurt (Eckert *et al.* 2009; Das *et al.* 2017; Campisi *et al.* 2018). In particular, peak height velocity is normally between 11 and 12 years of age, but in low-income settings the pubertal growth spurt is extended, and thus peak height velocity occurs at a later age (Eckert *et al.* 2009; Das *et al.* 2017). Nevertheless, these effects appear small, ranging from 0.01 cm to 0.03 cm higher height for a every additional centimetre higher than average rainfall in the locality.[9]

We also perform a placebo test of the robustness of the effects of rainfall shocks on mother's height through investigating the relationship between rainfall shocks realized after mother's height was measured. In particular, we regress mother's height, observed in Round 2, on rainfall shocks after Round 2, in the years when children were 7, 8, 9 and 10 years old. Results (presented in Table A6 in the Online Appendix) do not show a systematic and significant relationship between rainfall shocks in these periods and mother's height across countries and in the pooled sample that provides additional support to the robustness of our results.[10]

Although there is evidence of a significant effect of rainfall shocks during mother's adolescence on mother's adult height, partial F-statistics, presented in Table 3, suggest that these are expected to be weak instruments for mother's adult height. Therefore TSLS estimates are expected to be unreliable. In order to minimize problems arising from weak instruments, we conduct TSLS estimation using as a single instrument the rainfall shock during the mother's 13th year of life and pooling the samples from India, Peru and Vietnam (Angrist and Pischke 2009, p. 213). This also reduces concerns related to the validity of the exclusion restriction by restricting the sample to the countries in which the effect of rainfall shocks on height is negative and thus manifesting mainly through the disease channel.

Estimation results by TSLS are presented in Table 4. First-stage F-statistics across TSLS estimated specifications, presented in Table 4, are sufficiently high, suggesting no concerns related to a weak instrument. Estimates show a positive and significant effect of maternal nutritional status during adolescence on child nutritional status at age 1 year that persists through age 15 years. As Table 4 indicates, TSLS estimates are of medium size, but much larger than OLS. TSLS estimates suggest that 1 cm higher maternal growth during adolescence leads, on average, to around 0.19 standard deviations higher

TABLE 4
OLS AND TSLS ESTIMATES OF THE IMPACT OF MATERNAL ADOLESCENT NUTRITION ON CHILD NUTRITIONAL STATUS FROM AGES 1 YEAR TO 15 YEARS IN THE INDIA, PERU AND VIETNAM POOLED SAMPLE

	HAZ 1y	HAZ 5y	HAZ 8y	HAZ 12y	HAZ 15y
OLS					
Mother's adult height	0.057***	0.060***	0.058***	0.057***	0.057***
	(0.004)	(0.003)	(0.003)	(0.003)	(0.002)
Male	−0.165***	−0.015	−0.034	0.045	0.121***
	(0.034)	(0.026)	(0.026)	(0.028)	(0.032)
Child's age	−0.092***	0.026***	−0.006	−0.012***	−0.006
	(0.006)	(0.007)	(0.004)	(0.004)	(0.004)
R-squared	0.165	0.197	0.184	0.188	0.214
Observations	5383	5383	5383	5383	5383
TSLS					
Mother's adult height	0.188**	0.181***	0.164***	0.182**	0.153***
	(0.085)	(0.063)	(0.062)	(0.072)	(0.048)
Male	−0.137***	0.012	−0.011	0.072**	0.141***
	(0.040)	(0.031)	(0.029)	(0.033)	(0.036)
Child's age	−0.089***	0.021***	−0.003	−0.006	−0.002
	(0.008)	(0.007)	(0.005)	(0.006)	(0.005)
Kleibergen–Paap *F*-statistic	14.44	14.30	13.98	13.92	14
Observations	5383	5383	5383	5383	5383

Notes
Standard errors clustered at the sentinel site are in parentheses. The sample is restricted to children with non-missing or no extreme values in HAZ scores (greater than 6 in absolute value) in all rounds in India, Peru and Vietnam. Child's age is measured in months at the time the HAZ score measure is collected. TSLS estimation is using rainfall in the calendar year in which the mother completed her 13th year of age as an instrument for mother's adult height. All specifications control for mother's ethnicity, but estimates are not reported.
***, **, * indicate significant at 1%, 5%, 10%, respectively.

child height relative to the WHO reference child of the same age and gender at age 1 year, and that this effect is sustained through to age 15 years.

Our mediation analysis explores putative channels through which maternal adolescent nutrition impacts child outcomes, as discussed in one Section I and presented in Figure 1. As Figure 1 shows, first our analysis investigates whether the effect of maternal adolescent nutrition on child growth at age 1 year manifests through altering parental health investments on the child. Second, it considers whether the effect of maternal adolescent nutrition on child growth in subsequent years operates through or over and above child growth in interim periods. Third, it examines whether effects operating over and above child growth in interim periods are due to parental investments responses to maternal adolescent nutrition, which are implemented after these periods. And fourth, it investigates whether an effect through child growth in interim periods manifests through parental investments responses to child growth in interim periods, which are implemented in subsequent periods. In this way, our analysis allows us to sketch out the full set of temporal pathways linking maternal adolescent nutrition and child outcomes over the child's life course.

Our mediation analysis results are summarized in Figures 2a–2e (see also Tables A7i–A7iv in the Online Appendix for full estimation results). Figure 2a presents the

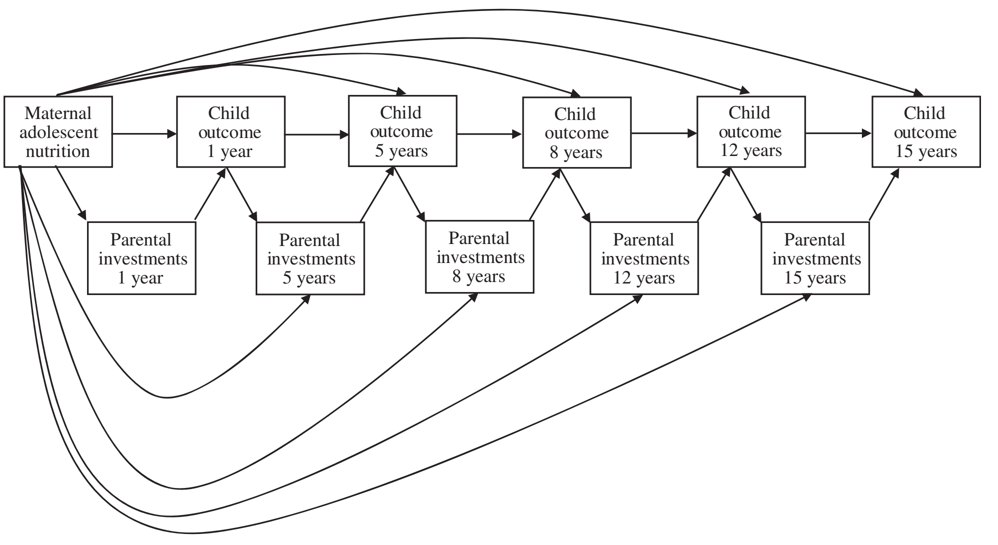

FIGURE 1. Mechanisms linking maternal adolescent nutrition and child growth over the life course.

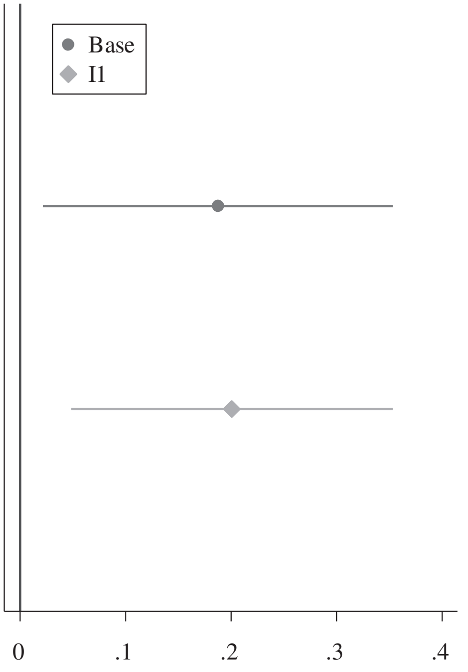

FIGURE 2A. TSLS coefficient estimates of the impact of maternal adolescent nutritional status on child HAZ score at age 1 year across specifications including mediators in the India, Peru and Vietnam pooled sample.*Notes*: Figure displays coefficient estimates and associated 95% confidence intervals. Base denotes the base specification, including child gender and age, and mother's ethnicity. I1 denotes a specification including controls in the base specification and parental investments on child health at age 1 year as a mediator. Parental investments on child health at age 1 year are approximated by parental education, household wealth and urban location.

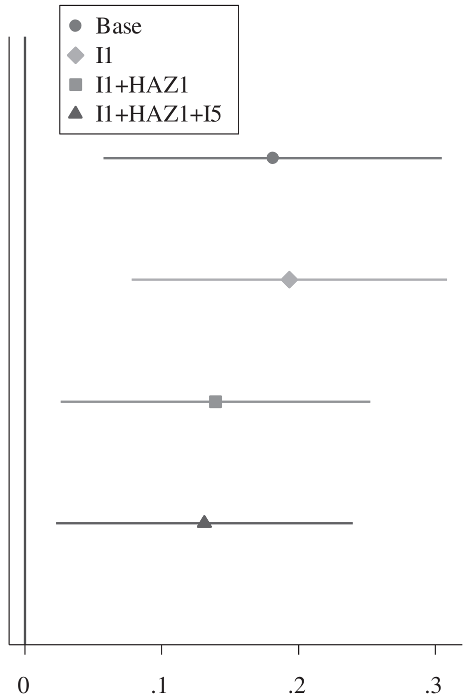

FIGURE 2B. TSLS coefficient estimates of the impact of maternal adolescent nutritional status on child HAZ score at age 5 years across specifications including mediators in the India, Peru and Vietnam pooled sample.*Notes*: Figure displays coefficient estimates and associated 95% confidence intervals. Base denotes the base specification, including child gender and age, and mother's ethnicity. I# denotes a specification including controls in the base specification and parental investments on child health at age # years as a mediator. Parental investments on child health at age 1 year are approximated by parental education, household wealth and urban location; parental investments on child health at all ages above 1 year are measured by expenditure on child's health, child's diversity score and number of meals consumed by the child in last 24 hours. HAZ1 denotes a specification including HAZ score at age 1 year as a mediator.

TSLS estimates of the effect of maternal adolescent nutrition on child HAZ score at age 1 year in the base specification, including only controls, and a specification also including a range of proxies for parental investments at age 1 year, such as measures of parental socioeconomic status.[11] The figure shows no noticeable difference between the two estimates, suggesting that parental investments at age 1 year do not appear to be a mediator of the relationship between maternal adolescent nutrition and child HAZ score at age 1 year. The same holds for the relationship between maternal adolescent nutrition and child HAZ score at age 5 years, as shown by Figure 2b. This figure, however, shows that the inclusion of HAZ score at age 1 year among the explanatory variables in the specification for HAZ score at age 5 years reduces the coefficient of maternal height markedly, but the coefficient remains statistically significant (the confidence interval does not cross the 0 line). This implies that the effect of maternal adolescent nutrition on child HAZ score at age 5 years operates partly through and partly over and above child HAZ score at age 1 year. Nevertheless, as shown by Figure 2b, inclusion of direct measures of parental investments on child health at age 5 years, such as expenditure on child health, child's dietary diversity and number of meals in the last 24 hours, does not change the coefficient of maternal height, as well as the coefficient of HAZ1 (see Table A7i in the

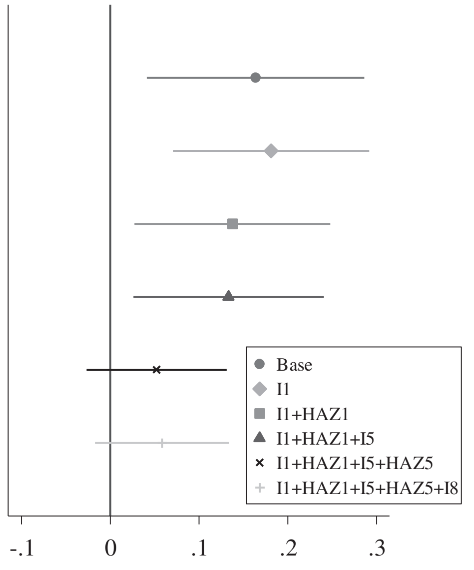

FIGURE 2C. TSLS coefficient estimates of the impact of maternal adolescent nutritional status on child HAZ score at age 8 years across specifications including mediators in the India, Peru and Vietnam pooled sample.*Notes*: Figure displays coefficient estimates and associated 95% confidence intervals. Base denotes the base specification, including child gender and age, and mother's ethnicity. I# denotes a specification including controls in the base specification and parental investments on child health at age # years as a mediator. Parental investments on child health at age 1 year are approximated by parental education, household wealth and urban location; parental investments on child health at all ages above 1 year are measured by expenditure on child's health, child's diversity score and number of meals consumed by the child in last 24 hours. HAZ# denotes a specification including HAZ score at age # years as a mediator.

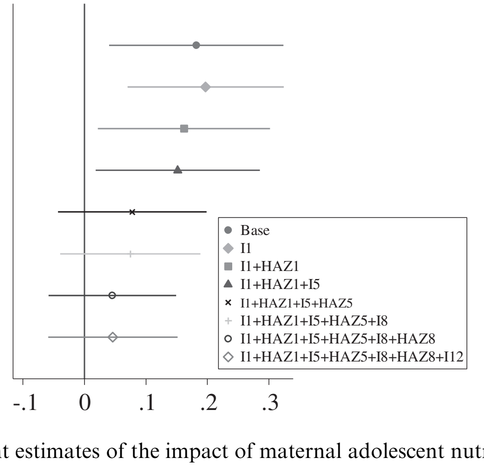

FIGURE 2D. TSLS coefficient estimates of the impact of maternal adolescent nutritional status on child HAZ score at age 12 years across specifications including mediators in the India, Peru and Vietnam pooled sample.*Notes*: See Figure 2c.

Online Appendix). This implies that effects of maternal adolescent nutrition on child HAZ score at age 5 years—manifesting either through or over and above HAZ score at age 1 year—may not be explained by (observed) parental investment responses, and thus are likely to reflect mainly biological effects.

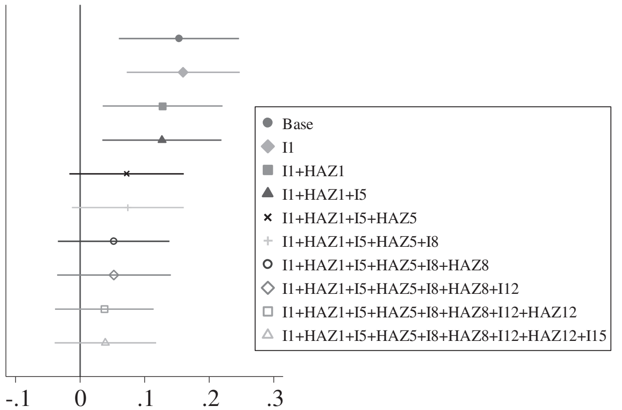

FIGURE 2E. TSLS coefficient estimates of the impact of maternal adolescent nutritional status on child HAZ score at age 15 years across specifications including mediators in the India, Peru and Vietnam pooled sample. *Notes*: See Figure 2c.

Results on potential channels through which effects of maternal adolescent nutrition on child HAZ score at ages 8, 12 and 15 years are presented in Figures 2c, 2d and 2e, respectively, and lead to conclusions similar to those for child HAZ score at age 5 years. The first conclusion is that the effect of maternal adolescent nutrition on child nutritional status at any given period manifests partly through child nutritional status in interim periods. Specifically, estimates in Figures 2c, 2d and 2e show that effects of maternal adult height on child HAZ score at ages 8, 12 and 15 years are mainly mediated by child HAZ score at ages 1 and 5 years, as inclusion of these in the specifications—particularly HAZ score at age 5 years—reduces the estimated effects substantially and renders them insignificant. This may explain the persistent effect of maternal adolescent nutrition on child growth from early childhood to adolescence. The second conclusion from our results is that there is no evidence that the effect of maternal adolescent nutrition on child nutrition from infancy to adolescence is mediated by parental health investments in the child.[12]

Turning to estimation results of the relationship between maternal adult height and child quantitative achievement test scores at different ages, presented in Table 5, OLS estimates show a positive and significant association between the two that persists as children age. TSLS estimates, however, do not indicate a significant effect of maternal adolescent nutritional status on child cognitive development at any age. Although this could be the result of larger standard errors arising from the smaller estimation sample compared to specifications with child HAZ score as the dependent variable, we find no supporting evidence for this. We find that effects on child HAZ score remain strongly positive and significant across ages even when the sample is restricted to the same sample as that for test scores at all ages (see Table A8 in the Online Appendix for details). This suggests that maternal adolescent nutritional status has larger and more systematic effects on child nutritional status than on child cognitive development. This seems to be in line with what one would expect considering that the relationship between maternal nutrition and child cognition may be mainly indirect, mediated through child nutritional status (Veena *et al.* 2016). Nevertheless, the lack of significant effects of maternal adolescent nutrition on child cognition may seem puzzling, considering its strongly significant effect on child nutrition and the evidence supporting a strong positive link between child nutrition and cognitive development (Glewwe *et al.* 2001). A potential

TABLE 5
OLS AND TSLS ESTIMATES OF THE IMPACT OF MOTHER'S ADOLESCENT NUTRITION ON CHILD QUANTITATIVE ACHIEVEMENT SCORES FROM AGES 5 YEARS TO 15 YEARS IN THE INDIA, PERU AND VIETNAM POOLED SAMPLE

	Score 5y	Score 8y	Score 12y	Score 15y
OLS				
Mother's adult height	0.005*	0.014***	0.010***	0.011***
	(0.003)	(0.003)	(0.003)	(0.003)
Male	−0.014	0.046	−0.002	0.078**
	(0.029)	(0.029)	(0.027)	(0.034)
R-squared	0.067	0.060	0.057	0.027
Observations	4857	4857	4857	4857
TSLS				
Mother's adult height	0.024	0.078	−0.078	0.026
	(0.077)	(0.062)	(0.067)	(0.068)
Male	−0.012	0.057*	−0.017	0.081**
	(0.034)	(0.033)	(0.029)	(0.032)
Kleibergen–Paap *F*-statistic	12.14	11.70	10.56	10.56
Observations	4857	4857	4857	4857

Notes
Standard errors clustered at the sentinel site are in parentheses. Dependent variables are age-normalized test scores. TSLS estimation is using rainfall in the calendar year in which the mother completed her 13th year of age as an instrument for mother's adult height. All specifications include controls for mother's ethnicity, the language of administration of the test, and whether the test was administered in the child's mother tongue, but estimates are not reported.
***, **, * indicate significant at 1%, 5%, 10%, respectively.

explanation of this may be that cognitive development of children who were undernourished in early childhood may improve in later periods of life, even in the face of persistent undernutrition, through compensatory parental investments in child education (Mendez and Adair 1999; Galasso *et al.* 2017).[13]

Overall, our results seem to suggest that the effect of maternal adolescent nutrition on child nutritional status from infancy to adolescence is likely to operate mainly through a biological channel reflecting direct transmission of undernutrition through early childhood. Moreover, this effect seems to persist through to adolescence because early childhood nutrition is a strong predictor of nutritional status in subsequent stages of life. These results have important policy implications, as they suggest that the intergenerational transmission of undernutrition in low- and middle-income countries may be more effectively addressed through interventions promoting the nutrition of adolescent girls as well as children's nutrition before age 5 years.

Rainfall shocks during mother's adolescence and child outcomes

This subsection presents results on the relationship between rainfall shocks during mother's adolescence and child outcomes. As discussed in Section I, this analysis aims to provide an additional indirect test of the robustness of the link between maternal adolescent nutritional status and child outcomes documented in the previous subsection through estimating the reduced-form relationship between the instrument and child outcomes. It also allows us to identify whether results in the pooled sample may be driven by a particular country, which was not possible when using TSLS, through investigating

TABLE 6
OLS ESTIMATES OF THE IMPACT OF RAINFALL SHOCKS IN THE MOTHER'S 13TH YEAR OF LIFE ON CHILD NUTRITIONAL STATUS FROM AGES 1 YEAR TO 15 YEARS IN THE INDIA, PERU AND VIETNAM POOLED SAMPLE, AND BY COUNTRY

	HAZ 1y	HAZ 5y	HAZ 8y	HAZ 12y	HAZ 15y
Pooled sample (India, Peru and Vietnam)					
Rainfall shock mother's 13y	−0.0026***	−0.0025***	−0.0022***	−0.0025***	−0.0021***
	(0.0008)	(0.0007)	(0.0006)	(0.0007)	(0.0006)
Male	−0.178***	−0.029	−0.046	0.033	0.109***
	(0.033)	(0.028)	(0.028)	(0.027)	(0.028)
Child's age	−0.093***	0.029***	−0.008*	−0.014***	−0.007*
	(0.006)	(0.004)	(0.004)	(0.005)	(0.004)
R-squared	0.108	0.093	0.089	0.105	0.095
Observations	5383	5383	5383	5383	5383
Ethiopia					
Rainfall shock mother's 13y	0.0005	0.0015	0.0017	0.0006	0.0040*
	(0.0041)	(0.0030)	(0.0024)	(0.0024)	(0.0022)
Male	−0.379***	−0.089*	−0.133***	0.035	−0.810***
	(0.097)	(0.049)	(0.048)	(0.057)	(0.055)
Child's age	−0.120***	−0.016**	0.002	−0.003	0.019***
	(0.016)	(0.008)	(0.007)	(0.005)	(0.006)
R-squared	0.104	0.024	0.019	0.021	0.162
Observations	1622	1622	1622	1622	1622
India					
Rainfall shock mother's 13y	−0.0043*	0.0011	0.0013	0.0015	−0.0002
	(0.0022)	(0.0014)	(0.0016)	(0.0016)	(0.0015)
Male	−0.181***	−0.114**	−0.070	0.016	0.012
	(0.062)	(0.045)	(0.050)	(0.045)	(0.045)
Child's age	−0.085***	0.006	−0.004	−0.006	−0.001
	(0.010)	(0.007)	(0.008)	(0.008)	(0.008)
R-squared	0.069	0.029	0.047	0.039	0.040
Observations	1803	1803	1803	1803	1803
Peru					
Rainfall shock mother's 13y	−0.0024	−0.0028*	−0.0046***	−0.0039**	−0.0020*
	(0.0021)	(0.0017)	(0.0015)	(0.0017)	(0.0011)
Male	−0.208***	0.001	−0.025	0.041	0.239***
	(0.060)	(0.051)	(0.047)	(0.046)	(0.046)
Child's age	−0.085***	0.059***	−0.005	−0.018**	−0.011*
	(0.007)	(0.006)	(0.007)	(0.008)	(0.006)
R-squared	0.108	0.129	0.064	0.054	0.056
Observations	1751	1751	1751	1751	1751
Vietnam					
Rainfall shock mother's 13y	−0.0013	−0.0026***	−0.0020***	−0.0026***	−0.0025***
	(0.0009)	(0.0008)	(0.0007)	(0.0009)	(0.0007)
Male	−0.166***	0.010	−0.051	0.039	0.074*
	(0.051)	(0.044)	(0.045)	(0.050)	(0.042)
Child's age	−0.111***	−0.004	−0.015**	−0.014**	−0.008
	(0.010)	(0.006)	(0.007)	(0.006)	(0.005)
R-squared	0.201	0.147	0.132	0.161	0.105
Observations	1829	1829	1829	1829	1829

Notes
Standard errors clustered at the community in which the mother was residing in the calendar year in which she turned 10 years old are in parentheses. Child's age is measured in months at the time when the HAZ score measure is collected. All specifications include mother's ethnicity and dummies for missing values of rainfall shock in the mother's 13th year of life, but estimates are not reported.
***, **, * indicate significant at 1%, 5%, 10%, respectively.

differences on the impact of shocks influencing mother's nutrition during adolescence on child outcomes across countries.

The top panel of Table 6 presents OLS estimation results of the effect of the rainfall shock during the mother's 13th year of life on child HAZ score at different ages in the sample resulting by pooling children from India, Peru and Vietnam on which TSLS estimation in the previous subsection was based. Coefficient estimates reveal a negative and significant effect of rainfall in mother's 13th year of life on child HAZ score at all ages. Effects, however, are small in magnitude, as estimates suggest that 1 cm higher rainfall, during the period mothers were between 12 and 13 years old, led, on average, to around 0.0025 standard deviations higher child height relative to the WHO reference child of the same age and gender at any given age. Effects also do not change when the sample is restricted to children with non-missing observations in both HAZ score and achievement tests in all rounds (see Table A9 in the Online Appendix for details). Moreover, reduced-form OLS estimates are in line in terms of sign and significance with OLS estimates of the first-stage equation and TSLS estimates of equation (1) using rainfall in mother's 13th year of life as an instrument for mother's adolescent nutritional status, presented in the previous subsection.

Results presented in the other panels of Table 6 are consistent with negative effects of the rainfall shock in the mother's 13th year on child HAZ score at age 1 year across the three countries, that is, India, Peru and Vietnam—although this is weakly significant only in India—with the effect persisting at older ages in Peru and Vietnam.

Mediation analysis results investigating the potential channels through which the effect of the rainfall shock in mother's adolescence may manifest are presented in Figures 3a–3e (full estimation results are presented in Tables A10i–A10iv in the Online Appendix). The patterns of estimates are similar qualitatively with those identified for maternal nutritional status in the previous section: the effect of the rainfall shock on child HAZ score does not seem to manifest through parental health investments, whereas its

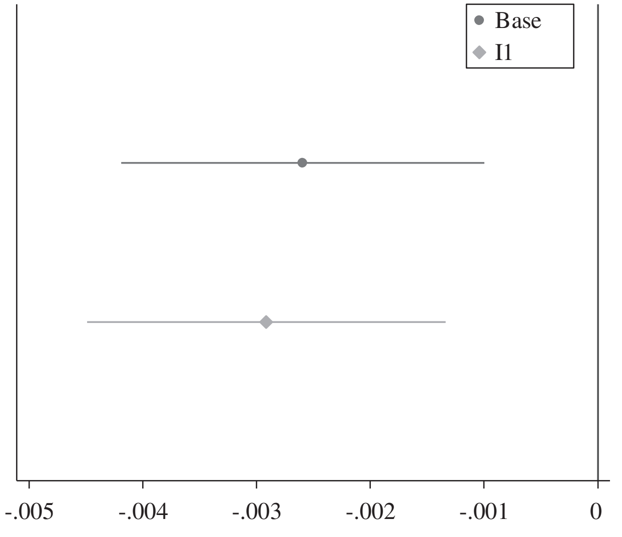

FIGURE 3A. OLS coefficient estimates of the impact of rainfall shocks in the mother's 13th year of life on child HAZ score at age 1 year across specifications including mediators in the India, Peru and Vietnam pooled sample. *Notes*: See Figure 2a.

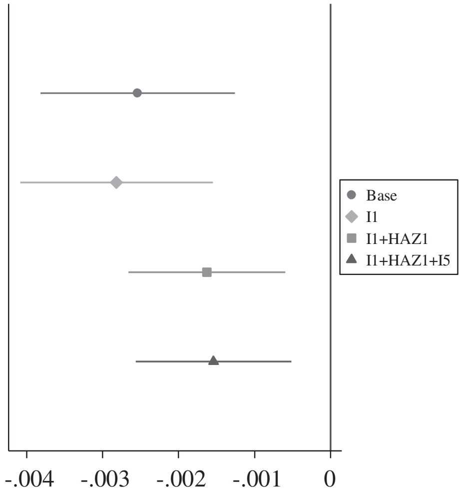

FIGURE 3B. OLS coefficient estimates of the impact of rainfall shocks in the mother's 13th year of life on child HAZ score at age 5 years across specifications including mediators in the India, Peru and Vietnam pooled sample. *Notes*: See Figure 2b.

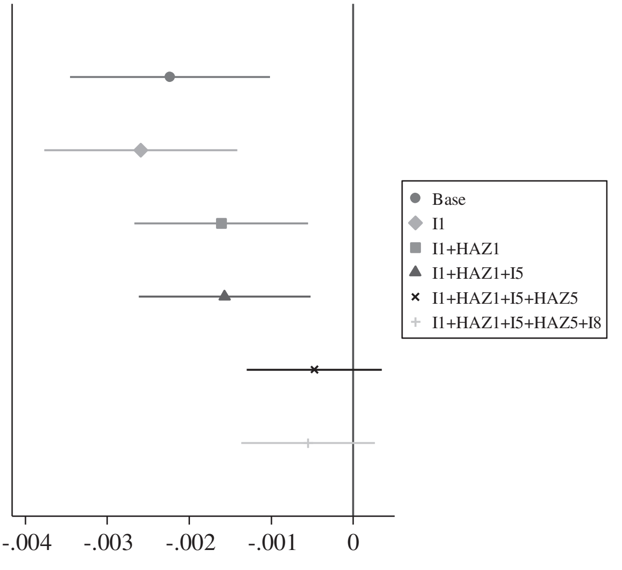

FIGURE 3C. OLS coefficient estimates of the impact of rainfall shocks in the mother's 13th year of life on child HAZ score at age 8 years across specifications including mediators in the India, Peru and Vietnam pooled sample. *Notes*: See Figure 2c.

effect on child HAZ score after age 5 years seems to mainly manifest through child HAZ score at or before age 5 years. Moreover, estimates in Figures 3a–3e show that effects of rainfall shocks on child HAZ score do not change much after the inclusion of other maternal outcomes, such as education and household income, that may provide additional support to the exclusion restriction that rainfall shocks impact mother's growth and nutrition mainly through a disease channel rather than an income channel.

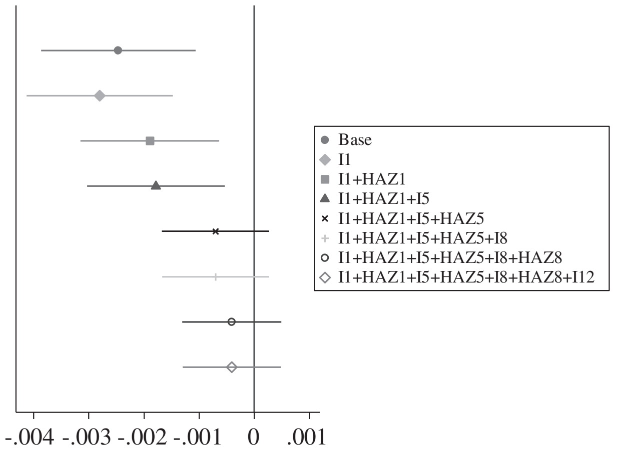

FIGURE 3D. OLS coefficient estimates of the impact of rainfall shocks in the mother's 13th year of life on child HAZ score at age 12 years across specifications including mediators in the India, Peru and Vietnam pooled sample.*Notes*: See Figure 2c.

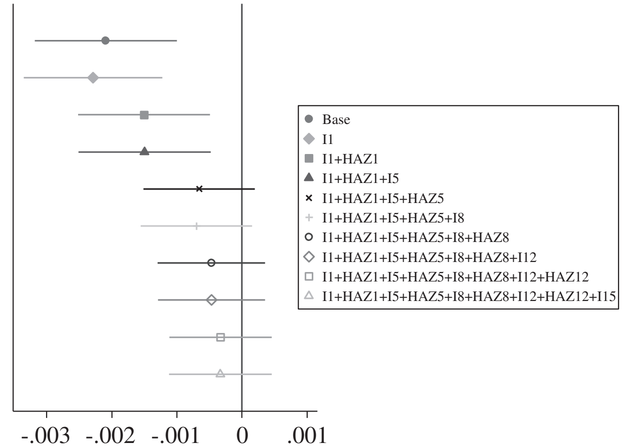

FIGURE 3E. OLS coefficient estimates of the impact of rainfall shocks in the mother's 13th year of life on child HAZ score at age 15 years across specifications including mediators in the India, Peru and Vietnam pooled sample.*Notes*: See Figure 2c.

Finally, Table 7 presents OLS estimation results of the impact of rainfall shock during the mother's 13th year of life on child quantitative achievement test scores at different ages. Estimates show small and insignificant effects at all ages in the pooled sample that reflect mainly small and insignificant effects across countries.

All in all, results in this subsection support a significant and persistent effect of rainfall deviations from the norm during the mother's early adolescence on her offspring's growth through the life course that is likely to manifest mainly through a biological channel, but no significant effect on her offspring's cognitive

TABLE 7
OLS ESTIMATES OF THE IMPACT OF RAINFALL SHOCKS DURING THE MOTHER'S 13TH YEAR OF LIFE ON CHILD QUANTITATIVE ACHIEVEMENT SCORES FROM AGES 5 YEARS TO 15 YEARS IN THE INDIA, PERU AND VIETNAM POOLED SAMPLE, AND BY COUNTRY

	Score 5y	Score 8y	Score 12y	Score 15y
Pooled sample (India, Peru and Vietnam)				
Rainfall shock mother's 13y	−0.0003	−0.0010	0.0010	−0.0003
	(0.0008)	(0.0007)	(0.0008)	(0.0007)
Male	−0.016	0.044	−0.004	0.077***
	(0.028)	(0.027)	(0.027)	(0.030)
R-squared	0.026	0.060	0.057	0.052
Observations	4857	4857	4857	4857
Ethiopia				
Rainfall shock mother's 13y	0.0018	0.0004	0.0004	0.0003
	(0.0022)	(0.0018)	(0.0022)	(0.0021)
Male	0.003	0.035	−0.006	0.030
	(0.053)	(0.051)	(0.057)	(0.050)
R-squared	0.073	0.179	0.112	0.161
Observations	1307	1307	1307	1307
India				
Rainfall shock mother's 13y	−0.0004	−0.0006	0.0029	0.0042***
	(0.0015)	(0.0017)	(0.0018)	(0.0016)
Male	−0.001	−0.014	−0.013	0.179***
	(0.051)	(0.048)	(0.051)	(0.048)
R-squared	0.039	0.077	0.069	0.084
Observations	1546	1546	1546	1546
Peru				
Rainfall shock mother's 13y	0.0005	−0.0025*	−0.0001	−0.0015
	(0.0019)	(0.0015)	(0.0012)	(0.0017)
Male	−0.093*	0.118**	0.055	0.175***
	(0.052)	(0.048)	(0.043)	(0.043)
R-squared	0.016	0.102	0.074	0.053
Observations	1688	1688	1688	1688
Vietnam				
Rainfall shock mother's 13y	0.0004	0.0001	0.0010	−0.0009
	(0.0009)	(0.0009)	(0.0010)	(0.0009)
Male	0.025	−0.013	−0.084**	−0.142***
	(0.043)	(0.039)	(0.042)	(0.047)
R-squared	0.106	0.119	0.093	0.089
Observations	1623	1623	1623	1623

Notes
Standard errors clustered at the community in which the mother was residing in the calendar year in which she turned 10 years old are in parentheses. Dependent variables are age-normalized test scores. All specifications include controls for mother's ethnicity, the language of administration of the test, and whether the test was administered in the child's mother tongue, but estimates are not reported.
***, **, * indicate significant at 1%, 5%, 10%, respectively.

development. This is in line with our findings in the previous subsection supporting a strong and persistent link between maternal nutrition during adolescence and child growth, and no link between maternal adolescent nutrition and child cognitive development.

IV Conclusion

Although adolescence has been highlighted as a period when investments and environments are critical for the human capital development of women and their children, there is very little evidence on this from low- and middle-income countries. In particular, many have argued that adolescence is a critical period for height formation and presents opportunities for remediation of deficits in growth arising from undernutrition in the early years of life. Nevertheless, this is not yet well-established, and little is known on the responsiveness of growth during adolescence to environmental insults as well as the long-run and intergenerational implications of maternal nutrition during adolescence

In this paper, we use data from an international cohort study in Ethiopia, India, Peru and Vietnam to identify the effect of mother's undernutrition in adolescence for her child's growth and cognitive achievement from infancy through middle adolescence as well as the potential channels through which these effects may manifest. Our analysis addresses potential biases in estimation arising from the endogeneity of mother's nutritional status through an IV identification strategy employing rainfall shocks during mother's adolescence as instruments for mother's adolescent nutritional status. We also examine the impacts of rainfall shocks during the mother's adolescent years on maternal adult height and child growth and development over the life course as an additional way to examine the long-run and intergenerational impacts of nutritional insults during adolescence, which has been little investigated in the literature.

We find evidence that better maternal nutrition in adolescence leads to significantly higher child growth from infancy to adolescence but does not significantly improve child performance in achievement tests. Our analysis further suggests that the effect of maternal adolescent nutrition on child nutrition is likely to manifest mainly through a biological channel that reflects a direct intergenerational transmission of undernutrition. This effect is reflected in poor child growth up to age 5 years and persists through to adolescence due to the strong positive link between growth in early childhood and growth in subsequent stages of development.

Overall, our findings have important policy implications and suggest that interventions that aim to improve the nutritional status of girls during early adolescence may contribute to breaking the intergenerational cycle of undernutrition in low- and middle-income countries.

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NOTES

1. This is the case in a forward-looking framework of child human capital determination under which mother's undernutrition in adolescence is determined by mother's decisions simultaneously with the choice of investments on child human capital in future periods.
2. Based on equation (1), this could be expressed as a correlation between the measure of MN_i and α_i, as the latter includes measurement error in HC_{ia}. In the case that the dependent variable is child achievement test scores, genetic variation in height may also be correlated with child cognitive endowment if there is a genetic correlation between physical stature and innate mental ability (Glewwe *et al.* 2001).
3. Adolescence is normally defined as the period from 10 to 19 years, when growth has terminated (WHO 2012).
4. Young Lives also collects information on a cohort of children born in 1994/5, but these data were not used in our analysis, as the children were not followed since infancy and early childhood and thus one cannot trace the impacts of maternal undernutrition on child outcomes since early life.
5. Descriptive statistics of other variables used in our analysis, such as mother's ethnicity, parental health investments at ages 8, 12 and 15 years, and language in which tests were administered to children, are presented in Tables A1 and A2 in the Online Appendix.
6. In Ethiopia, 28 items were administered at age 12 years, and 26 items at age 15 years, whereas in Peru, 34 items were administered at age 12 years, and in Vietnam, 30 items were administered at age 15 years.
7. There is also information on mother's community of residence prior to adolescence, but this is not included in estimation, as in most cases, communities included a single individual. This, however, is not expected to affect the consistency of the IV estimator, considering that, by construction, shocks are uncorrelated with fixed locality characteristics.
8. In the case of country-specific samples, clustered standard errors may provide poor estimates of standard errors due to the small number of clusters (Angrist and Pischke 2009, p. 319; Cameron and Miller 2015). We did not, however, find evidence of marked differences in *p*-values of significance tests based on clustered standard errors and *p*-values based on wild cluster bootstrap that performs better when the number of clusters is small (Cameron *et al.* 2008) (results are available from the lead author on request). Thus we chose to report clustered standard errors also because it is not possible to compute standard errors when using the wild cluster bootstrap approach (Cameron *et al.* 2008).
9. These effects are similar to or slightly smaller than those in existing studies looking at the impact of rainfall shocks on adult height (Pathania 2007; Maccini and Yang 2009). Nevertheless, our results are not directly comparable with these studies, as these differ from our study along a few dimensions: (i) they investigate at the effects of rainfall shocks in early years of life; (ii) some of these studies consider large deviations of rainfall, i.e. droughts; (iii) they mainly find a positive effect, suggesting that the effect operates predominantly via an income channel.
10. We find that only one out of the twenty rainfall shocks coefficients across samples is significant at 5%, which may be in line with the only significant coefficient arising due to chance.
11. These were used because, contrary to other rounds, there are no direct measures of parental health investments on the child in Round 1.
12. The evidence on this presented here is suggestive rather than conclusive, as in some cases child health investments measures do not have significant associations with child HAZ score or because we cannot rule out that there are unobserved child health investments responses to maternal adolescent nutritional status.
13. We have explored this by looking at the effect on maternal adult height on a range of educational inputs. Although there is some evidence of compensatory investments, such as more time spent in school and studying at home at age 5 years among children of shorter mothers, this effect is insignificant (results are available from the lead author on request).

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table A1. Descriptive statistics of mother's ethnicity and parental investments by country

Table A2. Descriptive statistics of language of administration of quantitative achievement tests

Table A3. OLS estimates of the impact of rainfall shocks at different periods of mother's adolescence on maternal adult height

Table A4. OLS estimates of the impact of rainfall shocks in the mother's 13th year of life on child nutritional status from age 1 to 15 y in the India, Peru, and Vietnam pooled sample and by country

Table A5. OLS estimates of the impact of rainfall shocks during the mother's 13th year of life on child quantitative achievement scores from age 5 to 15 y in the India, Peru, and Vietnam pooled sample and by country

Table A6. OLS estimates of the impact of rainfall shocks between the 7th and 10th year of the child's life, realised after mother's height was observed, on maternal height across countries and in the pooled countries sample

Table A7i. TSLS estimates of the impact of maternal adolescent nutritional status on child nutritional status at age 1 and 5 y including potential mediators in the India, Peru, and Vietnam pooled sample

Table A7ii. TSLS estimates of the impact of maternal adolescent nutritional status on child nutritional status at age 8 y including potential mediators in the India, Peru, and Vietnam pooled sample

Table A7iii. TSLS estimates of the impact of maternal adolescent nutritional status on child nutritional status at age 12 y including potential mediators in the India, Peru, and Vietnam pooled sample

Table A7iv. TSLS estimates of the impact of maternal adolescent nutritional status on child nutritional status at age 15 y including potential mediators in the India, Peru, and Vietnam pooled sample

Table A8. OLS and TSLS estimates of the impact of maternal adolescent nutrition on child nutritional status from age 1 to 15 y in the India, Peru, and Vietnam pooled sample of children with non-missing HAZ and achievement test scores in all rounds

Table A9. OLS estimates of the impact of rainfall shocks in the mother's 13th year of life on child nutritional status from age 1 to 15 y in the India, Peru, and Vietnam pooled sample and by country based on children with non-missing HAZ and achievement test scores in all rounds

Table A10i. OLS estimates of the impact of rainfall shocks in the mother's 13th year of life on child nutritional status at age 1 and 5 y including potential mediators in the India, Peru, and Vietnam pooled sample

Table A10ii. OLS estimates of the impact of rainfall shocks in the mother's 13th year of life on child nutritional status at age 8 y including potential mediators in the India, Peru, and Vietnam pooled sample

Table A10iii. OLS estimates of the impact of rainfall shocks in the mother's 13th year of life on child nutritional status at age 12 y including potential mediators in the India, Peru, and Vietnam pooled sample

Table A10iv. OLS estimates of the impact of rainfall shocks in the mother's 13th year of life on child nutritional status at age 15 y including potential mediators in the India, Peru, and Vietnam pooled sample