ENSO Drives Child Undernutrition in the Global Tropics*

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Abstract

The El Niño Southern Oscillation (ENSO) is a principal component of global climate variability known to influence a host of social and economic outcomes, but its systematic effects on human health remain poorly understood. We estimate ENSO's association with child nutrition at global scale by combining variation in ENSO intensity from 1986-2018 with children's height and weight from 186 surveys conducted in 51 teleconnected countries, containing 48% of the world's under-5 population. Warmer, drier El Niño conditions predict worse child undernutrition in most of the developing world, but better ones in the small number of areas where precipitation is positively affected by ENSO. This relationship looks similar at both global and regional scale, and has not appreciably weakened over the last four decades. Results imply that the 2015 El Niño pushed over 7 million children into undernutrition, demonstrating the degree to which human well-being remains subject to predictable climatic processes.

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1 Introduction

Climate variability is increasingly recognized as a key determinant of health outcomes (*1*) and a major concern for global climate policy and international public health (*2*), with the IPCC warning that anthropogenic climate change will very likely increase the frequency and intensity of extreme events (*3*, *4*). The El Niño Southern Oscillation (ENSO) is a major source of climate variability known to affect key social, economic and health outcomes (*5–14*), however, the systematic effects that these correlated shifts in the tropical climate have on global health remain understudied. ENSO's adverse large-scale effects have been documented for hundreds of years (*15*), yet despite our improved predictive capacity over ENSO, much of humanity is still susceptible to its consequences. Given that probabilistic forecasts of ENSO have skill at predicting conditions months in advance, there is an opportunity to decouple food insecurity and human nutrition from this predictable climate process. However, analyses of ENSO's impacts on food security have generally focused on a single country or El Niño episode (*16*) and lack global or regional scope to guide national and international public investments that preempt adverse effects of ENSO.

This paper provides the first estimate of ENSO's impacts on human nutrition in the global tropics, leveraging over one million geolocated child records spanning four decades and all developing country regions. We estimate the systematic effect of ENSO-driven tropical climate variability by examining the association between annual eastern equatorial Pacific ENSO state and measures of children's weight from surveys conducted during that year. Children's anthropometric measures are extremely sensitive to nutritional shocks due to their high caloric needs while growing (*17*), and provide a summary measure of contemporary household food security (*18*). Our interest is in estimating the total effect of ENSO variability across all channels of influence – from agricultural productivity to infectious disease to conflict – that might affect human nutrition, and documenting systematic differences in ENSO response within sample.

We capture ENSO variation using the widely-used Niño 3.4 index of equatorial Pacific sea surface temperature (*19*, *20*), which spans 5°N-5°S, 170°W-120°W (Fig. 1A). Children's weight-for-age z-scores (WAZ) at time of survey (Fig. 1B) are calculated using the NCHS/CDC/WHO International Reference Standard (*21*) intended to provide a single measure of child nutritional outcomes comparable across ages and sexes. We first identify all countries with local climates teleconnected to ENSO (Fig. 1C) for which Demographic and Health Surveys (DHS) anthropometric data exist. This yields a sample of 1.3 million children ages 0-4 interviewed in 186 household surveys between 1986 and 2018. The sample includes 51 countries containing 38% of the world's population and 48% of the world's under-5 population as of 2018. We assign treatment (i.e., the ENSO state when the child was surveyed) annually by tropical year, accounting for the spring barrier delay in ENSO state change (*8*), by calculating the maximum Niño 3.4 value between May-Dec of a given year. We assign that to all children interviewed by DHS during that period, as well as all children interviewed during the following year's Jan-Apr months (i.e., before the following year's spring barrier).

While a warmer ENSO leads to higher temperature throughout the tropics, shifts in precipitation pattern lead to some areas getting wetter than normal while others get drier. We account for potential differences in the effects of ENSO by allowing for different effects in subnational regions where precipitation is positively correlated to warmer ENSO (Figs. 1D and S1). Since only 6.4% of our sample lives in regions where warmer ENSO leads to clear wet anomalies, we focus our discussion on results for the majority of the sample. In order to remove potential confounders (*22*, *23*), we purge the estimates of average differences across countries and across rural and urban areas within each country using location fixed effects, and we detrend the data annually and remove monthly seasonality by major world regions. The temporal variation in ENSO anomalies – measured as a deviation from long-run average conditions – is used to statistically isolate the association of ENSO state and child malnutrition.

2 Results

We find that warmer, more El Niño-like ENSO conditions increase short-term undernutrition in children across the tropics, with the opposite occurring in places where precipitation tends to increase during El Niño. Even in the absence of controls, the empirical distribution of detrended WAZ is significantly and substantially different ($p < 0.001$) between El Niño and La Niña years (Fig. 2A). After detrending the data and controlling for location-specific unobservable confounders and mother characteristics (Table 1), a 1°C increase in the ENSO index is associated with 0.03σ ($p = 0.02$) average decrease in WAZ. We allow the relationship between ENSO and WAZ to vary flexibly (Fig. 2B) and find that the negative association remains across the distribution of ENSO values. The result is substantively similar across a broad range of model specifications (Table S2), and across other outcomes reflecting recent nutrition, including weight-for-height and body mass index ($-0.04\sigma/°C$ and $p<0.01$ for both measures). Height-for-age or stunting do not decrease with warmer ENSO conditions, consistent with height being slower to respond to health shocks than weight (*24*). Using WHO z-score classification thresholds, warmer ENSO increases the prevalence of undernourishment (below -2σ in weight for age) significantly by 0.6 percentage points per 1°C ($p < 0.05$). We find that the risk of wasting (below -2σ in weight for height) is positive but not significant (0.3pp/°C, $p = 0.21$), consistent with higher noise in height measurements, especially for very sick children (*25*). ENSO conditions do not have a contemporaneous effect on stunting (below -2σ in height for age). All of these patterns are reversed in the minority of places in our sample (6.4%) where warmer ENSO is correlated to wet anomalies. The heterogeneity in results across regions of wet and dry anomalies point towards the importance

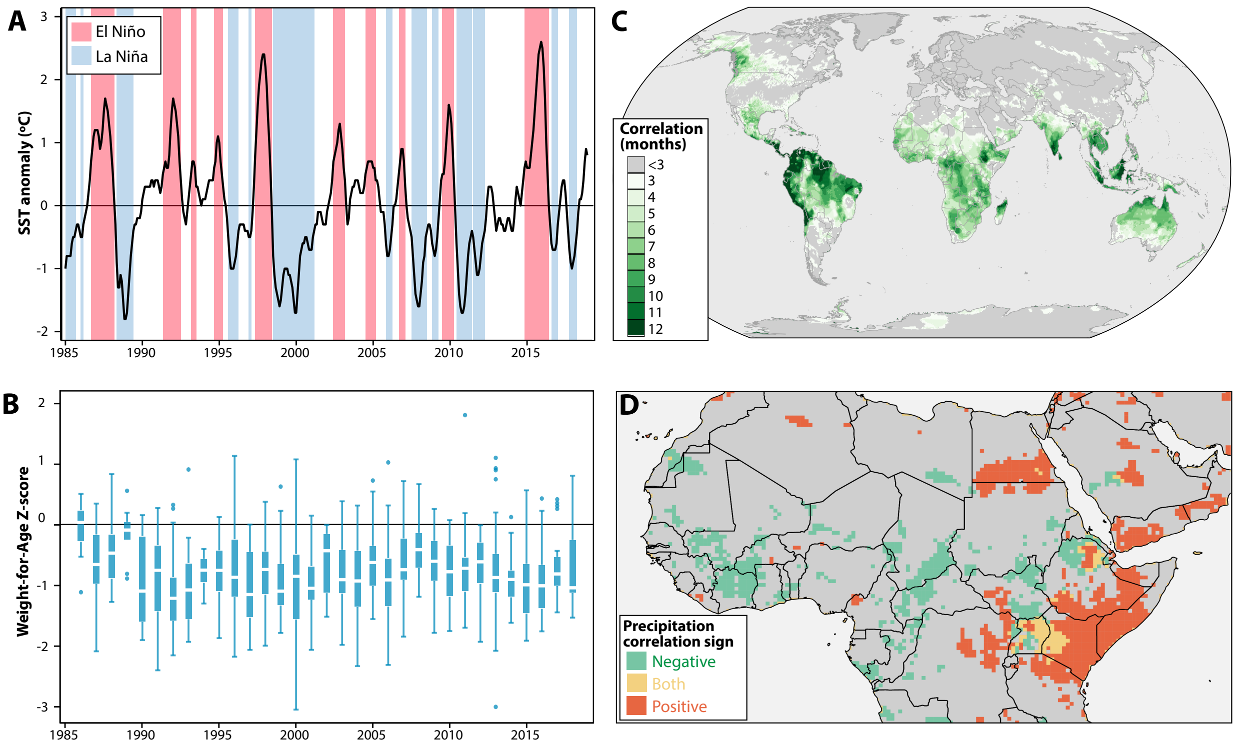

Figure 1: A) NINO3.4 time-series. El Niño or La Niña highlighted in red or blue, respectively. El Niño and La Niña states defined as when the maximum of a three month rolling mean of monthly values was greater than 0.5°C (Niño-like) or less than -0.5°C (Niña-like) compared to a 1981-2010 reference climatology following NOAA CPC guidelines. B) Weight-for-Age z-score distribution over time from all Demographic and Health Survey (DHS) data in teleconnected countries. Box represents interquartile range. Country composition within each year is different, as a rotating sample of countries is surveyed in each year under the DHS programme. C) Pixel-level monthly correlation of surface temperature (1980-2010) and two-month lag of NINO3.4 Sea Surface Temperature (SST), showing teleconnections. Values represent number of months in a year significantly associated with ENSO at the 10% level. D) Pixel-level monthly correlation of precipitation (1980-2010) and two-month lag NINO3.4 SST. Colors indicate the direction of the precipitation effects, highlighting Eastern Africa, the only major region in the DHS sample where precipitation is positively correlated with NINO3.4.

Table 1: Anthropometric effects of ENSO

	(1) Weight for age	(2) Weight for height	(3) Body mass index	(4) Height for age	(5) **Pr(WHO standard):** undernourished	(6) wasted	(7) stunted
Max NINO3.4	-0.0251**	-0.0377***	-0.0381***	0.00363	0.00588**	0.00319	-0.00275
std. error:	(0.0105)	(0.0130)	(0.0132)	(0.00955)	(0.00264)	(0.00251)	(0.00193)
p-value:	0.0234	0.00654	0.00674	0.706	0.0329	0.213	0.163
95% CI (lower):	(-0.0466)	(-0.0641)	(-0.0649)	(-0.0158)	(0.000510)	(-0.00192)	(-0.00669)
95% CI (upper):	-0.00363	-0.0113	-0.0113	0.0231	0.0113	0.00829	0.00118
$\boldsymbol{\rho(precip, NINO) > 0}$	0.0733***	0.0489	0.0370	0.0606*	-0.0195***	-0.00717	-0.0120
std. error:	(0.0222)	(0.0301)	(0.0330)	(0.0304)	(0.00489)	(0.00430)	(0.00769)
Mean of dep. var.	-0.931	-0.228	-0.0895	-1.311	0.204	0.100	0.343
Observations	1,253,176	1,205,335	1,206,659	1,218,846	1,253,176	1,205,335	1,218,846
R-squared	0.129	0.093	0.081	0.069	0.087	0.040	0.074

Notes: Different anthropometric effects of ENSO are concentrated on short run measures (1-3) weight-for-age, weight-for-height, and body mass index z-scores, which all measure shorter-run effects of scarce nutrition, show evidence of contemporaneous ENSO effects measured in °C, while (4) height-for-age, a slower-varying measure, shows only weak evidence in the minority (∼6%) of the sample where NINO3.4 is positively correlated to precipitation. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific mother's age at child's birth, total years of mother's education, and rural vs. urban indicator; and UNICEF world region-specific linear trends in survey year and fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and subnational administrative unit, and observations are reweighted using DHS sample weights and country size weights in order for estimates to be representative for an average country. (5-7) WHO threshold outcomes show ENSO increases the likelihood of being undernourished (below -2σ in weight for age), but shows a weaker, statistically insignificant effect on wasting (below -2σ in weight for height) and no relationship with stunting (below -2σ in height for age). Asterisks indicate statistical significance at the 1% (***), 5% (**) and 10% (*) levels.

of agriculture in mediating the ENSO-nutrition link, though others (e.g., conflict) cannot be ruled out.

The several degree variation in ENSO cycle implies that it is a meaningful source of variation in population nutrition in the tropics. According to these estimates, the 2.25°C increase in the Niño 3.4 index during the 2015 El Niño event, one of the largest on record, likely caused average WAZ in the representative child of our sample countries to decrease by 0.1σ. The human scale of this impact is large given that the under-5 population in our sample countries was 311 million in 2015. To give context to the size of these effects, we look at the scale of public health interventions needed to offset an event of similar magnitude to the 2015 El Niño, using published effect sizes of nutritional interventions (*26*). Fig. 3 shows that around 134 million children would have to receive either multiple micronutrient supplementation (CI 75-193 million), or 72 million (CI 33-105 million) would have to receive provision of complementary foods, or 72 million (CI 26-118) would have to receive nutrition education. The effect of the 2015 El Niño is also equivalent to the WAZ reduction from moving 46 million children from urban to rural areas, based on our model results. The 2015 El Niño increased risk of being below the WHO threshold for undernourished by 2.3 percentage points, i.e., an increase of nearly a tenth of the current population rate of 24%. This corresponds to an additional 7.1 million children being driven into undernourished status.

Our main result is consistent across alternative specifications, observation weighting, and ENSO variable

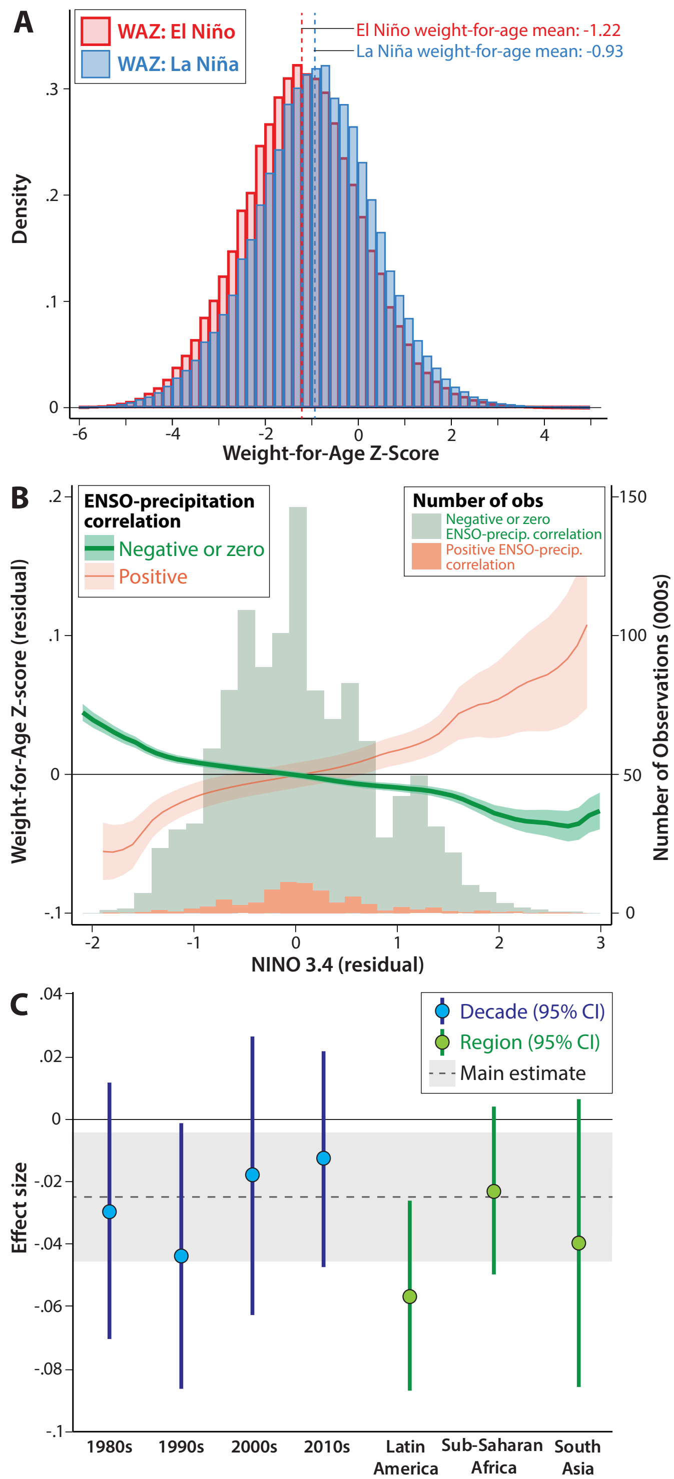

Figure 2: A) Distribution of Weight-for-Age z-scores (WAZ) during years classified as El Niño (red) and La Niña (blue) according to NOAA definition using NINO3.4 SSTs, with means of each distribution shown. B) Epanechnikov kernel-weighted local polynomial estimate (bandwidth 0.7) of association of WAZ with ENSO for areas where more than 50% of the land area of a country has precipitation correlated with ENSO for more than three months in the year negatively (green) and positively (orange). Histograms represent number of observations in each precipitation correlation subsample. C) Effect of ENSO on WAZ for each decade and UNICEF world region in the sample, excluding locations with positive precipitation teleconnections. Dots signify point estimates, bars signify 95% confidence intervals, and grey shaded region and dashed line show main effect from Table 1.

definitions (Tables S1-S3). Positive deviations from the ENSO index mean state decrease z-scores, and negative deviations of the ENSO index mean (La Niña events) reduce undernutrition compared to baseline state (Table S3). For the purposes of population-wide attribution statistics, we also calculate the average effect of warmer ENSO in the average country, without separating the sample by whether warm ENSO leads to dry or wet anomalies (Table S4). The average effect across the sample suggests that warmer ENSO leads to a $0.04\sigma/°C$ reduction in weight-for-age ($p = 0.02$), and a 1 percentage point increase in prevalence of undernourishment ($p < 0.01$). We also test the use of alternative detrending of the data with decade fixed effects (Table S5). The lagged effects of ENSO (Table S6) indicates no persistent effect of ENSO on child nutrition, except in the subsample with positively correlated rainfall. Finally, we show that timing of DHS survey does not vary as a result of ENSO state (Figure S2 and Table S10) and that results hold under a placebo randomization test (Figure S3).

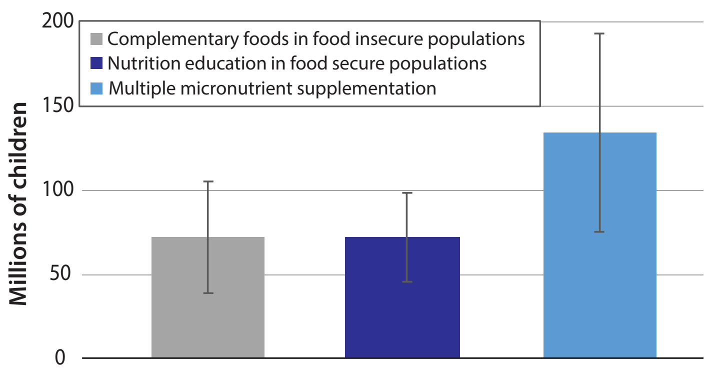

Figure 3: Interventions Required to Offset 2015 El Niño. Millions of children who must be targeted with specific interventions in order to reverse the effects on malnourishment caused by the 2015 El Niño. Effect sizes calculated using treatment effects in Bhutta et al. (2013).

3 Discussion

The negative relationship between child nutrition and warm ENSO state does not appear to vary appreciably across space and time, with the effects for major world regions and different decades in the sample being statistically indistinguishable from our main effect (Fig. 2C). That there has been little progress in attenuating the food security effects of ENSO despite increasing incomes and trade connectivity implies that the limits to adaptation may be strict, at least over the income range of countries in the sample. The international community has set the target of eliminating all forms of malnutrition worldwide by 2030 as part of the Sustainable Development Goals (SDG) agenda, and is making efforts to establish metrics, monitor, and implement policies to achieve this goal (*27*). Developing countries deemed to be making insufficient progress are being pressured to do more (*28*). During 2015-2018, 34% of the children in our sample countries were undernourished, implying that in order to meet the hunger SDG the percentage of undernourished children would have to decrease by 2.6 percentage points per year. Our estimates suggest that ENSO conditions similar to the 2015 El Niño would eliminate one year of progress towards that goal. Indeed, the 2015 El Niño likely played a major role in worsening famine conditions, and these results support a view of ENSO driving episodic famine in the tropics where yields are low during El Niño years even as global average yields increase due to gains in the extra-tropics. Governments and agencies engaged in multi-year humanitarian planning and budgetary frameworks could incorporate ENSO forecasts to anticipate fluctuations in availability of local vs. global resource streams needed to ensure progress in fighting malnutrition. Despite scientific progress characterizing ENSO and documenting its various channels of influence on society, much remains to be done to decouple nutrition outcomes in developing countries from this predictable interannual phenomenon.

4 Data and Methods

4.1 Data

ENSO Time Series Data capturing original monthly values of the NINO 3.4 index are from the NOAA Center for Weather and Climate Prediction website (*29*). We assemble our treatment variable by taking the maximum monthly anomaly value of the index during the May-Dec period of a given calendar year, assigning it to all children interviewed during that tropical year (May-April). We note that alternative constructions of ENSO3.4 state perform similarly (see Table S3).

DHS Children's Anthropometric Data are from all DHS surveys containing children's anthropometric data (N=186, 51 countries, 1986-2018). We standardize DHS administrative region names, aggregating to supersets if any regions changed borders or split during our sample period. We calculate each child's anthropometrics using his/her height and weight following the NCHS/CDC/WHO International Reference Standard (*21*) intended to provide a single measure of child nutritional outcomes comparable across ages and genders.

4.2 Methods

Time series data on El Niño are from the NOAA Climate Prediction Center's monthly time series. We designate a country as teleconnected if its temperature is closely coupled to ENSO9, defined as having at least 50% of the population living in locations where local temperature as reported in the UDEL global gridded temperature dataset (*30*) at month t is significantly correlated with the second month lag (t–2) of the ENSO state (NINO3.4 SST index) for at least three months of the year. We designate teleconnection at country level since price effects from ENSO in one subnational region would affect all parts of the country through domestic markets. Our treatment variable of interest is the maximum value of the NINO3.4 index between May and December in a given year. We also record the correlation between ENSO temperatures and precipitation at pixel-level within teleconnected countries, in order to differentiate between places where warmer ENSO leads to dry or wet precipitation anomalies. Our estimates separately identify effects in DHS clusters located in first-level administrative units (e.g., state/province) where more than 50% of land area has three months or more per year with a statistically significant positive correlation between precipitation and the second monthly lag of NINO3.4 (*8*).

Microdata on children's health are from the Demographic and Health Surveys (DHS). We identify all standard DHS surveys from teleconnected countries for which children's anthropometric data are available, generating a sample of 1,253,176 child-level observations in 186 surveys from 51 countries between 1986 and 2018. We calculated children's anthropometrics according to the WHO Anthro Child Growth Standard[1].

We estimate the effect of ENSO on anthropometric measure Y_{ict} for child i living in country c in year t (Table 1) using an equation of the form

$$Y_{ict} = \alpha + \beta_n NINO_t + \beta_p[NINO_t \times I(Positive_{(Precip_i)})] + \gamma \boldsymbol{X}_{ic} + f(t_{(globalregion)}) + FE_{cr} + \varepsilon_{ict} \tag{1}$$

for NINO3.4 anomalies defined as above for the tropical year t in which the anthropometrics for child i were measured, as well as country-specific controls for whether the household is urban or rural ($FE_{c\times rural}$), the mother's education in years, and the mother's age at time of child birth. $f(t)$ captures detrending and seasonality adjustments to the data for each of five major UNICEF world regions using both linear year trends and month of survey fixed effects. We normalize the data by country using fixed effects FEcr separately identified for rural and urban location within each country. This research design corresponds to looking at average differences in child outcomes within the same country, separately for rural and urban areas, under different global ENSO states. This allows for identification of ENSO's effect under minimal assumptions of potential confounding (*23*, *31*). Standard errors are two-way clustered at the level of interview year (N = 33) in order to correct for a common global ENSO shock, as well as at the level of subnational first administrative unit (N=532) in order to adjust for serial correlation in anthropometric indicators over time and space.

Most specifications identify β, the effect of ENSO, separately for children living in teleconnected areas where El Niño conditions tend to produce wet anomalies (β_p) and those with neutral or dry anomalies (β_n).

[1]Available at: http://www.who.int/childgrowth/software/en/

Depending on the specification, the regression weights observations either to produce an estimate of β that represents the effect of ENSO on the average country in our sample (that is, using the DHS sampling weights for observations, normalized such that all observations across all surveys sum to unity for each country), or an estimate of β that represents the effects on the average child in the countries of our sample (combining normalized DHS sampling weights with population weights for each country). In either case, weights adjust for the fact that countries had different numbers of DHS surveys with different sample sizes over the time period.

For Fig. 2B, we utilize the Frisch-Waugh-Lovell theorem and first residualize our outcome, WAZ, and our independent variable, NINO3.4 SST. That is, we run the following regressions separately for locations with negative / neutral precipitation correlation and positive precipitation correlation, weighted as in equation 1:

$$Y_{ict} = \alpha + \gamma \boldsymbol{X}_{ic} + f(t_{(globalregion)}) + FE_{cr} + \varepsilon_{ict} \tag{2}$$

$$NINO_t = \alpha + \gamma \boldsymbol{X}_{ic} + f(t_{(globalregion)}) + FE_{cr} + \varepsilon_{ict} \tag{3}$$

We plot the relationship between these residuals using an Epanechnikov kernel-weighted local polynomial regression with a bandwidth of 0.7 in the residualized x-variable.

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Supplementary Information

Robustness of empirical results

The negative association between the ENSO index and undernutrition remains robust to a variety of different model specifications controlling for a variety of different plausible observable and unobservable factors. Table S1 shows the build-up of our basic model for weight-for-age and undernourishment to illustrate this point. In Panel A (1), the negative association between higher NINO3.4 temperature and weight for age is apparent (though not statistically significant), with the opposite being true in places where precipitation is positively correlated with NINO3.4. Model (2) flexibly detrends the data by (tropical) year of interview, and normalizes by interview month and country using fixed effects to provide a plausibly causal estimate that is not confounded by trends, seasonality and country of survey. The association between NINO3.4 and weight-for-age is statistically significant at 95% confidence levels, with opposite signs in areas that have a positive correlation between precipitation and NINO3.4 and those that do not. Note that the coefficient of -0.026 for places without positive correlation (93.6% of observations) is statistically consistent for all subsequent specifications. Model (3) normalizes data by rural/urban location, and adds child-level controls, and results in a decrease in the coefficient for positive precipitation correlation locations but no change for other locations, consistent with anthropometric measures being standardized and comparable across age and sex of child. Model (4) flexibly detrends the data separately by UNICEF region and adds country-specific rural/urban fixed effects, resulting in no statistical change in the coefficients while increasing significance levels to 1% confidence. Model (5) adds country-specific interview month fixed effects to remove seasonality separately by country. This stricter specification makes estimates noisier, but they are not statistically different from those in (4). Model (6) controls for mother and child characteristics separately by country, resulting in no significant change in results. Finally, model (7) replaces the country fixed effects with fixed effects in first level administrative unit, thus comparing children living in the same state/province interviewed during different ENSO states. This stricter specification also does not lead to changes in results. Panel B performs all the same specifications using the binary outcome of undernourishment (below -2σ in weight for age). The pattern across specifications is similar: effects are consistent in direction and magnitude across all models, with statistical significance emerging after the data are detrended in model (2).

Table S2 presents models that vary observation weights to inform interpretation. Models (1)-(4) show results on weight for age, while (5)-(8) show results on undernourished (below -2σ in weight for age). Models (1) and (5) use weights as in main results in Table 1 in order produce estimates interpreted as ENSO's effect on a child in the average country. These weights use the DHS sampling weights, adjust for survey size differences across countries, and then adjust for different numbers of DHS surveys in different countries:

$$\omega_{isc}^{avgcountry} = \left(\frac{DHSweight_{isc}}{surveysize_{sc}}\right)\left(\frac{1}{totalsurveys_c}\right) \tag{4}$$

Models (2) and (6) weight observations such that results are interpreted as the effect on the average child in the sample countries. The weights are the same as above, but now weight across countries by country population:

$$\omega_{isc}^{avgchild} = \left(\frac{DHSweight_{isc}}{surveysize_{sc}}\right)\left(\frac{population_c}{totalsurveys_c}\right) \tag{5}$$

Results with these weights suggest larger effects of ENSO, although estimates are less precisely identified in the case of weight for age (2). Given that India represents 23% of the data and is by far the country with largest population, models (3) and (7) use average child weights but exclude India and find that results on the average child are larger than in (1) and (5) but not statistically different. In order to gauge whether the results might be driven by observation weights, models (4) and (8) use no weights and find results very similar to the main model. We maintain that weights are appropriate for the main specification given the stratified nature of DHS sampling and the fact that countries have different numbers of DHS surveys.

Table S3 columns (1)-(5) show alternative definitions of the ENSO variable for models on weight for age, while columns (6)-(10) are on undernourished (below -2σ in weight for age). While our main model uses the maximum monthly value of the May-Dec anomaly, models (1) and (6) use the maximum monthly value observed over the full (May-April) tropical year. Models (2) and (7) use the maximum over the May-Dec tropical year; models (3) and (8) use the mean over the tropical year; and models (4) and (9) use the maximum of a three month rolling mean of monthly values observed during the full tropical year. Columns (5) and (10) use indicator variables for El Niño-like and La Niña-like states designating all years where the maximum of a three month rolling mean of monthly values was greater than 0.5°C (Niño-like) or less than -0.5°C (Niña-like) from its 1981-2010 climatology. We note that in every case the association between decreased child weight for age and increased ENSO values remains, with some variation. The binary indicator for El Niño-like events in (5) and (10) is not statistically significant, while La Niña-like events exhibit statistically significant effects on increasing weight for age and reducing undernutrition, with opposite effects in places where precipitation correlation with NINO3.4 is positive.

Table S4 does not distinguish effects by the precipitation correlation to NINO3.4 to produce an average treatment effect of warmer ENSO across all children. The average effect is consistent with the effect size in Table 1 on children outside areas where precipitation is positively correlated to NINO3.4. The average effect is that warmer ENSO leads to a $0.04\sigma/°C$ reduction in weight-for-age ($p = 0.02$), and a 1 percentage point increase in prevalence of undernourishment ($p < 0.01$).

Table S5 implements an alternative detrending of the data using decade fixed effects and shows that coefficients are not statistically different from Table 1. Table S6 explores the lagged effects of ENSO by adding a one-year lag to the specification. There is only evidence of persistent effects of warmer ENSO on child nutrition in the subsample with positively correlated rainfall.

Tables S7-S8 test whether results are robust to alternative definitions of teleconnection. Figure S1 shows the global map of ENSO correlations to precipitation and temperature used for teleconnection assignment. Table S7 extends the main sample to include countries that are teleconnected with NINO3.4 in terms of precipitation but not temperature. Specifically, we added countries that are not already in the main sample, have DHS surveys and have at least 30% of their land area showing correlation between precipitation and NINO3.4. These countries are Kyrgyz Republic, Azerbaijan, Armenia, Turkey, Pakistan, Kazakhstan, and Egypt. No coefficient is statistically different from its analogue in Table 1.

Table S8 restricts the sample to include only those countries which have both a significant teleconnection with ENSO via temperatures and precipitation. This leads to a strictly smaller subsample of countries than the main tables in Table 1. The sample size drops to approximately 250,000, a significant change compared to approximately 1.25 million for the main sample, and 1.35 million for the extended sample in Table S7. We note that there is a priori ambiguity on whether the effects of ENSO in this smaller sample would be larger or smaller. On the one hand, the subsample represented by this table are those with presumably stronger (or at least more noticeable) climate variability induced by ENSO. This could imply that these countries are better adapted, and hence might display smaller effects of ENSO on outcomes. On the other hand, a number of other results would imply that, as a set of lower income countries, their ability to adapt to this climate variability may be limited. Therefore, by restricting to countries with stronger ENSO effects, we might expect that the effects would be stronger. The results in the table are supportive of the second hypothesis, i.e., worsening effects, but we they are nonetheless not statistically different from the results in Table 1.

Figure S2 and Tables S10-S11 explore whether the ENSO state might affect the timing of DHS surveys within the year, and therefore spuriously lead to changes in child anthropometrics due to seasonality. Figure S2 plots sample sizes by month and ENSO state with 95% CIs to show variation in these patterns across DHS surveys. There is no statistically different monthly pattern across ENSO states. Table S10 adds country-specific monthly fixed effects to ensure that only children interviewed in the same country during the same month of the year are being compared across ENSO states in their anthropometrics. Table S11 regresses the DHS month of interview on the ENSO state (including all covariates, detrending and fixed effects in the main regression) and shows that the two are not associated. These results suggest that the effects of ENSO state on child anthropometrics are not the result of correlated interview timing changes.

Table S12 employs a variety of standard error clustering in order to adjust for a covariate shock (all observations experience the same ENSO treatment variable per year) as well as spatial and serial correlation in child anthropometric estimates. Inference remains consistent whether standard errors are not clustered (1); clustered at UNICEF region (2), country (3) or admin1/state (4) to adjust for arbitrary serial and spatial autocorrelation at these geographic units. Inference is also consistent under two-way clustering at UNICEF region and decade (5), country and year (6), or admin1 and year (7, the main specification). Note that (7) is designed to address possible spatial and temporal autocorrelation through use of two-way clustering of standard errors (*32*) at the levels of interview year and first subnational administrative subunit (e.g., state or province, at which level the DHS is representative). This approach is conservative, and controls for arbitrary autocorrelation within both the level of treatment (i.e. tropical year) across space as well as within the DHS sample frame across multiple surveys at different times.

Finally, Figure S3 shows that a randomization inference test rejects the possibility that the structure of the data is spuriously resulting in the estimated effects on child anthropometrics (*33*). The procedure randomly permutes yearly NINO3.4 values across years, and estimates the main specification on child weight for age (as in Table 1 column 1, excluding the observations with positive precipitation correlation to NINO3.4):

$$Y_{ict} = alpha + \beta_n NINO_t + \gamma \boldsymbol{X}_i + f(t_{globalregion}) + FE_{(c \times rural)} + \varepsilon_{ict} \tag{6}$$

The figure plots the distribution of β_n estimated from the 2,000 random permutations of NINO3.4. This, in effect, creates 2,000 placebo datasets where every child surveyed in tropical year T, i.e., between May of calendar year T and April of calendar year T+1, is assigned a random NINO3.4 anomaly value from the time series of NINO3.4 without replacement. The distribution of estimates from running our main specification on these 2,000 datasets is the blue shaded region. It is centered at 0, providing evidence that this research design is not biased by, for example, temporal autocorrelation. Further, the coefficient we estimate using the actual NINO3.4 variation (-0.025) is substantially different from zero ($p = 0.08$). This Fisher randomization inference test illustrates that the residual annual variation in NINO3.4 and the child anthropometric data is meaningful compared to arbitrary degrees of freedom at the annual level.

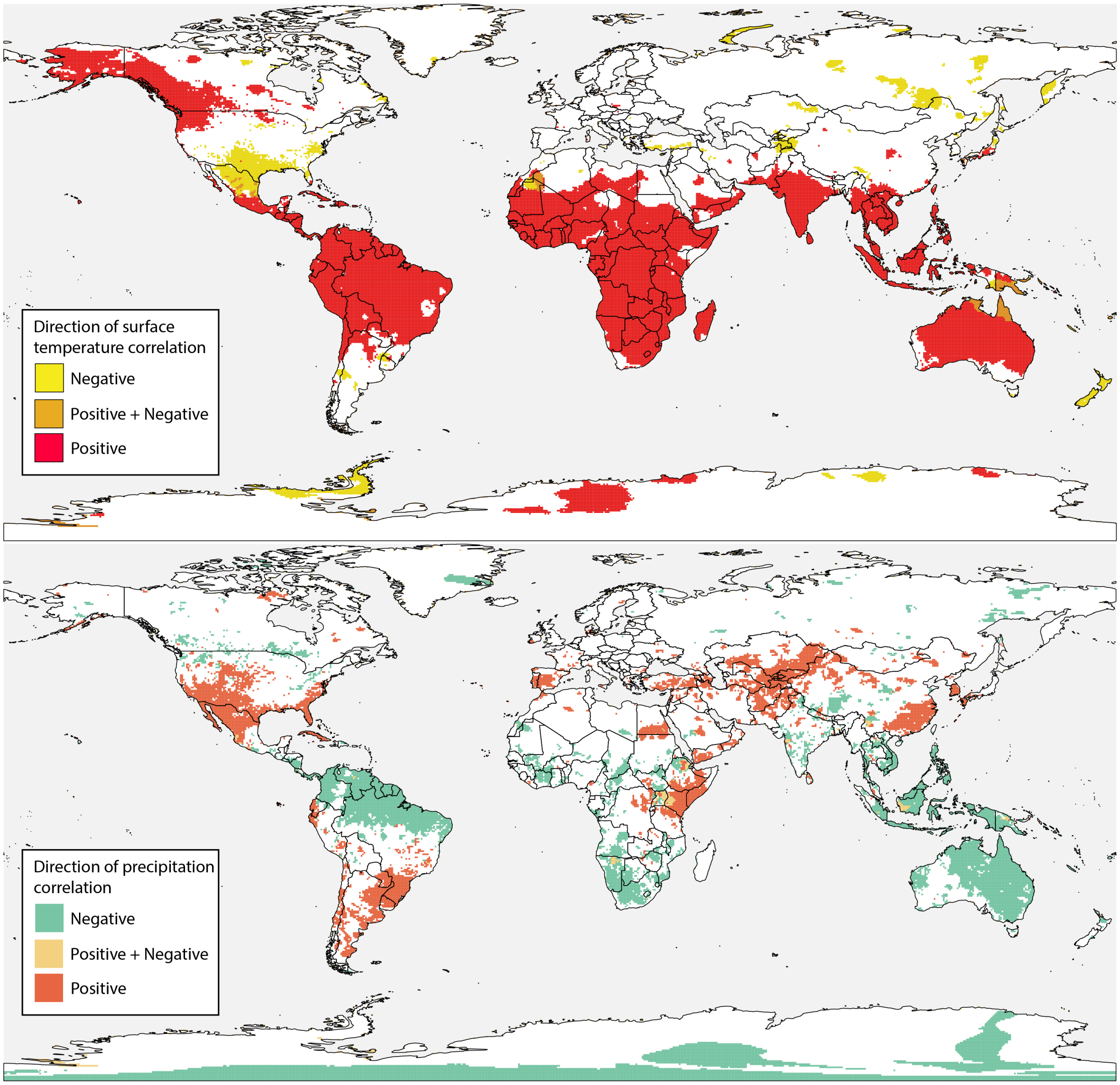

Figure S1: Global Map of ENSO Precipitation and Temperature Correlations. Upper Panel: teleconnection areas based on precipitation correlations. Teleconnections are defined as pixels where the local precipitation, as measured by UDEL gridded precipitation, show 3 or more statistically significant months of correlation with the second month lag of NINO3.4 SSTs. There is substantial heterogeneity in how precipitation is affected by ENSO, with areas of both positive and negative correlation. Lower Panel: teleconnection areas based on temperature correlations, defined as in the upper panel but using monthly temperatures from the UDEL climate dataset. This is the sample selection criterion used in the paper, and the direction of precipitation correlations informs the heterogeneity analysis.

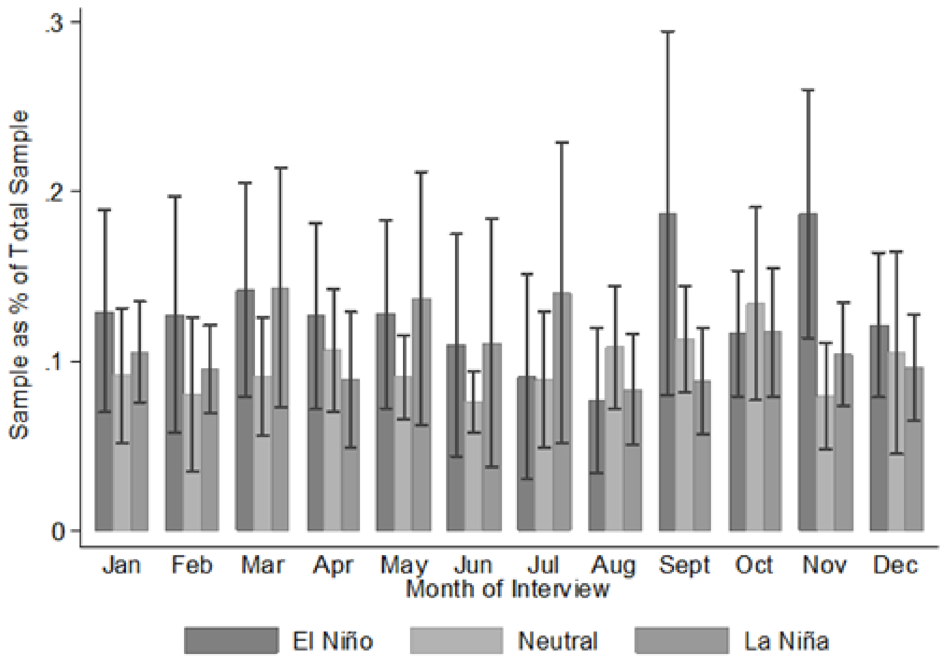

Figure S2: Sample sizes show no statistically different monthly pattern in DHS interviews across ENSO states. Graph plots the result of calculating the sample percentage of each DHS survey separately by month and ENSO state. Bar heights and error bars indicate mean and 95% confidence interval across DHS surveys.

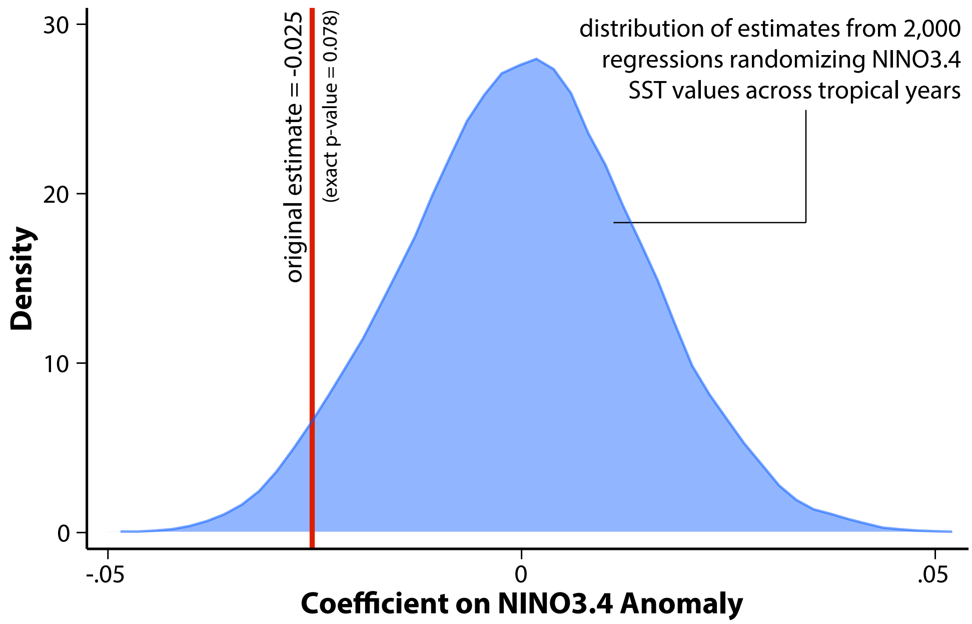

Figure S3: Randomization inference test indicates association of ENSO state and nutrition unlikely due to chance. The figure plots the distribution of coefficients β_n from the following regression matching the estimation in column 1 of Table 1 after excluding locations with positive precipitation correlation: $Y_{ict} = \alpha + \beta_n NINO_t + \gamma \boldsymbol{X}_i + f(t_{globalregion}) + FE_{(c \times rural)} + \varepsilon_{ict}$. Y is child weight for age. Estimates of β_n are produced after values of NINO3.4 are reshuffled across tropical years. The process is repeated with 2,000 random permutations of NINO3.4. The randomized permutation exercise rejects the possibility that the estimated β_n of -0.025 (shown by the vertical line) is a spurious result ($p = 0.08$). Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother's age at child's birth and total years of mother's education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country.

Table S1: Results under various fixed effect specifications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
				Panel A: Weight for Age			
Max NINO3.4	-0.00625	-0.0260**	-0.0294**	-0.0302***	-0.0181*	-0.0284***	-0.0276***
std. error:	(0.0357)	(0.0126)	(0.0116)	(0.0104)	(0.00931)	(0.00984)	(0.00939)
p-value:	0.862	0.0476	0.0162	0.00637	0.0605	0.00694	0.00600
95% CI (lower):	-0.079	-0.0516	-0.0529	-0.0513	-0.0371	-0.0484	-0.0468
95% CI (upper):	0.0665	-0.000294	-0.00580	-0.00914	0.000847	-0.00835	-0.00851
$\boldsymbol{\rho(precip, NINO) > 0}$	0.0569	0.184**	0.0652**	0.0683***	0.0592**	0.0718***	0.107**
std. error:	(0.175)	(0.0741)	(0.0260)	(0.0239)	(0.0258)	(0.0223)	(0.0408)
p-value:	0.747	0.0184	0.0176	0.00747	0.0285	0.00298	0.0130
95% CI (lower):	-0.299	0.0331	0.0122	0.0196	0.00665	0.0263	0.0242
95% CI (upper):	0.413	0.335	0.118	0.117	0.112	0.117	0.190
Mean of dep. var.	-0.941	-0.941	-0.931	-0.931	-0.931	-0.931	-0.931
R-squared	0.000	0.099	0.125	0.127	0.132	0.130	0.139
				Panel B: Undernourished (low weight for age)			
Max NINO3.4	0.00310	0.00537	0.00604*	0.00714**	0.00409*	0.00646**	0.00571**
std. error:	(0.00913)	(0.00340)	(0.00301)	(0.00263)	(0.00226)	(0.00239)	(0.00240)
p-value:	0.736	0.124	0.0536	0.0107	0.0796	0.0110	0.0233
95% CI (lower):	-0.0155	-0.00156	-0.000101	0.00178	-0.000511	0.00158	0.000827
95% CI (upper):	0.0217	0.0123	0.0122	0.0125	0.00868	0.0113	0.0106
$\boldsymbol{\rho(precip, NINO) > 0}$	-0.0267	-0.0539**	-0.0188***	-0.0187***	-0.0178***	-0.0191***	-0.0278**
std. error:	(0.0408)	(0.0215)	(0.00637)	(0.00532)	(0.00468)	(0.00502)	(0.0110)
p-value:	0.518	0.0173	0.00592	0.00136	0.000597	0.000623	0.0169
95% CI (lower):	-0.11	-0.0976	-0.0318	-0.0295	-0.0274	-0.0293	-0.0503
95% CI (upper):	0.0565	-0.0101	-0.00581	-0.00783	-0.00830	-0.00883	-0.00533
Mean of dep. var.	0.206	0.206	0.204	0.204	0.204	0.204	0.204
R-squared	0.000	0.069	0.083	0.085	0.089	0.087	0.094
Observations	1,268,295	1,268,295	1,253,176	1,253,176	1,253,173	1,253,176	1,253,176
Country FE		yes	yes	yes	yes	yes	
Year trend		yes	yes	×region	×region	×region	×region
Interview month FE		yes	yes	yes	×country	yes	yes
Rural FE			yes	×country	×country	×country	×country
Child & Mother controls			yes	yes	yes	×country	yes
Admin1 FE							yes

Notes: The top panel examines weight for age z-scores, while the bottom panel examines a binary variable for whether the child is undernourished by WHO standards (below -2σ in weight for age). Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. Asterisks indicate statistical significance at the 1% (***), 5% (**) and 10% (*) levels.

Table S2: Results under various observation weighting options

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		Weight for age				Probability of meeting WHO standard for undernourished		
Max NINO3.4	-0.0251**	-0.0420**	-0.0446*	-0.0231**	0.00588**	0.0109***	0.00619*	0.00512**
std. error:	(0.0105)	(0.0194)	(0.0253)	(0.00985)	(0.00264)	(0.00370)	(0.00321)	(0.00229)
p-value:	0.0234	0.0383	0.0875	0.0255	0.0329	0.00608	0.0633	0.0322
95% CI (lower):	(-0.0466)	(-0.0815)	(-0.0961)	(-0.0431)	(0.000510)	(0.00333)	(-0.000362)	(0.000464)
95% CI (upper):	-0.00363	-0.00242	0.00693	-0.00301	0.0113	0.0184	0.0127	0.00978
$\boldsymbol{\rho(precip, NINO) > 0}$	0.0733***	0.0226	0.0714**	0.0678***	-0.0195***	-0.0104	-0.0207***	-0.0193***
std. error:	(0.0222)	(0.0418)	(0.0338)	(0.00793)	(0.00489)	(0.0126)	(0.00293)	(0.00287)
Mean of dep. var.	-0.931	-1.425	-1.019	-1.078	0.204	0.343	0.242	0.238
Observations	1,253,176	1,253,176	960,857	1,253,233	1,253,176	1,253,176	960,857	1,253,233
R-squared	0.129	0.179	0.159	0.162	0.087	0.118	0.107	0.111
Weights	Avg Ctry	Avg Child	Avg Child	None	Avg Ctry	Avg Child	Avg Child	None
Sample	All	All	Exclude India	All	All	All	Exclude India	All

Notes: 1-4 examine weight for age z-scores, while 5-8 examine a binary variable for whether the child is undernourished by WHO standards (below -2σ in weight for age). Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother's age at child's birth and total years of mother's education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions. 1 and 5 use weights to represent the effect on an average country in the sample, 2 and 6 weigh observations to represent the average child in the sample; 3 and 7 use the same weights but exclude India given its dominance in the sample. 4 and 8 use no weights. Asterisks indicate statistical significance at the 1% (***), 5% (**) and 10% (*) levels.

Table S3: Results under various definitions of ENSO

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Weight for age					Probability of meeting WHO standard for undernourishment				
NINO3.4 variable	May-Apr Max NINO3.4	May-Dec Max NINO3.4	May-Apr Mean NINO3.4	May-Apr Max of 3mo Rolling Mean NINO3.4	El Niño / La Niña binary	May-Apr Max NINO3.4	May-Dec Max NINO3.4	May-Apr Mean NINO3.4	May-Apr Max of 3mo Rolling Mean NINO3.4	El Niño / La Niña binary
	-0.0301**	-0.0306**	-0.0215**	-0.0322**		0.00569	0.00651	0.00459*	0.00595	
std. error:	(0.0141)	(0.0145)	(0.0103)	(0.0152)		(0.00413)	(0.00421)	(0.00268)	(0.00444)	
p-value:	0.0406	0.0420	0.0453	0.0417		0.178	0.131	0.0962	0.189	
95% CI (lower):	-0.0588	-0.0601	-0.0425	-0.0631		-0.00273	-0.00206	-0.000865	-0.00309	
95% CI (upper):	-0.00137	-0.00119	-0.000476	-0.00129		0.0141	0.0151	0.0101	0.0150	
$\boldsymbol{\rho(precip, NINO) > 0}$	0.00147	0.00148	0.00152	0.00147		-0.000278	-0.000280	-0.000290	-0.000278	
std. error:	(0.00146)	(0.00146)	(0.00153)	(0.00146)		(0.000305)	(0.000304)	(0.000320)	(0.000305)	
p-value:	0.321	0.316	0.327	0.321		0.369	0.364	0.371	0.369	
95% CI (lower):	-0.0015	-0.00149	-0.00159	-0.0015		-0.000898	-0.0009	-0.000941	-0.0009	
95% CI (upper):	0.00443	0.00446	0.00463	0.00444		0.000343	0.000340	0.000361	0.000343	
El Niño State					0.00884					-0.000510
std. error:					(0.0152)					(0.00485)
p-value:					0.564					0.917
95% CI (lower):					-0.0221					-0.0104
95% CI (upper):					0.0397					0.00936
$\boldsymbol{\rho(precip, NINO) > 0}$					0.0616					-0.0175*
std. error:					(0.0440)					(0.0103)
p-value:					0.171					0.1000
95% CI (lower):					-0.0281					-0.0386
95% CI (upper):					0.151					0.00354
La Niña State					0.116***					-0.0256***
std. error:					(0.0342)					(0.00779)
p-value:					0.00183					0.00248
95% CI (lower):					0.0465					-0.0415
95% CI (upper):					0.186					-0.00972
$\boldsymbol{\rho(precip, NINO) > 0}$					-0.261**					0.0757**
std. error:					(0.0968)					(0.0312)
p-value:					0.0109					0.0212
95% CI (lower):					-0.459					0.0121
95% CI (upper):					-0.0643					0.139
Mean of dep. var.:	-0.931	-0.931	-0.931	-0.931	-0.931	0.204	0.204	0.204	0.204	0.204
Observations	1,253,176	1,253,176	1,253,176	1,253,176	1,253,176	1,253,176	1,253,176	1,253,176	1,253,176	1,253,176
R-squared	0.129	0.129	0.129	0.129	0.129	0.087	0.087	0.087	0.087	0.087

Notes: 1-5 examine weight for age z-scores, while 6-10 examine a binary variable for whether the child is undernourished by WHO standards (below -2σ in weight for age). (1) and (6) use the maximum monthly value observed over the full (May-April) tropical year. (2) and (7) use the maximum over the May-Dec tropical year; models (3) and (8) use the mean over the tropical year; and models (4) and (9) use the maximum of a three month rolling mean of monthly values observed during the full tropical year. (5) and (10) use indicator variables for El Niño-like and La Niña-like states designating all years where the maximum of a three month rolling mean of monthly values was greater than 0.5°C (Niño-like) or less than -0.5°C (Niña-like) from its reference climatology following NOAA CPC guidelines. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother's age at child's birth and total years of mother's education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. Asterisks indicate statistical significance at the 1% (***), 5% (**) and 10% (*) levels.

Table S4: Results as an average treatment effect

	(1) Weight for age	(2) Weight for height	(3) Body mass index	(4) **Pr(WHO standard):** undernourished	(5) wasted
Max NINO3.4	-0.0405*	-0.0357**	-0.0327**	0.0101**	0.00312**
std. error:	(0.0217)	(0.0170)	(0.0142)	(0.00422)	(0.00141)
p-value:	0.0710	0.0436	0.0277	0.0225	0.0336
95% CI (lower):	(-0.0847)	(-0.0704)	(-0.0615)	(0.00152)	(0.000257)
95% CI (upper):	0.00367	-0.00108	-0.00383	0.0187	0.00598
Mean of dep. var.	-1.422	-0.664	-0.501	0.342	0.168
Observations	1,274,773	1,226,664	1,228,010	1,274,773	1,226,664
R-squared	0.179	0.130	0.107	0.118	0.052

Notes: Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother's age at child's birth and total years of mother's education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average child in the sample countries. Asterisks indicate statistical significance at the 1% (***), 5% (**) and 10% (*) levels.

Table S5: Results using decade fixed effects

	(1) Weight for age	(2) Weight for height	(3) Body mass index	(4) **Pr(WHO standard):** undernourished	(5) wasted
Max NINO3.4	-0.0217*	-0.0370***	-0.0373***	0.00501*	0.00201
std. error:	(0.0122)	(0.0122)	(0.0117)	(0.00288)	(0.00182)
p-value:	0.0835	0.00466	0.00311	0.0918	0.278
95% CI (lower):	(-0.0465)	(-0.0617)	(-0.0610)	(-0.000861)	(-0.00170)
95% CI (upper):	0.00305	-0.0122	-0.0135	0.0109	0.00573
$\boldsymbol{\rho(precip, NINO) > 0}$	0.0681***	0.0464	0.0349	-0.0180***	-0.00562
std. error:	(0.0232)	(0.0324)	(0.0354)	(0.00508)	(0.00419)
Mean of dep. var.	-0.931	-0.228	-0.0895	0.204	0.100
Observations	1,253,176	1,205,335	1,206,659	1,253,176	1,205,335
R-squared	0.129	0.093	0.081	0.087	0.040

Notes: Different anthropometric effects of ENSO are concentrated on short run measures (1-3) weight for age, weight for height, and body mass index z-scores, which all measure shorter-run effects of scarce nutrition, show evidence of contemporaneous ENSO effects measured in °C. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother's age at child's birth and total years of mother's education; country-specific fixed effects for rural vs. urban; fixed effects for month of interview, and fixed effects for decade of survey year. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. (4-5) WHO threshold outcomes show ENSO increases the likelihood of being undernourished (below -2σ in weight for age) or wasted (below -2σ in weight for height). Asterisks indicate statistical significance at the 1% (***), 5% (**) and 10% (*) levels.

Table S6: Results as a distributed lag model

	(1) Weight for age	(2) Weight for height	(3) Body mass index	(4) **Pr(WHO standard):** undernourished	(5) wasted
Max NINO3.4	-0.0257**	-0.0374***	-0.0378***	0.00597**	0.00325
std. error:	(0.0105)	(0.0128)	(0.0131)	(0.00268)	(0.00252)
p-value:	0.0197	0.00641	0.00691	0.0330	0.207
95% CI (lower):	(-0.0471)	(-0.0635)	(-0.0644)	(0.000514)	(-0.00189)
95% CI (upper):	-0.00439	-0.0113	-0.0111	0.0114	0.00839
$\boldsymbol{\rho(precip, NINO) > 0}$	0.0691***	0.0419	0.0303	-0.0185***	-0.00654
std. error:	(0.0135)	(0.0292)	(0.0333)	(0.00211)	(0.00532)
First lag of Max NINO3.4	-0.0101	0.00332	0.00391	0.00151	0.00103
std. error:	(0.0104)	(0.0140)	(0.0150)	(0.00209)	(0.00236)
p-value:	0.335	0.814	0.796	0.476	0.667
95% CI (lower):	(-0.0312)	(-0.0252)	(-0.0267)	(-0.00276)	(-0.00379)
95% CI (upper):	0.0110	0.0319	0.0345	0.00577	0.00584
$\boldsymbol{\rho(precip, NINO) > 0}$	0.0809***	0.0960***	0.0893**	-0.0168**	-0.0107
std. error:	(0.0292)	(0.0324)	(0.0327)	(0.00730)	(0.00660)
Mean of dep. var.	-0.931	-0.228	-0.0895	0.204	0.100
Observations	1,253,176	1,205,335	1,206,659	1,253,176	1,205,335
R-squared	0.129	0.093	0.081	0.087	0.040

Notes: Different anthropometric effects of ENSO are concentrated on short run measures (1-3) weight for age, weight for height, and body mass index z-scores, which all measure shorter-run effects of scarce nutrition, show evidence of contemporaneous ENSO effects measured in °C. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother's age at child's birth and total years of mother's education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. (4-5) WHO threshold outcomes show ENSO increases the likelihood of being undernourished (below -2σ in weight for age), but shows a statistically insignificant effect on wasting (below -2σ in weight for height). Asterisks indicate statistical significance at the 1% (***), 5% (**) and 10% (*) levels.

Table S7: Results with precipitation teleconnected countries added

	(1) Weight for age	(2) Weight for height	(3) Body mass index	(4) Pr(WHO standard): undernourished	(5) Pr(WHO standard): wasted
Max NINO3.4	-0.0212**	-0.0364***	-0.0369***	0.00537**	0.00303
std. error:	(0.00997)	(0.0119)	(0.0121)	(0.00248)	(0.00243)
p-value:	0.0412	0.00447	0.00468	0.0375	0.223
95% CI (lower):	(-0.0415)	(-0.0607)	(-0.0616)	(0.000332)	(-0.00193)
95% CI (upper):	-0.000900	-0.0122	-0.0122	0.0104	0.00799
$\boldsymbol{\rho(precip, NINO) > 0}$	0.0916***	0.0808***	0.0646**	-0.0148***	-0.00692**
std. error:	(0.0210)	(0.0252)	(0.0245)	(0.00217)	(0.00328)
Mean of dep. var.	-0.882	-0.185	-0.0503	0.196	0.0967
Observations	1,356,895	1,305,087	1,306,592	1,356,895	1,305,087
R-squared	0.146	0.101	0.086	0.094	0.040

Notes: effects on (1-3) weight for age, weight for height, and body mass index z-scores, which all measure shorter-run effects of scarce nutrition, show evidence of contemporaneous ENSO effects measured in °C. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother's age at child's birth and total years of mother's education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. (4-5) WHO threshold outcomes show ENSO increases the likelihood of being undernourished (below -2σ in weight for age) and wasted (below -2σ in weight for height). Asterisks indicate statistical significance at the 1% (***), 5% (**) and 10% (*) levels.

Table S8: Results including only locations teleconnected through both precipitation and temperature

	(1) Weight for age	(2) Weight for height	(3) Body mass index	(4) Pr(WHO standard): undernourished	(5) Pr(WHO standard): wasted
Max NINO3.4	-0.0321*	-0.0456**	-0.0501**	0.00780	0.00434
std. error:	(0.0159)	(0.0202)	(0.0197)	(0.00523)	(0.00461)
p-value:	0.0530	0.0317	0.0167	0.147	0.355
95% CI (lower):	(-0.0647)	(-0.0870)	(-0.0904)	(-0.00291)	(-0.00509)
95% CI (upper):	0.000449	-0.00429	-0.00973	0.0185	0.0138
$\boldsymbol{\rho(precip, NINO) > 0}$	0.0679**	0.0701**	0.0672**	-0.0200***	-0.0117*
std. error:	(0.0247)	(0.0293)	(0.0325)	(0.00419)	(0.00672)
Mean of dep. var.	-0.835	-0.163	-0.0352	0.185	0.0867
Observations	247,154	238,174	238,456	247,154	238,174
R-squared	0.152	0.110	0.090	0.103	0.052

Notes: effects on (1-3) weight for age, weight for height, and body mass index z-scores, which all measure shorter-run effects of scarce nutrition, show evidence of contemporaneous ENSO effects measured in °C. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother's age at child's birth and total years of mother's education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. (4-5) WHO threshold outcomes show ENSO increases the likelihood of being undernourished (below -2σ in weight for age) and wasted (below -2σ in weight for height). Asterisks indicate statistical significance at the 1% (***), 5% (**) and 10% (*) levels.

Table S9: Countries and surveys in sample.

Country	**Survey Years**
East Asia & Pacific	
Cambodia	2000, 2005, 2010, 2014,
Timor Leste	2009
Latin America & Caribbean	
Bolivia	1989, 1994, 1998, 2003, 2008
Brazil	1986, 1996
Colombia	1986, 1995, 2000, 2005, 2010
Dominican Republic	1986, 1991, 1996, 2002, 2007, 2013,
Guatemala	1987, 1995
Haiti	1995, 2000, 2006, 2017
Honduras	2006, 2012
Nicaragua	1998, 2001
Peru	1992, 1996, 2000
Middle East & North Africa	
Morocco	1987, 1992, 2003
Yemen	1992
Sub-Saharan Africa	
Angola	2016
Benin	1996, 2001, 2006, 2012, 2018
Burkina Faso	1993, 1999, 2003, 2010
Burundi	2010
Cameroon	1991, 1998, 2004, 2011
Central African Republic	1994
Chad	1997, 2004
Comoros	1996, 2012
Congo, Rep.	2005, 2012
Congo, Dem. Rep.	2007, 2014
Cote d'Ivoire	1994, 1998, 2012
Ethiopia	2000, 2005, 2010, 2016
Gabon	2000, 2012
Ghana	1988, 1993, 1998, 2003, 2008, 2014
Guinea	1999, 2005, 2012
Kenya	1993, 1998, 2003, 2008, 2014
Lesotho	2004, 2009, 2014
Liberia	2007, 2013
Madagascar	1992, 1997, 2004
Malawi	1992, 2000, 2004, 2010, 2016
Mali	1987, 1996, 2001, 2006, 2013
Mozambique	1997, 2003, 2011
Namibia	1992, 2000, 2006, 2013
Niger	1992, 1998, 2006, 2012
Nigeria	1990, 1999, 2003, 2008, 2013
Rwanda	1992, 2000, 2005, 2010, 2015
São Tomé e Príncipe	2009
Senegal	1986, 1993, 2005, 2010, 2014, 2015, 2016, 2017
Sierra Leone	2008, 2013
Swaziland	2006
Tanzania	1992, 1996, 1999, 2005, 2010
Togo	1988, 1998, 2014
Uganda	1989, 1995, 2000, 2006, 2011
Zambia	1992, 1996, 2002, 2007, 2014
Zimbabwe	1988, 1994, 1999, 2005, 2010, 2015
South Asia	
Bangladesh	1997, 2000, 2004, 2007, 2011, 2014
India	1993, 1999, 2006, 2016
Maldives	2017

Table S10: Results adding country-month fixed effects

	(1) Weight for age	(2) Weight for height	(3) Body mass index	(4) **Pr(WHO standard):** undernourished	(5) wasted
Max NINO3.4	-0.0161*	-0.0329***	-0.0354***	0.00328	0.00139
std. error:	(0.00943)	(0.00986)	(0.00982)	(0.00212)	(0.00206)
p-value:	0.0975	0.00218	0.00106	0.132	0.505
95% CI (lower):	(-0.0353)	(-0.0529)	(-0.0554)	(-0.00104)	(-0.00281)
95% CI (upper):	0.00311	-0.0128	-0.0154	0.00759	0.00559
$\boldsymbol{\rho(precip, NINO) > 0}$	0.0617**	0.0243	0.0152	-0.0178***	-0.00417
std. error:	(0.0234)	(0.0330)	(0.0372)	(0.00421)	(0.00483)
Mean of dep. var.	-1.078	-0.371	-0.228	0.238	0.122
Observations	1,253,173	1,205,332	1,206,655	1,253,173	1,205,332
R-squared	0.133	0.099	0.087	0.090	0.043

Notes: Different anthropometric effects of ENSO are concentrated on short run measures (1-3) weight for age, weight for height, and body mass index z-scores, which all measure shorter-run effects of scarce nutrition, show evidence of contemporaneous ENSO effects measured in °C. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother's age at child's birth and total years of mother's education; country-specific fixed effects for rural vs. urban; country-specific fixed effects for month of interview, and linear and quadratic trends in survey year. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. Asterisks indicate statistical significance at the 1% (***), 5% (**) and 10% (*) levels.

Table S11: Month of interview not associated to NINO3.4 Anomaly

VARIABLES	(1) Month of interview
Max NINO3.4	-0.309
std. error:	(0.342)
p-value:	0.373
95% CI (lower):	(-1.007)
95% CI (upper):	0.388
Observations	1,445,660
R-squared	0.283
Sample	All

Notes: Estimate is from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother's age at child's birth and total years of mother's education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. Asterisks indicate statistical significance at the 1% (***), 5% (**) and 10% (*) levels.

Table S12: Alternative standard error clustering strategies

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Weight for age						
Max NINO3.4	-0.0251***	-0.0251**	-0.0251**	-0.0251***	-0.0251*	-0.0251**	-0.0251**
std. error:	(0.00182)	(0.00666)	(0.0116)	(0.00767)	(0.00792)	(0.0119)	(0.0105)
p-value:	0	0.0196	0.0359	0.00113	0.0504	0.0435	0.0234
95% CI (lower):	(-0.0287)	(-0.0436)	(-0.0485)	(-0.0402)	(-0.0503)	(-0.0495)	(-0.0466)
95% CI (upper):	-0.0215	-0.00662	-0.00172	-0.0100	8.90e-05	-0.000780	-0.00363
$\boldsymbol{\rho(precip, NINO) > 0}$	0.0733***	0.0733***	0.0733***	0.0733***	0.0733**	0.0733**	0.0733***
std. error:	(0.00765)	(0.00900)	(0.0246)	(0.0204)	(0.0223)	(0.0285)	(0.0222)
Standard Error Clustering	None	UNICEF Region	Country	Admin1	Twoway UNICEF Region & Decade	Twoway Country & Year	Twoway Admin1 & Year
Mean of dep. var.	-0.931	-0.931	-0.931	-0.931	-0.931	-0.931	-0.931
Observations	1,253,176	1,253,176	1,253,176	1,253,176	1,253,176	1,253,176	1,253,176
R-squared	0.129	0.129	0.129	0.129	0.129	0.129	0.129

Notes: Anthropometric effects of ENSO on weight for age show evidence of contemporaneous ENSO effects measured in °C. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother's age at child's birth and total years of mother's education; country-specific fixed effects for rural vs. urban; fixed effects for month of interview; and UNICEF world region-specific linear trends in survey year. Inference remains consistent whether standard errors are not clustered (1); clustered at UNICEF region (2), country (3) or admin1/state (4) to adjust for arbitrarily serial and spatial autocorrelation at these geographic units, or two-way clustered at UNICEF region & decade (5), country & year (6), or admin1 & year (7, the main specification). Observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. Asterisks indicate statistical significance at the 1% (***), 5% (**) and 10% (*) levels.