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Climatic conditions and child height:
Sex-specific vulnerability and the protective effects of sanitation and food markets in Nepal

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Abstract

Environmental conditions in early life are known to have causal impacts on later health outcomes, but mechanisms and potential remedies have been difficult to discern. This paper uses the Nepal Demographic and Health Surveys (DHS) of 2006 and 2011, combined with earlier NASA satellite observations of variation in vegetation density (NDVI) at each child's location and time of birth, to identify the trimesters of gestation and infancy during which climate variation can be linked to heights attained between 12 and 59 months of age. We find significant differences by sex of the fetus: males are most affected by conditions in their second trimester of gestation, and females in their first trimester after birth. Each 100 point difference in NDVI at those times is associated with a difference in height-for-age Z-score (HAZ) of 0.088 for boys and 0.054 for girls, an effect size that is similar to moving within the distribution of household wealth by one quintile for boys, and one decile for girls. The entire seasonal change in NDVI from peak to trough is on the order of 200-300 points, implying a seasonal effect on HAZ similar to 1-3 quintiles of household wealth. This effect is observed only in households without toilets; with toilets there is no seasonal fluctuation, implying protection against climatic changes in disease transmission. We also use data from the Nepal Living Standards Surveys on district-level agricultural production and marketing, and find a vegetation effect on child growth only in districts where households' food consumption comes primarily from own production. Robustness tests find no evidence of selection effects, and placebo regressions reveal no significant artefactual correlations. Our findings regarding timing and sex-specificity are consistent with previous results, and the protective effect of sanitation and markets is a novel indication of the mechanisms by which households can gain resilience against adverse climatic conditions.

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1. INTRODUCTION AND MOTIVATION

Attained height is among the most important indicators of childhood deprivation. About 25 percent of each year's worldwide cohort of infants grow up to be stunted, and the dietary or disease conditions that limit linear growth in childhood also contribute to poor educational attainment, low earnings and high mortality later in life (International Food Policy Research Institute, 2014; UNICEF, 2015).

Stunting rates have been especially high in Nepal where extreme poverty and political instability led to rates as high as 57 percent in 2001, before declining to 41 percent in 2011 (UNICEF, 2013). Despite this improvement Nepal remains one of the 10 countries in the world with the highest stunting prevalence (UNICEF, 2014), making it a high-priority location for research into increasingly effective ways of protecting children from harmful early-life circumstances.

Socioeconomic factors associated with stunting in Nepal are described by Headey and Hoddinott (2015), who show how changes in household and community-level characteristics help explain local variation and the overall improvement from 2001 to 2011. Key changes involve both greater sanitation and access to improved diets, which are pillars of the Nepal government's multi-sector nutrition plan (Government of Nepal, 2012). Despite this progress poor sanitation and inadequate food intake remain widespread, and are likely to be worsened by rising temperatures and more variable rainfall associated with climate change (IPCC, 2014).

This paper uses satellite data on vegetation near each child's home as an indicator of changing agroclimatic conditions, with randomness in the month of birth providing a natural experiment in the timing of exposure to more or less advantageous circumstances. This contributes to a rapidly growing literature using natural experiments (Angrist & Krueger, 2001) to study how environmental shocks affect health (Brown et al., 2014; Tiwari et al., 2013; Lokshin and Radyakin, 2012; Akresh et al., 2011; Angrist and Krueger, 2001), with a particular focus on the timing and mechanism by which early conditions influence later outcomes (Kumar, Molitor and Vollmer 2016, Schultz-Nielsen, Tekin and Greve 2016; Skoufias and Vinha 2012).

Our identification strategy is a difference-in-differences approach, testing whether household sanitation and district-level food markets can protect children against the health consequences of unfavorable agroclimatic conditions at sensitive times. The specific data we use are the Nepal Demographic Health Survey (NDHS) for child health, sanitation and other household characteristics in 2006 and 2011, combined with Normalized Difference Vegetation Index (NDVI) data from NASA for 2000-2012 at each child's location, and the Nepal Living Standard Survey (NLSS) to characterize local agricultural markets for 2003-04 and 2010-11.

By combining three kinds of data, we can identify patterns in attained heights of children observed at 12-59 months of age, and test whether sanitation and food markets limit their association with agroclimatic conditions experienced during pregnancy and the first year after birth. We find that the underlying patterns are sex-specific, with systematic differences in how later heights relate to NDVI fluctuations during infancy and pregnancy. These differences are consistent with both gender bias in infant care (Maccini and Yang 2009) and physiological differences in fetal development before the sex of the child is known (DiPietro and Voegtline, 2015; Rosenfeld, 2015). We find that improved sanitation and more commercialized food markets limit both kinds of vulnerability, providing significant protection from agroclimatic conditions for both pregnant mothers and first-year infants.

2. BACKGROUND AND IDENTIFICATION STRATEGY

2.1 Agriculture and climate in Nepal

Nepal is a landlocked country with a population of about 27 million people of whom about 85 percent live in rural areas (Ministry of Health and Population, 2012) and are highly reliant on rain-fed agriculture (MoAD, 2013). There are three distinct ecological zones: Mountains (52,000 km^2), Hills (61,000 km^2) and Terai (34,000 km^2), with varying population densities (Joshi et al., 2012). The Mountain zone has a dry alpine climate and is situated at the highest altitude (> 2,500 m), with steep and rugged terrain and short growing seasons. The Hills have mostly temperate climate (500 – 2,500 m) and the Terai (<500 m) has a mostly subtropical and humid climate (Ministry of Health and Population, 2012). Although the Terai occupies less than a quarter of the country's landmass (23%), it hosts almost half of the population (48%) and most of the cultivable land (56%) (MoAD, 2013). The most commonly grown crops are cereals including maize, millet, barley, rice, and wheat (WFP, 2014). Consistent with global trends of increasing temperature and erratic rainfall patterns (NASA, 2015), temperatures in Nepal increased by 1.5°C over the period from 1978 to 2005 (Krishnamurthy et al., 2013), while rainfall has declined in frequency and increased in intensity (Malla, 2008).

Figure 1. Map of Nepal

Source: un.org.np

Impacts of climate trends and fluctuations can be seen through changes in sowing dates, crop duration, crop yields and management practices (IPCC, 2014). Between 1978 and 2008 the summer months (May through August) became increasingly hotter and wetter, and winter months (November through February) became colder and drier; during that time the higher levels of rainfall in summer increased rice yields but decreased yields for other crops, while lower levels of rainfall in winter decreased maize yields (Joshi et al., 2011). For this paper we use NDVI to summarize the complex pattern of variation in both rainfall and temperature, providing a simple index of changing agroecological conditions in the area around each child's home.

2.2 Seasonality and child nutrition

Seasonal variation and other climatic changes have a clear link to the nutritional status of children in many contexts, even in industrialized countries (Chodick et al., 2009). In the UK, for example, babies born in winter have significantly worse birth weights, educational attainment and adult heights, perhaps due to low vitamin D levels (Day et al., 2015), and in the US children conceived in the summer have a higher prevalence of birth defects (McKinnish et al., 2014) and different genetic characteristics (Rietveld and Webbink 2016). Some seasonal patterns may be due to selection effects, as Buckles & Hungerman (2013) show that winter births in the US occur disproportionately among disadvantaged youths, but in developing countries studies have repeatedly found relatively large agroclimatic patterns that cannot be explained by selection effects. For example, in the Democratic Republic of Congo, Darrouzet-Nardi (2015) shows that children born during wet seasons grow up to be shorter, with no evidence for selection into adverse birth timing of children with lower levels of household wealth or education.

Agroclimatic fluctuations may affect child nutrition through both disease risk and dietary intake. A principal source of variation in both kinds of risk is rainfall: children born during monsoon months in India have lower height and weight than children born during fall-winter months (Lokshin and Radyakin, 2012), and rainfall fluctuations in Indonesia have been shown to affect child health in both rural and urban areas (Yamauchi, 2012; Cornwell and Inder, 2015). These associations often depend on the timing of exposure. For example, Tiwari et al. (2013) show that in Nepal, a child's weight for age is positively correlated with rainfall in the previous monsoon season, but negatively correlated with rainfall in the current monsoon. Temperature may play an independent role, as suggested by Hu and Li (2016) among others, although Nepal's complex topography complicates efforts to analyze the effects of spatial variation in temperature. In any case, covariance among climatic variables, agricultural conditions and dietary intake makes it difficult to distinguish one factor from another. In Malawi, for example, the prevalence of underweight among children under five rises during the rainy season, which is also the pre-harvest period when maize prices are highest (Sassi, 2015).

2.3 Vulnerability in utero and after birth

Gestation and the first two years after birth are the most critical periods for child development, with clear impacts on physical, cognitive and other outcomes later in life (Almond, 2006; Black et al., 2013; Hoddinott et al., 2013). Adverse conditions in utero and during the first two years of life can cause high perinatal mortality and also subsequent stunting (Coffey 2015) as well as low weight and anemia (Kumar, Molitor and Vollmer 2016), economic productivity (Hoddinott et al., 2013; Paxson and Schady, 2007) and academic success (Schultz-Nielsen, Tekin and Greve 2016). Affected children may also have higher odds of cardiovascular disease and other conditions (Popkin et al., 1996; Sawaya et al., 2003), as in the fetal origins hypothesis of Barker (1995).

This paper expands on the previous literature by using quarterly variation in NDVI to identify sex-specific differences in the timing of vulnerability before and after birth, and test for possible protective effects of sanitation and food markets. Our focus on sex differences follows Skoufias and Vinha (2012), and our attention to the exact timing of exposure follows Andalon et al. (2014) and Carlson (2015) among others, building on previous work in South Asia using Demographic Health Surveys in both India and Nepal that suggest a stronger link between rainfall variation and child height during early months in infancy than during other periods of a child's life (Lokshin and Radyakin, 2012; Tiwari et al., 2013). Moreover, focusing on growing seasons of Nepal, others find that anomalies in vegetation density in utero and infancy show higher correlations with stunting than in other phases of a child's development (Shively et al., 2015).

The timing and magnitude of vulnerability to agroclimatic conditions could differ by sex of the child. There is a growing body of evidence suggesting differential effects of prenatal stress on male and female fetuses on perinatal outcomes (Aibar et al., 2012; Mulla et al., 2013; Persson and Fadl, 2014) and adult health (Scholte et al. 2015). In general, female fetuses are more resilient and adaptive to stress than male fetuses (DiPietro and Voegtline, 2015; Rosenfeld, 2015). Evidence from studies that examine effects of stressors such as intrauterine lead and pesticide exposure, and maternal alcohol and drug use suggest that exposed male fetuses are more likely to be born preterm and have poorer scores on developmental assessments than females (Rosenfeld, 2015). Historical data from Danish cemeteries suggest that male heights rose over the 19th century while women's did not (Jørkov, 2015). In malnourished populations today, on average boys are more likely to be stunted than girls, but after birth when the child's sex is known, gender discrimination may play an important role in health outcomes. For example, Maccini and Yang (2009) show that Indonesian families commonly protected boys more than girls from early-life shocks, and countries with more gender discrimination in favor of boys have lower rates of stunting in males relative to females (World Bank, 2008) with intergenerational effects (Osmani and Sen 2003).

2.4 Protective effects of sanitation and food markets

Numerous interventions could potentially provide protection against the disease transmission and dietary inadequacy associated with agroclimatic conditions. In this paper, we study two kinds of variables that are of particular interest to policymakers: household sanitation and local food markets. Sanitation has become an increasingly important policy tool in recent years especially for South Asia (e.g. Hammer and Spears, 2013), while the impacts of agricultural commercialization on nutrition has been a longstanding concern all around the world (e.g. Von Braun and Kennedy, 1994).

The potential efficacy of sanitation against stunting operates through preventing fecal-oral transmission of diseases such as diarrhea and enteropathy, which cause both mortality and stunting through loss of nutrients, decreased absorption of nutrients and weakened immune system (Checkley et al., 2008, Humphrey, 2009). There may also be selection effects, as households with toilets may also have other favorable conditions for child development, but the prevention of disease transmission provides a clear causal mechanism to explain how sanitation might improve nutritional status (Coffey and Geruso 2015) and linear growth (Checkley et al., 2004; Lin et al., 2013). In this study we focus on the average effects on each child of having a toilet in their own household; future work could address the externalities among households found in Hammer and Spears (2013).

The potential efficacy of food markets is likely to operate primarily through dietary intake, as shown for Ethiopia by Abay and Hirvonen (2016). As shown by Puentes et al. (2016), total intake especially of nutrient-rich foods can have a major impact on child growth. In this study, we focus on whether households have access to food from elsewhere as opposed to their own farm production, by using their district's share of total food consumption that is either purchased or received in-kind, as opposed to consumed on-farm. We employ district fixed effects to control for other time invariant district characteristics, thereby isolating the specific effect of being in districts where households are more reliant on local conditions and unable to use markets to improve diet quality as in Sibhatu, Krishna and Qaim (2015).

2.5 Identification strategy and data sources

Our study uses a two stage difference-in-differences design, comparing the association between child heights and earlier agroclimatic conditions among children with different birth exposure, in households with and without toilets, and in districts with low and high food market use. The first set of differences exploits a natural experiment in exposure to different levels of NDVI at each stage of gestation, while the second splits the sample to isolate the protective effects of sanitation and food markets. This strategy relies on combining three distinct kinds of information: NDHS data on child heights and household characteristics, NDVI data on agroclimatic conditions, and NLSS data on agricultural commercialization. With these data we can address a number of potential threats to identification, first showing that the month of conception is uncorrelated with maternal and household socioeconomic status or other characteristics, then using fixed effects and statistical controls to narrow the parallel-trends assumption implicit in our method, and finally a set of placebo regressions to demonstrate that results are not an artefact of that method. In all regressions we control for observables known to correlate with maternal health and child size such as parental education, maternal BMI, household wealth and altitude (Wehby et al. 2010).

The Nepal Demographic and Health Survey (NDHS) is a comprehensive and nationally representative survey, typically conducted every five years to gather data on population and health. The NDHS is carried out under the Ministry of Health and Population (MOHP), and conducted by New ERA as part of the worldwide Demographic Health Survey (DHS) program that use standardized questionnaires and fieldworks to allow comparisons across years in demographics, health and nutrition-related variables. This paper uses two recent rounds of the NDHS conducted in 2006 (February-August) and 2011 (February-June). Both the years use two-stage, stratified sampling including households in all 75 districts across all ecological zones and development regions. The 2006 survey uses 2001 population census sampling frame while the 2011 survey uses an updated 2001 population census for sampling frame that accounts for population growth, internal, and external migration. Anthropometrics for children under five years of age were collected from 5,237 and 2,335 children in 2006 and 2011, respectively (Ministry of Health and Population, 2007; 2012).

The normalized difference vegetation index (NDVI) is a measure of vegetation density resulting from the interaction of rainfall, temperature and soil fertility over time. Green vegetation, due to its presence of chlorophyll, absorbs red (visible) light and reflects near infrared light while sparse vegetation reflects more red light and less of near infrared light. NDVI values are measured as NDVI = NIR – RED/ NIR+ RED. Here, the numerator denotes normalized difference between red and near infrared bands and the denominator is the sum of red and near infrared bands (Weier & Herring, 2000). Those data are obtained from the NASA satellite remote sensors using Moderate Resolution Imaging Spectroradiometer (MODIS) Climate Modeling Grid (CMG), which provides data at 5km resolution (Shively et al., 2015). The dataset includes monthly NDVI values for 12 years (2000 – 2011) for each child’s location of birth corresponding with 260 and 289 clusters in 2006 and 2011 NDHS, respectively (Ministry of Health and Population, 2007; 2012).

The full distributions of NDVI levels for each month are shown in Appendix A. This variable provides an attractive measure of green biomass and leaf area (Thenkabail, 2009), which in turn depends on available moisture, temperature and soil fertility as well as human intervention in response to those underlying conditions (Laidler et al., 2008). NDVI is also influenced by factors other than plant growth such as cloud cover and ground conditions. It is not a simple index of climatic conditions or crop production (Shively et al., 2015), but NDVI does provide a powerful measure of trends and fluctuations in various agroclimatic conditions that could affect child development.

The Nepal Living Standard Survey (NLSS) is a comprehensive, national, multi-topic household survey conducted by Nepal Central Bureau of Statistics (CBS) with methodologies developed and promoted by the World Bank. NLSS use multi-stage and stratified sampling using 2001 Population Census of Nepal as a basis of sample frame. Data collection spans over a year, unlike NDHS, in order to capture effects of seasonality. The purpose of the survey is to assess changes in living standards of the population using a combination of panel data and cross-sectional data for a given survey round. A wide range of topics covered by the NLSS includes poverty, access to finances, health, education, agriculture and rural development, and labor market (Central Bureau of Statistics, 2004, 2011). For the paper, however, only agriculture and rural development data, which includes a range of information on food consumption, food production and expenses, are utilized. In order to align temporality between NLSS and NDHS, NLSS II 2003-2004 is merged with the NDHS 2006 and NLSS III 2010-2011 is merged with the NDHS 2011 (Shively et al., 2015).

3. DATA AND RESULTS

Our main outcome variable is each child's height-for-age z score (HAZ), defined as the gap between that child's measured height and the median of a healthy population at each age and sex, expressed in terms of standard deviations of the healthy population (WHO and UNICEF, 2009). Children are classified as stunted when their HAZ is two or more standard deviations below the median, but here we focus on HAZ scores as a continuous variable to capture variation at every level of attained height. In addition, although the NDHS enumerators measured the length or height of all children under five years of age, here we focus on heights attained between the child's first and fifth birthdays, as a function of agroclimatic conditions experienced in utero and the child's first year after birth. Control variables include the child's age in months at the time of measurement, total number of siblings ever born, maternal age, maternal education and BMI, household wealth, altitude and region, urban residence and survey round.

3.1 Descriptive statistics

Means and standard deviations for nutritional outcomes and control variables in addition to other variables of interest are shown in **Table 1**. All data are from the NDHS 2006 and 2011 except for district-level data on food market participation and distance to market centers, which are obtained from the two waves of the NLSS. Because later regressions will be split by sex of the child, we show the pooled dataset of all children aged 12-59 months (n=6,127), and the subsamples of boys (n=3,129) and girls (n=2,998).

Table 1. Summary statistics for all outcome and control variables

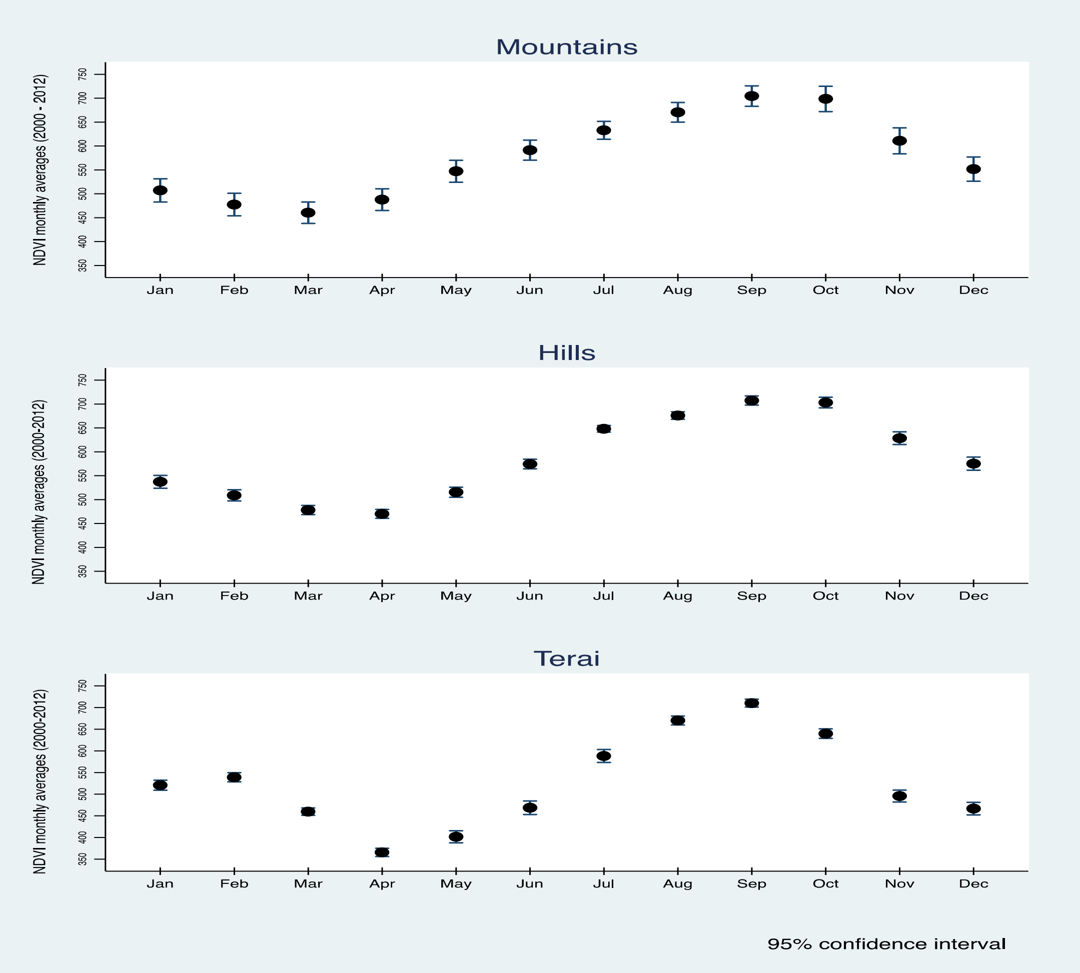
	(1) **All observations** N=6,127	**(2)** **Male** N= 3,129	**(3)** **Female** N= 2,998	**(4)** **Male vs. Female** P-value
Nutritional status outcomes				
HAZ	-2.11 (1.25)	-2.10 (1.24)	-2.12 (1.26)	0.6363
Mother's BMI (kg/m^2)	20.55 (2.74)	20.54 (2.77)	20.57 (2.71)	0.7546
Child characteristics				
Female	48.9%	na	na	na
Child age (months)	35.65 (13.75)	35.89 (13.66)	35.41 (13.85)	0.1736
Total no. of siblings ever born	2.11 (1.96)	2.04 (1.93)	2.17 (1.99)	**0.0088**
Maternal characteristics				
Age (years)	27.42 (6.06)	27.37 (5.90)	27.46 (6.22)	0.5811
Primary education completed	18.0%	18.1%	17.9%	0.857
Secondary educat. completed	21.2%	21.4%	21.1%	0.822
Tertiary education completed	3.3%	3.3%	3.2%	0.846
Household characteristics				
Wealth (quintile)	2.66 (1.42)	2.67 (1.43)	2.65 (1.42)	0.6013
Has toilet	45.7%	46.6%	44.7%	0.146
District-level characteristics				
Food market participation (share of food consumption purchased or donated)	0.52 (0.20)	0.52 (0.20)	0.52 (0.20)	0.6698
Urbanization (pct. rural)	78.2%	78.3%	78.1%	0.863
Altitude (average, in meters)	833.42 (732.18)	846.86 (734.87)	819.38 (729.23)	0.1420

Note: Summary statistics pertain to all observations included in regressions (every measured child aged 12 to 59 months). Data presented in columns 1-3 are means (sd) or %. Column 4 show p-values of comparisons between male and female children using either chi-squared or independent samples t-test as appropriate.

The summary statistics shown in **Table** 1 show the two subsamples to be balanced in all regards except that the male subsample is larger and girls have more siblings, which is consistent with sex-selective stopping rules by which parents might seek additional children until they reach their desired number of boys (Bongaarts, 2013).

Turning to agroclimatic conditions, the NDVI levels to which each child is exposed at each stage of their development depends on their month and location of birth. **Figure 2** shows the seasonal patterns of NDVI variation in Nepal's three main regions. Vegetative cover generally peaks during August-October, with greater month-to-month variation in the Terai region. There is greater uncertainty about each month's mean in the Mountain region, partly due to smaller sample size: only 87 of the 547 cluster locations for our two NDHS surveys were in the Mountains, while the rest were almost equally distributed between Hills and Terai.

Figure 2. Month-to-month variation of average NDVI at surveyed household locations, by region



Note: The height of each line represents confidence interval and the point symbols represent mean of monthly NDVI from years 2000-2012 in 547 DHS clusters by regions; 87 clusters in Mountains, 226 clusters in Hills, and 234 clusters in Terai.

3.2 Exploratory regressions

Our identification strategy relies on randomness in birth timing relative to variation in agroclimatic conditions around the home. Before proceeding, we test for possible selection effects, asking whether some kinds of mothers are more likely to conceive in certain months of the year. Seasonal patterns of conception could be due to seasonal migration of family members, variation in natural fertility, or even deliberate pursuit of conception at more favorable times. **Table 2** tests for selection patterns in a very general way, using a multinomial logit model of selection into each month of conception, nine months before the observed month of birth.

Table 2. Timing of conception on maternal and household characteristics, by month

	(1) Jan	(2) Feb	(3) Mar	(4) Apr	(5) May	(6) Jun	(7) Jul	(8) Aug	(9) Sep	(10) Oct	(11) Nov
Maternal age (log)	0.029	-0.111	-0.357	-0.348	0.574	0.239	0.217	-0.157	0.272	0.034	0.487
	(0.42)	(0.44)	(0.44)	(0.44)	(0.43)	(0.43)	(0.46)	(0.46)	(0.42)	(0.42)	(0.41)
Maternal primary education	0.133	0.222	0.047	0.410**	0.262	0.240	0.456**	0.089	0.442**	0.146	0.468***
	(0.18)	(0.18)	(0.18)	(0.17)	(0.18)	(0.18)	(0.18)	(0.19)	(0.17)	(0.18)	(0.17)
Maternal secondary education	0.077	0.205	0.124	0.125	0.048	0.037	0.191	-0.031	0.146	0.192	0.014
	(0.18)	(0.19)	(0.18)	(0.19)	(0.18)	(0.19)	(0.20)	(0.20)	(0.18)	(0.18)	(0.18)
Maternal tertiary education	0.157	0.155	0.497	0.113	0.392	0.105	0.577	0.224	0.473	0.095	0.540
	(0.39)	(0.41)	(0.38)	(0.40)	(0.38)	(0.42)	(0.41)	(0.41)	(0.38)	(0.40)	(0.36)
Maternal BMI	-0.042*	-0.013	-0.002	-0.045*	-0.054**	-0.023	-0.009	-0.006	0.007	-0.022	0.003
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)
Total children ever born	-0.038	0.004	0.012	0.037	-0.040	-0.010	0.043	0.033	0.009	0.031	-0.007
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Wealth Quintile	0.003	-0.048	-0.021	0.051	0.010	-0.004	-0.057	-0.005	-0.023	-0.008	0.015
	(0.05)	(0.06)	(0.05)	(0.06)	(0.05)	(0.06)	(0.06)	(0.06)	(0.05)	(0.05)	(0.05)
Altitude	0.042	0.247**	0.174*	0.272***	0.235**	0.265**	0.234**	0.367***	0.187*	0.179*	0.123
	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.10)	(0.11)	(0.11)	(0.10)	(0.10)	(0.10)
2011 DHS observation	-0.015	0.279**	-0.063	0.032	0.029	-0.104	0.015	0.195	0.128	-0.009	0.001
	(0.14)	(0.13)	(0.14)	(0.14)	(0.13)	(0.14)	(0.14)	(0.14)	(0.13)	(0.13)	(0.13)
Hill	0.510**	0.312	0.322*	0.120	0.189	0.084	0.194	0.259	0.181	0.428**	0.151
	(0.21)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)	(0.19)
Terai	0.425	0.549*	0.373	0.383	0.394	0.358	0.306	0.424	0.236	0.523*	0.263
	(0.33)	(0.32)	(0.31)	(0.31)	(0.31)	(0.32)	(0.35)	(0.33)	(0.31)	(0.31)	(0.31)
Constant	0.054	-1.435	-0.259	-0.252	-2.504*	-2.284	-2.584	-2.338	-2.570*	-1.355	-2.790*
	(1.45)	(1.51)	(1.54)	(1.51)	(1.51)	(1.52)	(1.66)	(1.63)	(1.51)	(1.46)	(1.44)
Observations	6,127	6,127	6,127	6,127	6,127	6,127	6,127	6,127	6,127	6,127	6,127

Notes. Unit of observation is individual children between 12 and 60 months of age. Results shown are a multinomial logit model of selection into each month of conception, which is inferred to be 9 months before the observed month of birth (for example, April births imply conception in July.). Coefficients are relative to the omitted month, December. Robust standard errors are in parentheses. 2011 DHS observation indicate dummy=1 if the DHS survey was conducted in 2011. Hill and Terai dummies indicate likelihood compared to the Mountain region. *** p<0.01, ** p<0.05, * p<0.1

Results of **Table 2** show 12 of 121 coefficients with statistical significance at the 5% level. Half of these are the significant coefficients on altitude, as households at higher altitudes are more likely to conceive between February and August. These are the cooler months, especially at higher elevations, which is consistent with Levitas et al. (2013) who found sperm counts and motility to be greater at colder times. The remaining six significant coefficients have no clear pattern, confirming the absence of selection effects on the timing of conception in this context. These results contrast with the strong selection effects in the US (Buckles and Hungerman, 2013), but are consistent with studies elsewhere such as Taiwan (Fan et al., 2014), India (Lokshin and Radyakin, 2012) and Nepal itself (Panter-Brick 1996).

Without selection by education or other parental characteristics into specific birth months, differences in attained height by month of birth are most likely due to environmental exposure effects. To identify this purely seasonal pattern in how birth timing relates to attained heights, we employ Ordinary Least Squares (OLS) regressions using the following base specification:

$$\mathbf{Y_i = \beta_0 + \beta_{1m}\, birthmonth_{im} + \delta_i Z_i + u_i} \qquad (1)$$

Where $\mathbf{Y_i}$ indicates HAZ score of a child between 12-59 months, $\mathbf{birthmonth_{im}}$ is a vector of dummy variables equal to one when m = the birth month of that child and zero otherwise, and $\mathbf{Z_i}$ is a vector of control variables at the child-, maternal-, household- and district level. District fixed effects are also included, and standard errors are clustered by birth year and districts. To account for effects of a child's age on their measured HAZ as in Cummins (2015), we use two different specifications: age and age squared in columns 1, 3 and 5, and a linear year of birth term in columns 2, 4 and 6. The two types of age control yield similar month of birth effects, so for the remaining tests we use only the simple age in months and months-squared specification, and focus attention on the differences between boys and girls in regard to what birth timing might be relatively unfavorable.

Results in **Table 3** reveal that the worst month for all children to be born is April, but boys are also disadvantaged by being born in June and September relative to the omitted month, January. As shown in **Figure 2**, April is one of the lowest-NDVI months, while September the highest. A few other months have some correlation with attained heights, and the magnitude of these seasonality effects are very large: Being born in April has an effect size similar to 1.9 quintiles of wealth, and for boys being born in September has an effect size similar to 2.4 quintiles of wealth.

Table 3. Child height on month of birth by sex with alternative controls for age

	(1) Both sexes, age in months	(2) Both sexes, age in years	(3) Males, age in months	(4) Males, age in years	(5) Females, age in months	(6) Females, age in years
February	-0.010	0.001	-0.042	-0.032	0.020	0.034
	(0.08)	(0.08)	(0.12)	(0.12)	(0.09)	(0.09)
March	-0.077	-0.054	-0.085	-0.067	-0.057	-0.027
	(0.09)	(0.08)	(0.13)	(0.13)	(0.06)	(0.05)
April	-0.198***	-0.321***	-0.188***	-0.279***	-0.213**	-0.349***
	(0.06)	(0.07)	(0.06)	(0.09)	(0.09)	(0.10)
May	-0.036	-0.125	-0.139	-0.208*	0.078	-0.026
	(0.07)	(0.10)	(0.10)	(0.12)	(0.08)	(0.12)
June	-0.143**	-0.211**	-0.235**	-0.287***	-0.059	-0.137
	(0.07)	(0.08)	(0.10)	(0.11)	(0.08)	(0.09)
July	-0.108	-0.161*	-0.091	-0.127	-0.111	-0.175
	(0.08)	(0.09)	(0.10)	(0.10)	(0.09)	(0.12)
August	-0.115	-0.150	-0.144	-0.159	-0.087	-0.142
	(0.09)	(0.11)	(0.10)	(0.12)	(0.12)	(0.13)
September	-0.127	-0.159	-0.277***	-0.288***	0.030	-0.017
	(0.09)	(0.11)	(0.09)	(0.11)	(0.13)	(0.15)
October	-0.090	-0.112	-0.197*	-0.212*	0.002	-0.027
	(0.11)	(0.11)	(0.11)	(0.12)	(0.14)	(0.15)
November	-0.059	-0.076	0.013	0.002	-0.169	-0.193*
	(0.10)	(0.10)	(0.10)	(0.10)	(0.11)	(0.11)
December	-0.099	-0.107	-0.182	-0.181	-0.011	-0.022
	(0.10)	(0.10)	(0.13)	(0.13)	(0.10)	(0.10)
Female	-0.017	-0.013				
	(0.04)	(0.04)				
Age (in months)	-0.067***		-0.061***		-0.078***	
	(0.01)		(0.01)		(0.01)	
Age squared (in months)	0.001***		0.001***		0.001***	
	(0.00)		(0.00)		(0.00)	
Number of siblings ever born	-0.073***	-0.073***	-0.080***	-0.081***	-0.061***	-0.061***
	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)
Maternal age (log)	0.410***	0.403***	0.535***	0.529***	0.298*	0.299**
	(0.11)	(0.11)	(0.16)	(0.16)	(0.16)	(0.15)
Maternal primary education	0.064*	0.064**	0.093*	0.093*	0.056	0.060
	(0.03)	(0.03)	(0.05)	(0.05)	(0.06)	(0.06)
Maternal secondary education	0.305***	0.310***	0.336***	0.342***	0.289***	0.292***
	(0.06)	(0.06)	(0.06)	(0.06)	(0.08)	(0.08)
Maternal tertiary education	0.664***	0.672***	0.610***	0.618***	0.750***	0.759***
	(0.09)	(0.09)	(0.07)	(0.06)	(0.15)	(0.14)
Maternal BMI	0.041***	0.041***	0.046***	0.044***	0.037***	0.037***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Wealth Quintile	0.107***	0.107***	0.107***	0.109***	0.111***	0.109***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Altitude (log)	-0.266***	-0.264***	-0.299***	-0.301***	-0.230**	-0.224**
	(0.08)	(0.08)	(0.08)	(0.08)	(0.09)	(0.09)
2011 DHS observation	0.141***	-0.642***	0.112**	-0.387***	0.187***	-0.887***
	(0.04)	(0.10)	(0.06)	(0.11)	(0.05)	(0.17)
Hill	-0.104	-0.118	0.048	0.043	-0.189	-0.202
	(.)	(.)	(.)	(.)	(.)	(.)
Terai	-0.277*	-0.232	-0.358**	-0.310**	-0.194	-0.159
	(0.15)	(0.15)	(0.16)	(0.15)	(0.26)	(0.25)
Urban	0.022	0.028	-0.024	-0.022	0.052	0.061
	(0.06)	(0.06)	(0.05)	(0.05)	(0.07)	(0.07)
Year of Birth		0.212***		0.156***		0.257***
		(0.04)		(0.05)		(0.04)
Constant	-1.392**	-427.182***	-1.715***	-314.317***	-1.160	-516.367***
	(0.55)	(89.35)	(0.63)	(96.70)	(0.76)	(81.48)
Observations	6,127	6,127	3,129	3,129	2,998	2,998
R-squared	0.187	0.187	0.197	0.199	0.209	0.209

Notes: Unit of observation is individual children between 12 and 60 months of age. Robust standard errors in parentheses, clustered at the birth year and district levels. All regressions include fixed effects for district (n=75). Omitted month is January. 2011 DHS observation =1 if the DHS survey was conducted in 2011. *** p<0.01, ** p<0.05, * p<0.1.

3.3 Empirical methods

To investigate causal mechanisms and potential remedies for the effect of birth timing on attained height, we turn to variation in NDVI at each stage of child development, defined as each trimester of pregnancy and the first four trimesters after birth. Our focus is on heterogeneity and effect modifiers, so we divide the sample into boys and girls to identify sex-specific vulnerability at each stage of child development, and then test for protective effects of sanitation and food markets by dividing the sample into households with or without toilets, and districts with above- or below-median reliance on local production as opposed to food purchases or gifts. This split-sample approach, made possible by our large number of observations, permits variation among subsamples in all coefficients while avoiding a proliferation of collinear interaction terms.

In this design, exposure to climate variation is a natural experiment, to which children are exposed under conditions that might or might not be protective. Testing for heterogeneity in treatment response can help identify causal mechanisms, target services to those most at risk, and help spread desirable effect modifiers. In this case, we seek to identify the protective effects of toilets and food markets against adverse "treatments" which cannot be experimentally assigned, but are experienced randomly by infants in utero and the first year after birth.

In each subsample we employ OLS with the following base specification:

$$\mathbf{Y_i = \beta_0 + \beta_{1t}\,NDVI_{it} + \delta_i Z_i + u_i} \qquad (2)$$

Our notation is the same as for equation (1), except that the vector of $\mathbf{NDVI_{it}}$ conditions is the average value of NDVI in each three-month period *t*, from the first trimester of pregnancy through the first year after birth when the child is aged 0-2 months, 3-5 months, 6-8 months, and 9-11 months. All $\mathbf{Z_i}$ control variables are the same as in our exploratory regressions, first using both types of age controls, and then using only the more flexible quadratic approach to controlling for child's age at the time of measurement.

Our hypothesis is that the $\boldsymbol{\beta_{1t}}$ coefficients of significance in the whole sample (**Table 4**) become insignificant among households with toilets (**Table 5**) and in districts with more food market activity (**Table 6**). We conduct this difference-in-differences test using a split sample approach to gain maximum flexibility for the coefficients on each regressor. The test is powered by a large sample size achieved through merging two DHS rounds, and a large magnitude of the baseline $\boldsymbol{\beta_1}$ effects which could be brought to zero by sanitation and food markets.

The results of **Table 4** reveal similar results with either the flexible specification in columns 1, 3 and 5, or the linear specification in 2, 4 and 6. In both cases, higher NDVI in the second trimester of pregnancy is associated with greater attained heights, but only for boys. Girls have lower attained heights with higher NDVI in the first trimester after birth. Boys also have lower attained heights with higher NDVI in the second trimester after birth, but only in the less flexible functional form for age at measurement in column 4.

The magnitudes of effects are quite large. Coefficients shown are scaled to be per 1000 points of NDVI, so from our preferred specifications in columns 3 and 5, each 100 point change in NDVI experienced by boys in mid-gestation is associated with an 0.088 difference in HAZ which is almost as large as the 0.107 difference associated with each quintile of household wealth. For girls, each 100 point change NDVI experienced in the first three months after birth is associated with 0.054 difference in HAZ, which is about half of the 0.112 difference associated with each quintile of wealth. Coefficients on wealth and other control variables are similar in direction and significance for both boys and girls, except that the magnitude of coefficients is somewhat larger for boys suggesting greater susceptibility to variables such as altitude and maternal age.

Table 4. Child height on NDVI before and after birth by sex with alternative controls for age

	(1) Both sexes, age in months	(2) Both sexes, age in years	(3) Males, age in months	(4) Males, age in years	(5) Females, age in months	(6) Females, age in years
1st trimester	-0.102	0.034	-0.201	0.110	-0.074	-0.063
	(0.28)	(0.37)	(0.27)	(0.33)	(0.27)	(0.37)
2nd trimester	0.395**	0.445**	0.879***	1.016***	-0.225	-0.236
	(0.16)	(0.20)	(0.29)	(0.30)	(0.36)	(0.42)
3rd trimester	0.358	0.352	0.451	0.432	0.297	0.337
	(0.39)	(0.42)	(0.39)	(0.45)	(0.49)	(0.52)
0-2 mo. of age	-0.313*	-0.308	-0.086	-0.041	-0.544**	-0.575*
	(0.17)	(0.20)	(0.29)	(0.28)	(0.26)	(0.31)
3-5 mo. of age	-0.123	-0.422	-0.164	-0.608***	-0.044	-0.247
	(0.31)	(0.34)	(0.24)	(0.23)	(0.36)	(0.38)
6-8 mo. of age	-0.309*	-0.262*	-0.335	-0.408	-0.123	0.030
	(0.16)	(0.15)	(0.34)	(0.33)	(0.31)	(0.37)
9-11 mo. of age	-0.238	-0.123	-0.366	-0.250	-0.179	-0.099
	(0.36)	(0.37)	(0.49)	(0.50)	(0.41)	(0.42)
Female	-0.016	-0.012				
	(0.04)	(0.04)				
Age (in mo.)	-0.068***		-0.064***		-0.076***	
	(0.01)		(0.01)		(0.01)	
Age squared	0.001***		0.001***		0.001***	
	(0.00)		(0.00)		(0.00)	
Siblings ever born	-0.073***	-0.073***	-0.080***	-0.079***	-0.064***	-0.065***
	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)
Mat. age (log)	0.413***	0.399***	0.550***	0.532***	0.323**	0.316**
	(0.11)	(0.11)	(0.15)	(0.15)	(0.16)	(0.16)
Mat. primary ed.	0.066**	0.066**	0.105**	0.105**	0.055	0.058
	(0.03)	(0.03)	(0.05)	(0.05)	(0.06)	(0.06)
Mat. secondary ed.	0.305***	0.310***	0.341***	0.348***	0.284***	0.286***
	(0.06)	(0.06)	(0.07)	(0.07)	(0.08)	(0.08)
Mat. tertiary ed.	0.664***	0.670***	0.607***	0.612***	0.743***	0.750***
	(0.09)	(0.09)	(0.07)	(0.07)	(0.15)	(0.14)
Maternal BMI	0.040***	0.040***	0.046***	0.044***	0.037***	0.037***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Wealth Quintile	0.108***	0.108***	0.107***	0.110***	0.112***	0.110***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Altitude (log)	-0.254***	-0.252***	-0.304***	-0.308***	-0.200**	-0.194*
	(0.08)	(0.08)	(0.09)	(0.09)	(0.10)	(0.10)
2011 DHS	0.134***	-0.558***	0.106*	-0.324***	0.174***	-0.803***
	(0.04)	(0.11)	(0.06)	(0.11)	(0.05)	(0.17)
Hill	-0.129	-0.143	0.053	0.054	-0.267	-0.283
	(.)	(.)	(.)	(.)	(.)	(.)
Terai	-0.290**	-0.247*	-0.357*	-0.305*	-0.235	-0.201
	(0.15)	(0.14)	(0.18)	(0.18)	(0.24)	(0.22)
Urban	0.017	0.022	-0.025	-0.026	0.037	0.047
	(0.06)	(0.06)	(0.06)	(0.06)	(0.07)	(0.07)
Year of Birth		0.141***		0.050		0.230***
		(0.05)		(0.05)		(0.07)
Constant	-1.340**	-285.369***	-1.930***	-103.063	-0.923	-463.169***
	(0.55)	(106.24)	(0.66)	(101.59)	(0.71)	(136.52)
Observations	6,127	6,127	3,129	3,129	2,998	2,998
R-squared	0.187	0.186	0.196	0.197	0.207	0.205

Notes: As for Table 3, except the first seven rows show NDVI in each trimester of pregnancy and quarter of the child's first year, scaled to show difference in HAZ score per 1000-point difference in NDVI . *** p<0.01, ** p<0.05, * p<0.1.

Turning to the effects of NDVI for households with and without toilets, from **Table 5** we observe the predicted heterogeneity in effect sizes and significance. In households without toilets, fluctuations in NDVI affect males only in utero (column 3), and affect females only in the first three months after birth (column 5). Households with toilets are largely immune to the effects of

NDVI fluctuations at any stage of child development. Effect sizes for the subsample without toilets are larger than for the country as a whole, with 100 points of NDVI during the second trimester of pregnancy affecting boys' heights as much as 1.2 quintiles of wealth, while 100 points of NDVI during the first three months after birth affecting girls' heights as much as 1.6 quintiles of wealth. Those effects completely disappear in households with toilets.

Table 5. Child height on NDVI before and after birth by sex and toilet in household

	(1) Both sexes no toilet	(2) Both sexes has toilet	(3) Male no toilet	(4) Male has toilet	(5) Female no toilet	(6) Female has toilet
1st trimester	-0.071	-0.070	-0.397	0.109	0.100	-0.231
	(0.34)	(0.35)	(0.58)	(0.48)	(0.43)	(0.21)
2nd trimester	0.522***	0.282*	1.016***	0.586	-0.172	-0.115
	(0.16)	(0.14)	(0.38)	(0.61)	(0.43)	(0.31)
3rd trimester	0.470	0.168	0.522**	0.275	0.392	0.133
	(0.38)	(0.56)	(0.22)	(0.71)	(0.59)	(0.65)
0-2 months of age	-0.445*	-0.010	-0.041	0.003	-0.869***	-0.054
	(0.25)	(0.20)	(0.37)	(0.35)	(0.31)	(0.29)
3-5 months of age	-0.179	-0.066	-0.137	-0.201	-0.105	-0.100
	(0.28)	(0.34)	(0.34)	(0.53)	(0.52)	(0.26)
6-8 months of age	-0.568*	0.003	-0.691	0.183	-0.230	-0.203
	(0.30)	(0.31)	(0.43)	(0.60)	(0.61)	(0.42)
9-11 months of age	-0.299	-0.167	-0.401	-0.209	-0.237	-0.232
	(0.36)	(0.48)	(0.47)	(0.66)	(0.51)	(0.64)
Female	-0.086*	0.061				
	(0.05)	(0.06)				
Age (in months)	-0.061***	-0.079***	-0.059***	-0.070***	-0.068***	-0.092***
	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)
Age squared (in months)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Number of siblings ever born	-0.068***	-0.086***	-0.082***	-0.079***	-0.055***	-0.089***
	(0.01)	(0.01)	(0.02)	(0.03)	(0.01)	(0.03)
Maternal age (log)	0.466***	0.390**	0.589**	0.587**	0.362*	0.288
	(0.15)	(0.17)	(0.27)	(0.25)	(0.19)	(0.20)
Maternal primary education	0.100**	0.025	0.121**	0.096	0.084	0.005
	(0.04)	(0.07)	(0.06)	(0.10)	(0.06)	(0.10)
Maternal secondary education	0.249***	0.285***	0.323***	0.355***	0.221**	0.227**
	(0.08)	(0.07)	(0.09)	(0.09)	(0.10)	(0.11)
Maternal tertiary education	1.190***	0.595***	1.336***	0.575***	1.071***	0.648***
	(0.22)	(0.11)	(0.16)	(0.12)	(0.39)	(0.16)
Maternal BMI	0.033***	0.044***	0.039***	0.051***	0.030**	0.041***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Wealth Quintile	0.067***	0.095***	0.082***	0.090***	0.056**	0.095***
	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.03)
Altitude	-0.135	-0.264***	-0.170	-0.314***	-0.118	-0.207
	(0.08)	(0.07)	(0.10)	(0.09)	(0.12)	(0.14)
2011 DHS observation	0.215***	0.077*	0.181**	0.046	0.273***	0.096
	(0.06)	(0.04)	(0.08)	(0.07)	(0.09)	(0.06)
Hill	-0.093	-0.199	-0.216	0.213	0.036	-0.496
	(.)	(.)	(.)	(.)	(0.09)	(.)
Terai	0.128***	-0.380**	-0.043	-0.354	0.207	-0.416
	(0.04)	(0.16)	(.)	(0.28)	(0.23)	(0.38)
Urban	-0.081	0.091	-0.058	0.038	-0.121	0.145***
	(0.09)	(0.07)	(0.12)	(0.09)	(0.10)	(0.05)
Constant	-2.209***	-1.223	-2.712***	-2.282*	-1.669**	-0.283
	(0.45)	(0.80)	(0.78)	(1.20)	(0.77)	(1.31)
Observations	3,329	2,797	1,672	1,457	1,657	1,340
R-squared	0.134	0.221	0.169	0.230	0.143	0.272

Notes: As for Table 4. *** p<0.01, ** p<0.05, * p<0.1

The effects of NDVI on children in districts with higher and lower levels of food-market activity in **Table 6** reveals a slightly less clear picture. In the low market-use districts, girls are again susceptible to NDVI fluctuations only in their first three months after birth, and boys are susceptible to NDVI fluctuation in their second trimester of gestation, but these subsamples also show a significant correlation with NDVI during the period of complementary feeding from six to eight months of age. That particular correlation holds for boys in districts with low market use, and for girls in districts with high market use. This could be a spurious correlation arising by chance in this sample, in part because these two periods in a child's life occur in the same season on successive years so the two NDVIs are highly collinear. Effect sizes for the main results are roughly similar as before. For boys in districts with low market participation, 100 points of NDVI in mid-pregnancy has an effect similar to 1.5 quintiles of wealth. For girls 100 points of NDVI in the three months after birth has a smaller effect, similar to about 0.5 quintiles of wealth.

Table 6. Child height on NDVI before and after birth by sex and use of food markets

	(1) Both sexes low mkt use	(2) Both sexes high mkt use	(3) Male low mkt use	(4) Male high mkt use	(5) Female low mkt use	(6) Female high mkt use
1st trimester	0.054	-0.292	-0.170	-0.231	0.151	-0.337
	(0.33)	(0.31)	(0.55)	(0.53)	(0.25)	(0.41)
2nd trimester	0.411*	0.399	1.346***	0.416	-0.610	0.395
	(0.22)	(0.39)	(0.14)	(0.54)	(0.45)	(0.54)
3rd trimester	0.178	0.446	0.420	0.314	-0.073	0.381
	(0.36)	(0.60)	(0.61)	(0.56)	(0.23)	(0.86)
0-2 months of age	-0.211	-0.520	0.137	-0.353	-0.650*	-0.571
	(0.25)	(0.34)	(0.23)	(0.46)	(0.34)	(0.49)
3-5 months of age	-0.379	0.048	-0.231	-0.073	-0.485	0.178
	(0.42)	(0.29)	(0.50)	(0.54)	(0.38)	(0.44)
6-8 months of age	-0.468**	-0.254	-1.088***	0.254	0.260	-0.801***
	(0.22)	(0.34)	(0.28)	(0.54)	(0.48)	(0.29)
9-11 months of age	-0.406	-0.097	-0.501	-0.105	-0.292	-0.041
	(0.31)	(0.54)	(0.60)	(0.65)	(0.27)	(0.74)
Female	-0.009	-0.035				
	(0.07)	(0.04)				
Age (in months)	-0.069***	-0.067***	-0.068***	-0.057***	-0.074***	-0.084***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Age squared (in months)	0.001***	0.001***	0.001***	0.001***	0.001***	0.001***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Number of siblings ever born	-0.078***	-0.058***	-0.081***	-0.059*	-0.071***	-0.057***
	(0.01)	(0.01)	(0.02)	(0.03)	(0.02)	(0.02)
Maternal age (log)	0.495***	0.284**	0.612***	0.355	0.423*	0.238
	(0.16)	(0.12)	(0.18)	(0.25)	(0.23)	(0.24)
Maternal primary education	0.076	0.036	0.190***	0.014	0.024	0.066
	(0.05)	(0.06)	(0.06)	(0.07)	(0.07)	(0.09)
Maternal secondary education	0.257***	0.335***	0.307***	0.363***	0.238***	0.320***
	(0.06)	(0.08)	(0.07)	(0.12)	(0.07)	(0.11)
Maternal tertiary education	0.753***	0.620***	0.904***	0.454***	0.602***	0.827***
	(0.06)	(0.14)	(0.17)	(0.13)	(0.12)	(0.18)
Maternal BMI	0.036**	0.044***	0.041**	0.050***	0.033**	0.038***
	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)
Wealth Quintile	0.112***	0.104***	0.088***	0.124***	0.141***	0.089***
	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)	(0.02)
Altitude (log)	-0.298***	-0.190*	-0.384***	-0.188	-0.172	-0.189
	(0.08)	(0.11)	(0.10)	(0.14)	(0.11)	(0.12)
2011 DHS observation	0.038	0.146**	-0.069	0.190*	0.159*	0.094
	(0.06)	(0.07)	(0.07)	(0.10)	(0.08)	(0.09)
Hill	-0.280	0.311*	0.070	-0.186	-0.561***	0.735***
	(.)	(0.16)	(.)	(0.22)	(0.09)	(0.18)
Terai	-0.565***	0.376***	-0.636***	-0.021	-0.438	0.704
	(0.14)	(0.14)	(0.13)	(0.32)	(0.30)	(.)
Urban	0.092	-0.026	0.181	-0.066	0.036	-0.004
	(0.15)	(0.05)	(0.14)	(0.08)	(0.16)	(0.06)
Constant	-0.762	-1.881**	-1.188	-2.452**	-0.749	-1.198
	(0.74)	(0.81)	(0.89)	(1.19)	(1.19)	(0.93)
Observations	3,064	3,063	1,561	1,568	1,503	1,495
R-squared	0.180	0.197	0.212	0.209	0.209	0.228

Notes: As for Table 5. *** p<0.01, ** p<0.05, * p<0.1

4. ROBUSTNESS CHECKS

To test robustness of our results we look for artefacts of the method, checking whether our regressions generate more statistically significant results than would arise by chance. We design these placebo regressions using the same data as our main results in **Tables 5 and 6**, with dependent variables that were predetermined long before the NDVI fluctuations occurred so no causal effect is possible. These are primarily maternal characteristics in columns 1-6, plus household wealth and urban or rural location in columns 7 and 8. The base rate of entirely spurious placebo effects is proportional to p-values, with for example one tenth of effects appearing significant at a p-value of ten percent. **Table 7** reveals that, among the 7x8=56 distinct placebo "treatments" tested, there arise only five effects with a p-value below 0.1, four effects with a p-value below 0.05, and one with a p-value below 0.01.

Table 7. Placebo results for predetermined variables on NDVIs during pregnancy and infancy

	(1) Age of mom	(2) Maternal primary education	(3) Maternal secondary education	(4) Maternal tertiary education	(5) Maternal BMI	(6) Total child ever born	(7) Wealth quintile	(8) Urban
1st trimester	-0.023	-0.202	0.088	0.047	-0.149	0.166	0.074	-0.196**
	(0.04)	(0.13)	(0.10)	(0.04)	(0.52)	(0.32)	(0.34)	(0.09)
2nd trimester	-0.081***	0.045	-0.018	0.030	-0.042	-0.219	0.075	-0.180
	(0.03)	(0.07)	(0.08)	(0.02)	(0.49)	(0.40)	(0.24)	(0.13)
3rd trimester	-0.011	-0.031	0.142	-0.021	-0.316	-0.070	-0.526*	0.045
	(0.07)	(0.12)	(0.09)	(0.04)	(0.30)	(0.50)	(0.30)	(0.16)
0-2 months	0.019	0.064	0.045	0.018	-0.216	-0.165	-0.211	-0.138
	(0.03)	(0.07)	(0.07)	(0.03)	(0.22)	(0.21)	(0.21)	(0.10)
3-5 months	0.051	0.246**	-0.051	-0.019	0.462	-0.210	-0.388	-0.017
	(0.04)	(0.12)	(0.11)	(0.03)	(0.62)	(0.29)	(0.27)	(0.10)
6-8 months	0.104**	0.048	0.058	0.004	-0.759	0.094	-0.112	-0.053
	(0.04)	(0.06)	(0.06)	(0.03)	(0.54)	(0.45)	(0.25)	(0.16)
9-11 months	0.012	-0.048	-0.025	0.037	0.141	-0.064	0.346	-0.279
	(0.08)	(0.11)	(0.09)	(0.04)	(0.54)	(0.46)	(0.27)	(0.19)
Mat. prim. ed.	-0.046***				0.248*	-0.266***	0.336***	0.049*
	(0.01)				(0.14)	(0.05)	(0.06)	(0.03)
Mat. sec. ed.	-0.038***				0.389***	-0.502***	1.052***	0.062**
	(0.01)				(0.12)	(0.05)	(0.05)	(0.03)
Mat. ter. ed.	0.068***				0.943***	-1.338***	1.382***	0.126**
	(0.01)				(0.26)	(0.06)	(0.12)	(0.05)
Maternal BMI	0.003***	0.002	0.004**	0.003***		-0.015*	0.051***	0.007***
	(0.00)	(0.00)	(0.00)	(0.00)		(0.01)	(0.00)	(0.00)
Total children	0.080***	-0.003	-0.021***	-0.020***	-0.062*		-0.082***	-0.002
	(0.00)	(0.00)	(0.00)	(0.00)	(0.03)		(0.01)	(0.00)
Wealth quint.	0.007***	-0.013	0.106***	0.024***	0.353***	-0.134***		0.093***
	(0.00)	(0.01)	(0.01)	(0.00)	(0.04)	(0.02)		(0.01)
Alt. (log)	0.015**	0.015	0.004	-0.010	0.469***	0.010	-0.099	-0.033
	(0.01)	(0.02)	(0.02)	(0.01)	(0.17)	(0.05)	(0.10)	(0.06)
2011 DHS	0.025*	0.017	0.083***	0.022***	0.649***	-0.192***	-0.193***	-0.050**
	(0.01)	(0.01)	(0.02)	(0.01)	(0.18)	(0.05)	(0.05)	(0.02)
Urban	0.012**	0.026	0.030	0.020**	0.374***	-0.021	0.712***	
	(0.00)	(0.02)	(0.02)	(0.01)	(0.13)	(0.06)	(0.09)	
Mat. age (log)		-0.275***	-0.191***	0.151***	1.125***	6.401***	0.321***	0.077***
		(0.05)	(0.04)	(0.03)	(0.34)	(0.20)	(0.06)	(0.03)
Constant	2.868***	0.956***	0.616***	-0.514***	14.268***	-17.133***	0.611	0.180
	(0.07)	(0.22)	(0.17)	(0.08)	(1.44)	(0.98)	(0.64)	(0.50)
Observations	6,127	6,127	6,127	6,127	6,127	6,127	6,127	6,127
R-squared	0.586	0.061	0.252	0.109	0.176	0.617	0.558	0.313

Notes: As for Table 6. *** p<0.01, ** p<0.05, * p<0.1

The number and pattern of significant coefficients in **Table 7** corresponds to the frequency of significant correlations we would expect to occur by chance alone, and there is no temporal pattern to these correlations as each occurs at a different stage of child development. Since our placebo tests use the same data and model structure as **Tables 5 and 6**, the clear pattern that we observe for NDVI treatment effects on child heights is very likely to be a robust result of causal mechanisms.

4. CONCLUSIONS

The objective of this study is to identify the influence of early-life agroclimatic conditions on children's attained heights in Nepal, and test for protective effects of sanitation and food markets. In so doing, we find clear heterogeneity in vulnerability: boys are most affected by agroclimatic circumstances in their second trimester of gestation, while girls are most vulnerable in the three months after birth. These findings are consistent with biomedical studies of sex-specific fetal development and socioeconomic studies of gender bias in child care. Both kinds of vulnerability are eliminated in households with toilets, and greatly reduced in districts that have more active use of food markets.

The magnitude of fluctuations against which sanitation and food markets are protective is very large: on average, for boys each 100 points of variation in NDVI during the second trimester of pregnancy is associated with as much difference in attained heights as 1.2 quintiles of household wealth, while for girls that same variation during the first three months after birth is associated with as much as difference in height as 1.6 quintiles of wealth. The average seasonal change in NDVI from peak to trough in Nepal during the 2000-2011 period was about 200 points in the Mountains and Hills regions, and about 300 points in the Terai (lowland) region. Among unprotected households, the difference in attained heights between most and least favorable times of year depend on location, but are similar to the differences associated with more than one quintile of wealth. To test the internal validity of these findings, we conduct a number of placebo regressions that reveal no significant artefactual correlations that could be due to selection effects in birth timing.

Heterogeneity in response to agroclimatic conditions provides important clues as to the causal mechanisms involved, and valuable guidance regarding the targeting of interventions. Our results are consistent with sanitation protecting children against fecal-oral transmission of disease, while food purchases protect children against fluctuations in local food production. Policy interventions to promote sanitation and strengthen food markets could help protect children against adverse conditions in the future, helping children grow up healthy despite climate change. Our research design exploits random exposure to varying agroclimatic circumstances based on birth timing. To detect selection effects we test for effects of socioeconomic status on month of birth, and find no correlations. We also use a series of placebo regressions to test whether our research design generates spurious correlations, and find only the expected base rate of non-causal statistical significance. These empirical tests increase confidence in the robustness of our results for the Nepali context.

The main limitation of our study concerns the protective effect of sanitation and food markets, as household toilets and market activity are not randomly assigned. Our regressions control for observable influences on child height such as household wealth, parental education, maternal BMI and altitude, as well as district fixed effects. Violations of the parallel trends assumption behind our difference-in-differences design would involve other factors that make households less vulnerable to agroclimatic conditions, such as cultural differences. For example, perhaps households with toilets and in districts with stronger food markets have access to more effective social insurance than the average household with similar levels of observable control variables. The large protective effects found in our data are plausibly explained by differences in fecal-oral disease transmission and food consumption smoothing, but cultural differences or other unobserved factors cannot be ruled out without large-scale randomized trials.

Future work could extend our results using other natural experiments in observational data, perhaps over longer periods and more countries, or refining the measurement of agroclimatic conditions and the timing of exposure. This study confirms that exploiting natural experiments can be of great value in identifying the periods in utero and infancy when child development is most at risk, and extends previous results to reveal the socioeconomic conditions that are most able to protect children against those risks. Results point to the power of investments in maternal health during pregnancy to protect boys, and in immediate post-natal care to protect girls, as well as the value of sanitation and food markets in building resilience against variation in agroclimatic conditions.

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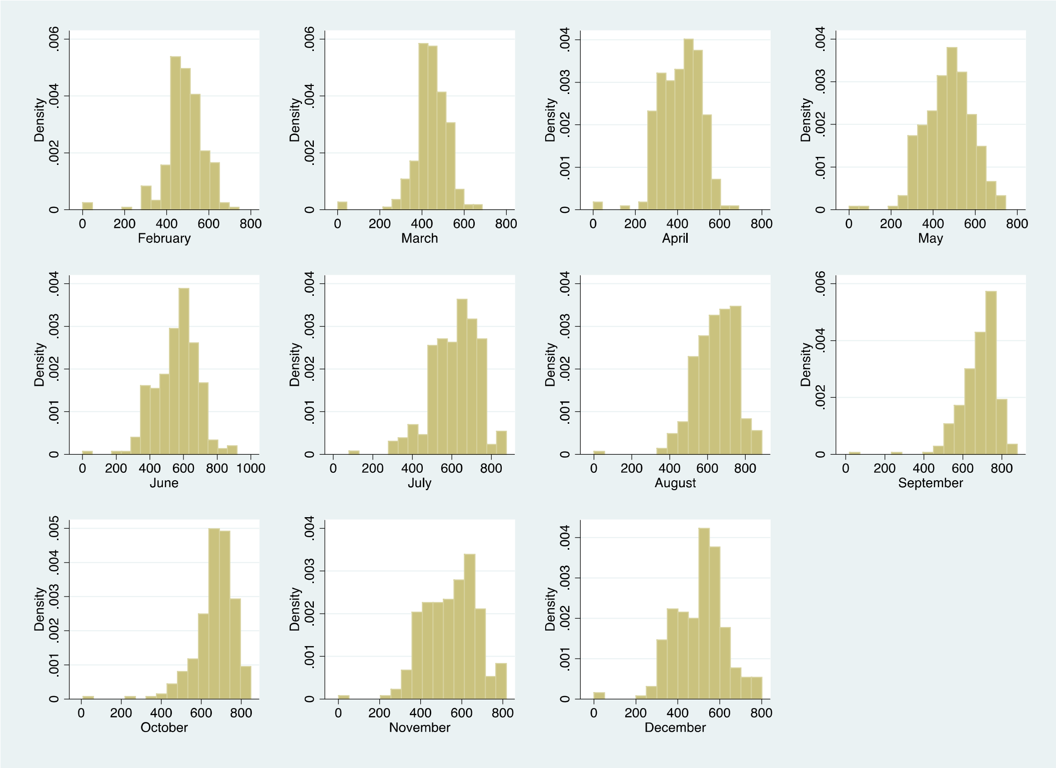
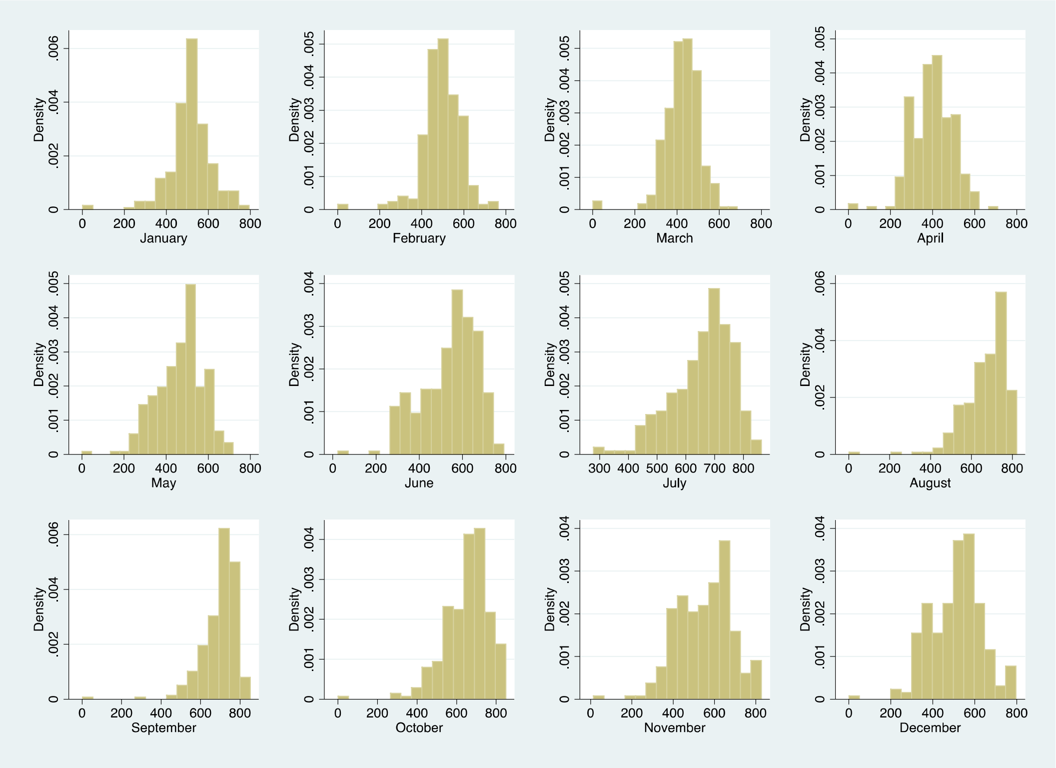
APPENDIX A: Monthly histograms of NDVI by year

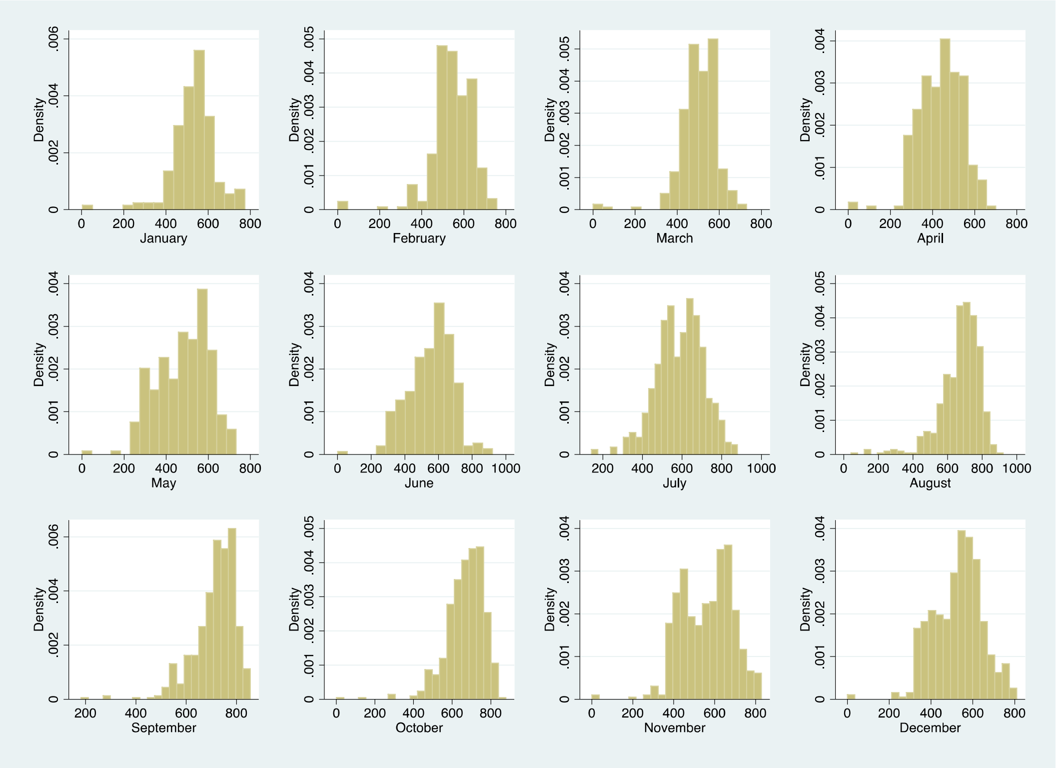
1) Distribution of NDVI (February- December) in each of the 547 NDHS clusters (Year 2000)



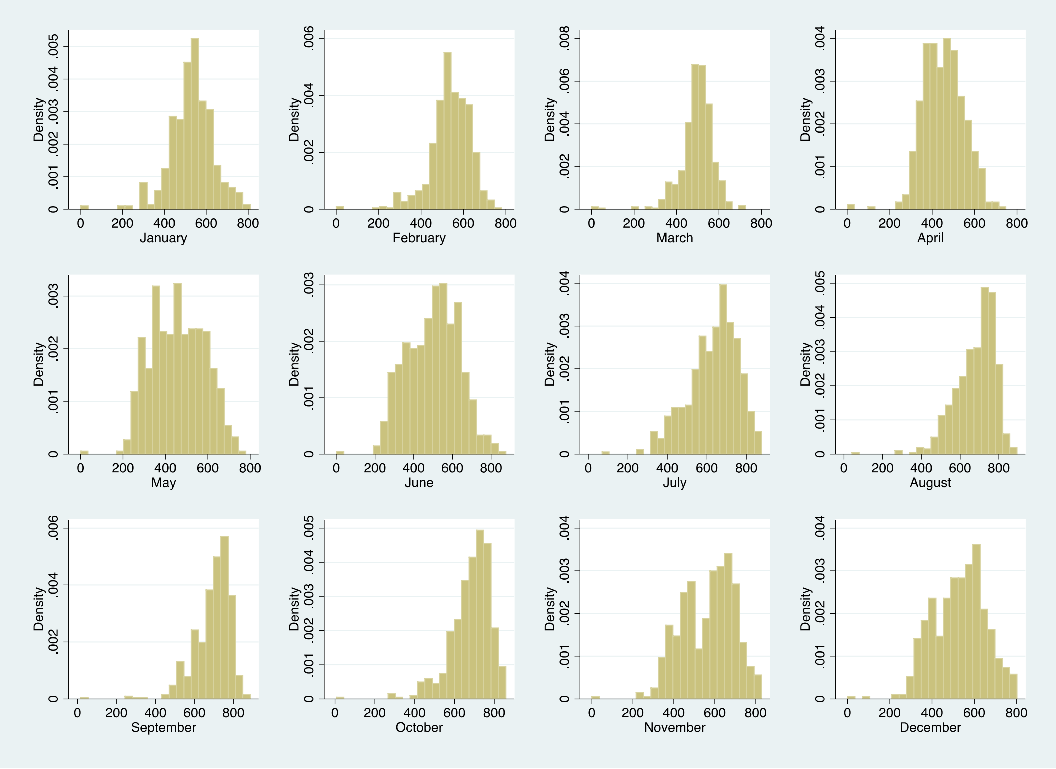
2) Distribution of monthly NDVI in each of the 547 NDHS clusters (Year 2001)



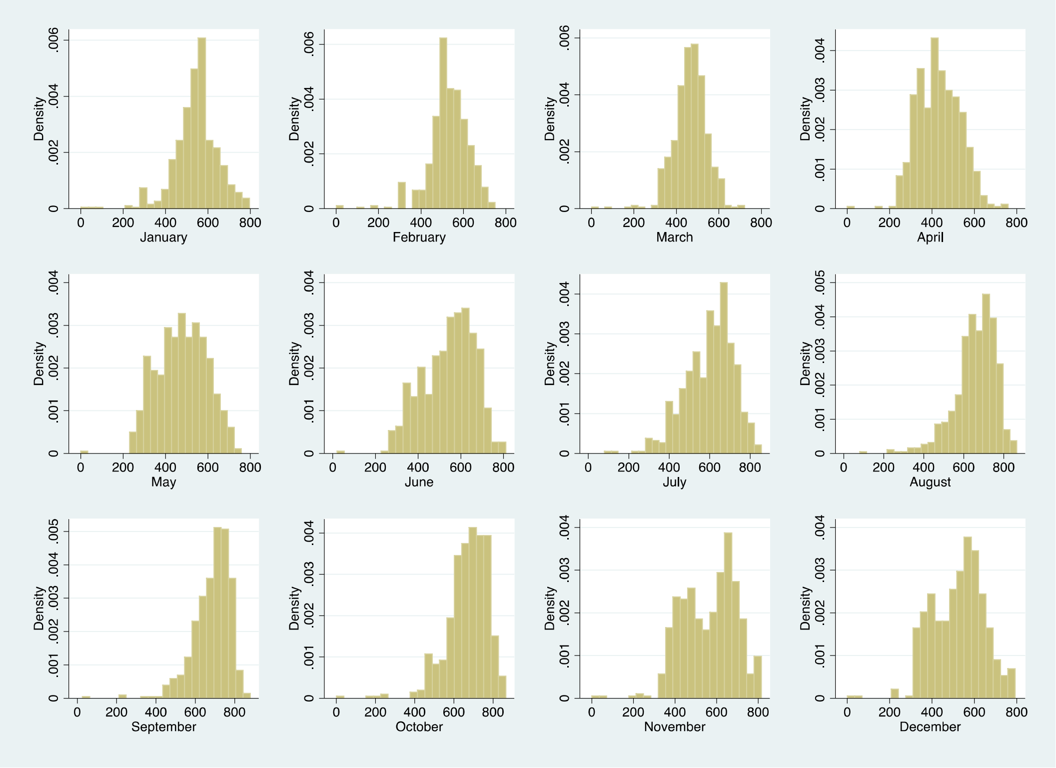
3) Distribution of monthly NDVI in each of the 547 NDHS clusters (Year 2002)



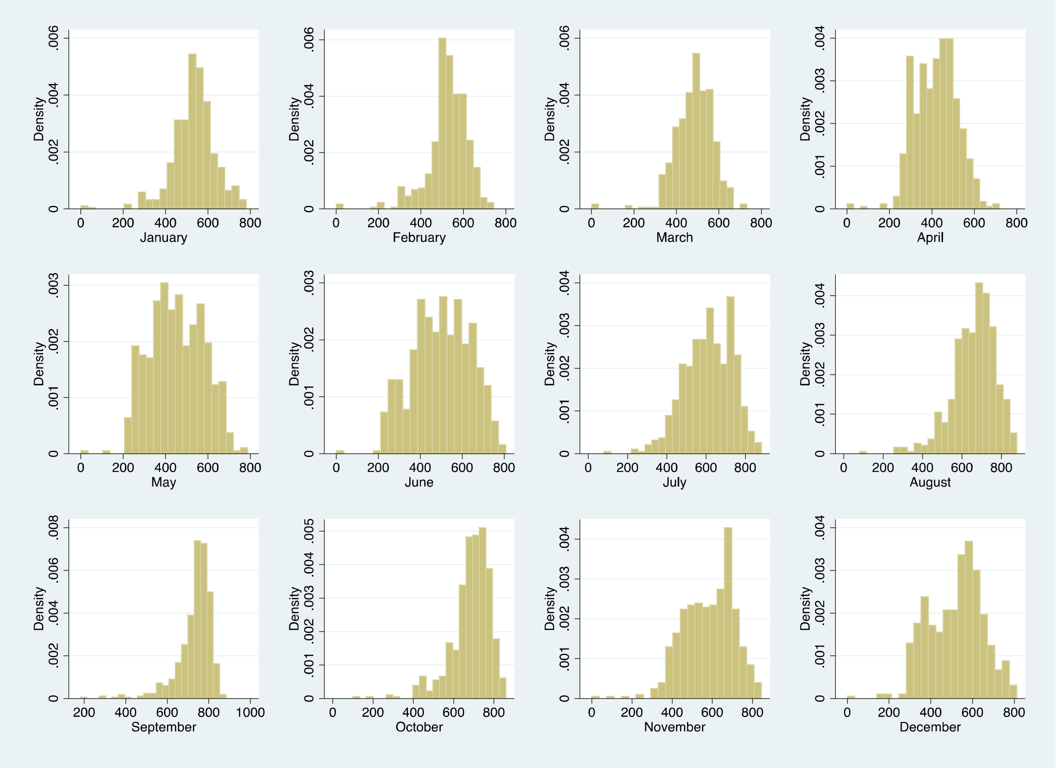
4) Distribution of monthly NDVI in each of the 547 NDHS clusters (Year 2003)



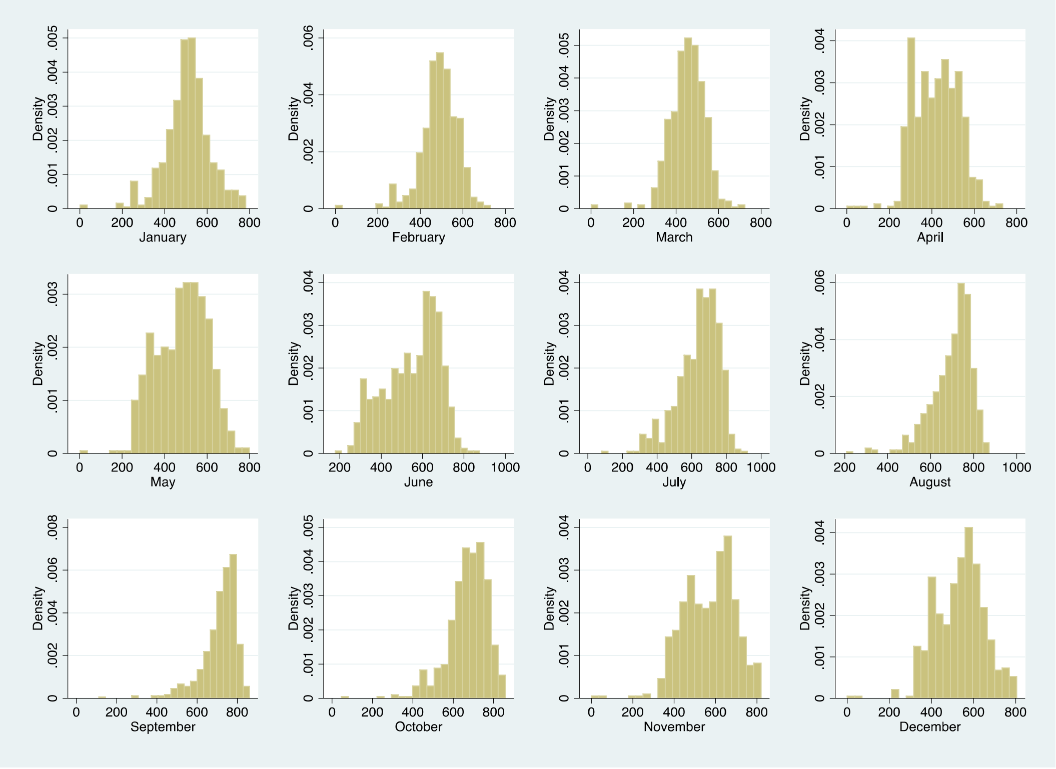
5) Distribution of monthly NDVI in each of the 547 NDHS clusters (Year 2004)



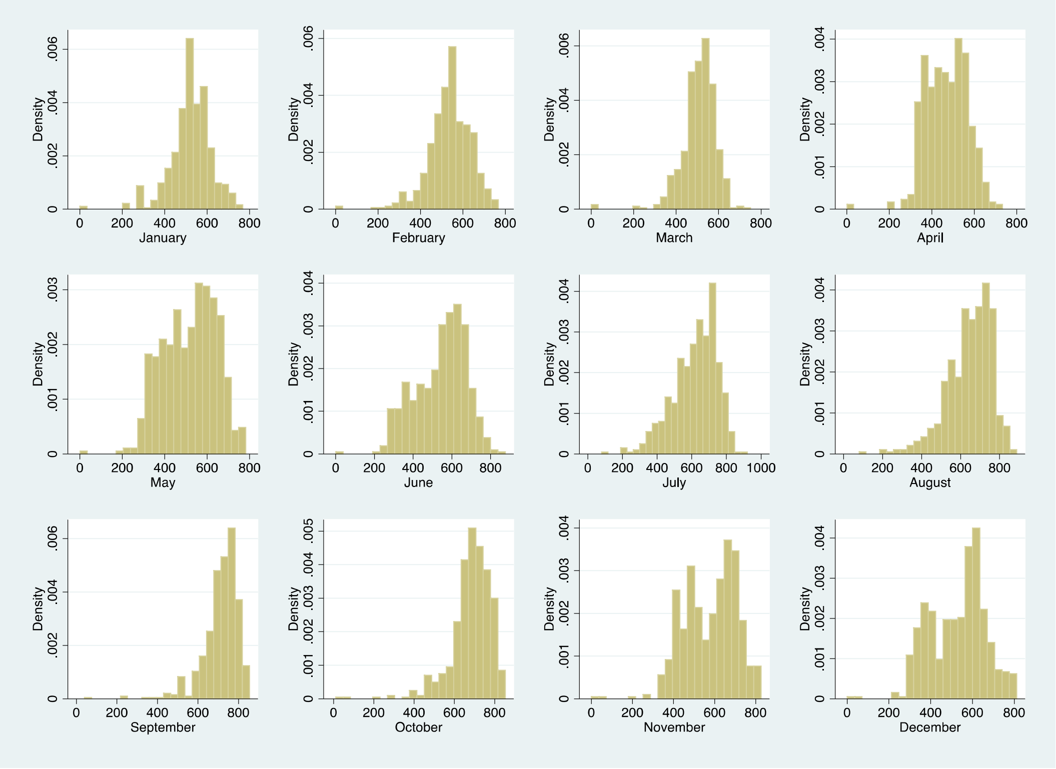
6) Distribution of monthly NDVI in each of the 547 NDHS clusters (Year 2005)



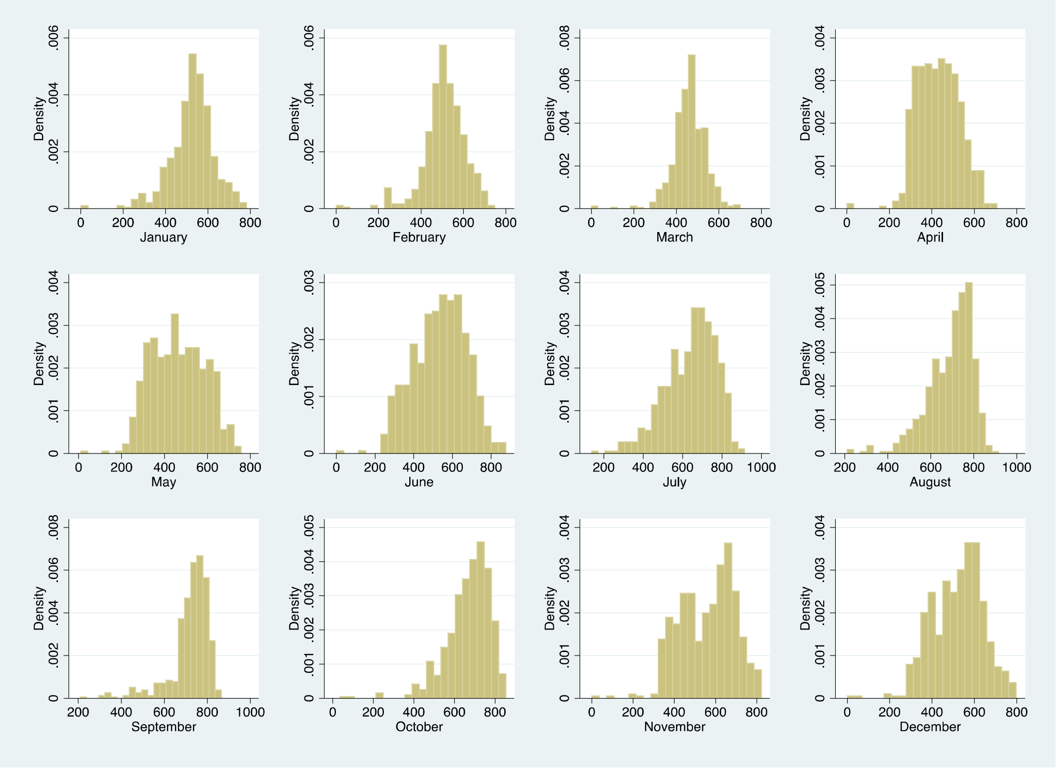
7) Distribution of monthly NDVI in each of the 547 NDHS clusters (Year 2006)



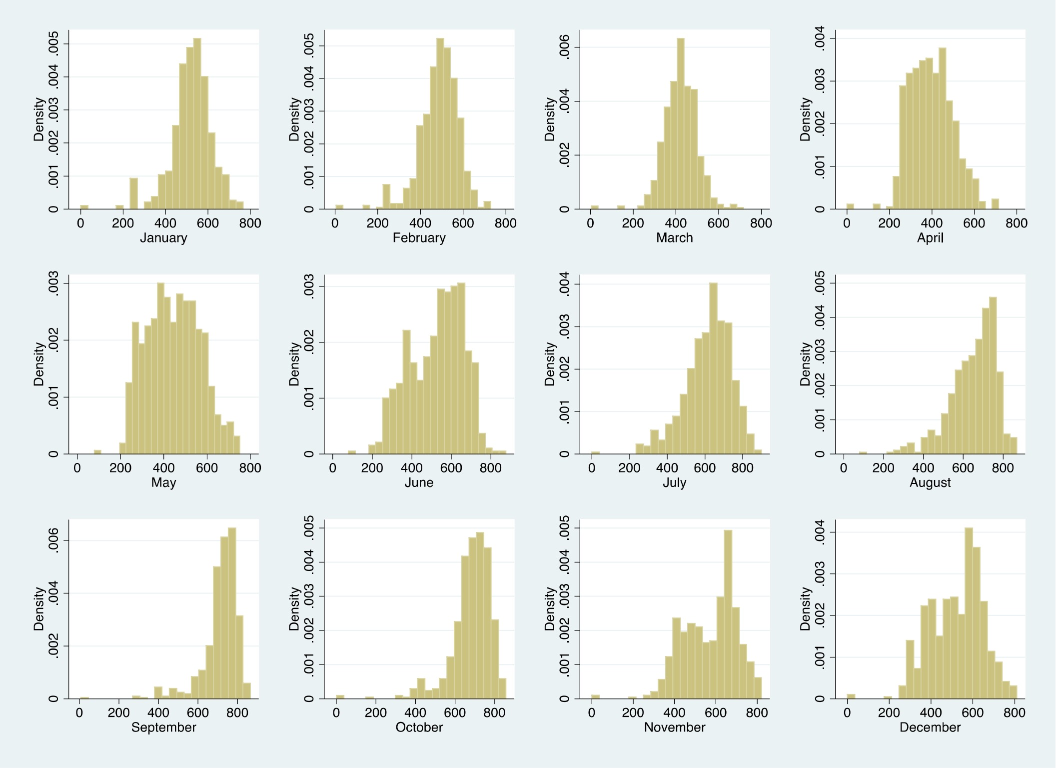
8) Distribution of monthly NDVI in each of the 547 NDHS clusters (Year 2007)



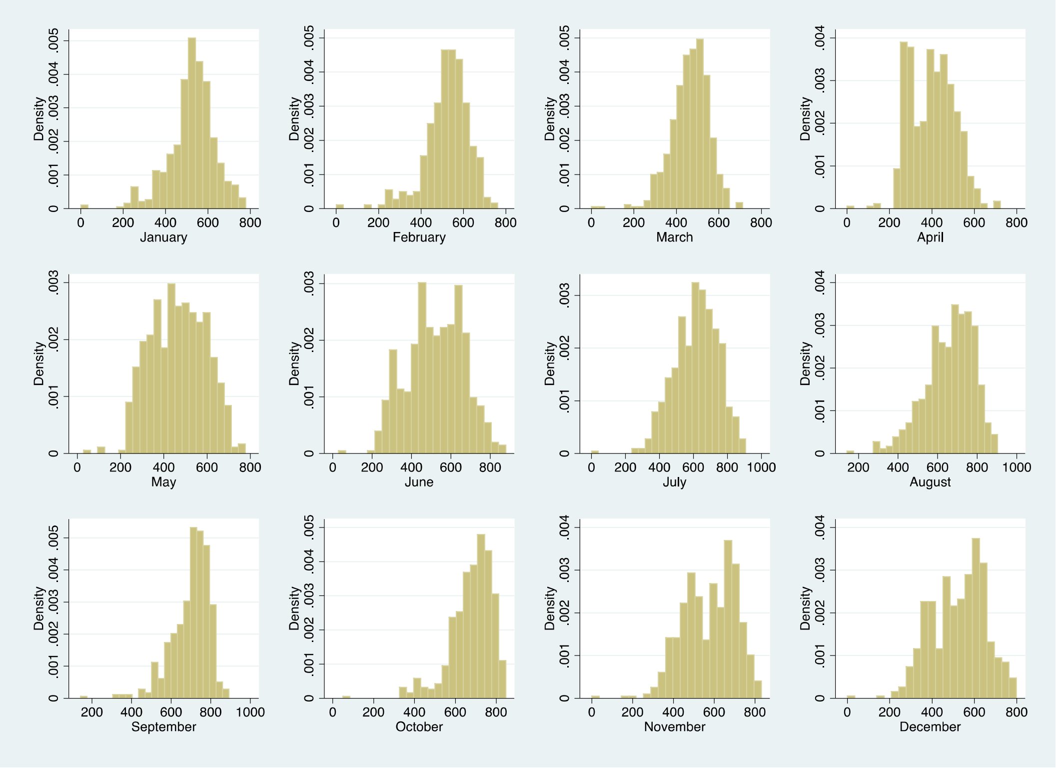
9) Distribution of monthly NDVI in each of the 547 NDHS clusters (Year 2008)



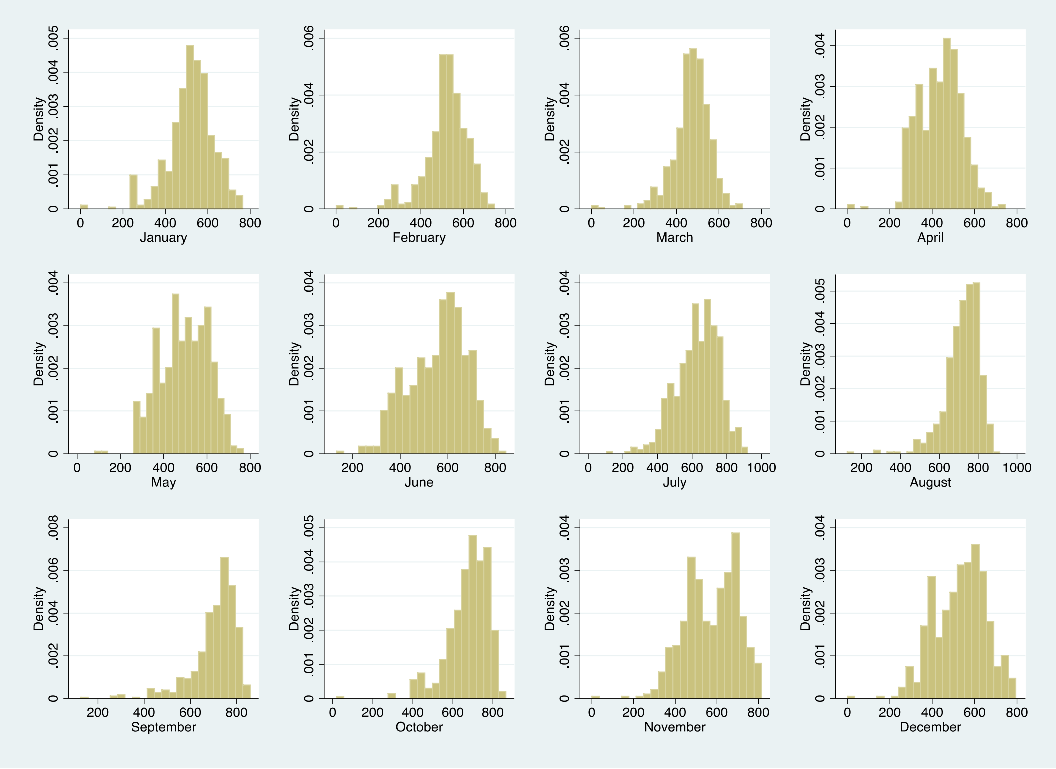
10) Distribution of monthly NDVI in each of the 547 NDHS clusters (Year 2009)



11) Distribution of monthly NDVI in each of the 547 NDHS clusters (Year 2010)



12) Distribution of monthly NDVI in each of the 547 NDHS clusters (Year 2011)



13) Distribution of NDVI (January-May) in each of the 547 NDHS clusters (Year 2012)