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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 impacts on later health outcomes, but causal mechanisms and potential remedies have been difficult to discern. This paper uses the Nepal Demographic and Health Surveys of 2006 and 2011, combined with earlier NASA satellite observations of variation in the Normalized Difference Vegetation Index (NDVI) at each child's location and time of birth to identify the trimesters of gestation and periods of infancy when climate variation is linked to attained height later in life. We find significant differences by sex: males are most affected by conditions in their second trimester of gestation, and females in the first three months after birth. Each 100-point difference in NDVI at those times is associated with a difference in height-for-age *z*-score (HAZ) measured at age 12–59 months of 0.088 for boys and 0.054 for girls, an effect size similar to that of moving within the distribution of household wealth by close to one quintile for boys and one decile for girls. The entire seasonal change in NDVI from peak to trough is approximately 200–300 points during the 2000–2011 study period, implying a seasonal effect on HAZ similar to one to three quintiles of household wealth. This effect is observed only in households without toilets; in households with toilets, there is no seasonal fluctuation, implying protection against climatic conditions that facilitate disease transmission. We also use data from the Nepal Living Standards Surveys on district-level agricultural production and marketing, and find a climate effect on child growth only in districts where households' food consumption derives primarily from their own production. Robustness tests find no evidence of selection effects, and placebo regression results reveal no significant artefactual correlations. The timing and sex-specificity of climatic effects are consistent with previous studies, while the protective effects of household sanitation and food markets are novel indications of mechanisms by which households can gain resilience against adverse climatic conditions.

1. Introduction and motivation

Attained height is among the most important indicators of childhood health or deprivation. Approximately 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 rates later in life (IFPRI, 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 (United Nations, 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 in this indicator from 2001 to 2011. Key changes involved both greater household sanitation and access to improved diets, which are pillars of the Nepal government's multisector nutrition plan (Nepal

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NPC, 2012). Despite this progress, however, 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. Our use of variation in birth timing relative to changes in climatic conditions contribute to a rapidly growing body of literature using natural experiments to study the determinants of human health (Angrist and Krueger, 2001; Akresh et al., 2011; Lokshin and Radyakin, 2012; Tiwari et al., 2013; Brown et al., 2014), addressing the timing and mechanisms by which early conditions influence later outcomes (Skoufias and Vinha, 2012; Kumar et al., 2016 ; Schultz-Nielsen et al., 2016).

Our identification strategy takes 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 in their early growth and development. The specific data we use are the Nepal Demographic Health Survey (NDHS) for child health, sanitation, and other household characteristics from 2006 and 2011, combined with Normalized Difference Vegetation Index (NDVI) data from the National Aeronautics and Space Administration (NASA) for 2000–2012 at each child's location, and the Nepal Living Standard Survey (NLSS) to characterize local agricultural markets for 2003–2004 and 2010–2011.

By combining three kinds of data, we are able to identify patterns in attained heights of children observed at 12–59 months of age, and test whether sanitation and food markets limited their association with agroclimatic conditions experienced during gestation and the first year after birth. We find the underlying patterns to be sex-specific, with systematic differences in how later heights relate to NDVI fluctuations that occurred 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 household sanitation and more commercialized food markets limit both kinds of vulnerability, providing significant protection from agroclimatic conditions for both pregnant mothers and infants.

2. Background and identification strategy

2.1. Agriculture and climate in Nepal

Nepal is a landlocked country with a population of approximately 27 million people, of whom about 85 percent live in rural areas (Nepal MoHP, 2012) and are highly reliant on rain-fed agriculture (Nepal MoAD, 2013). The country features three distinct ecological zones: Mountains (52,000 km^2), Hills (61,000 km^2), and Terai or lowlands (34,000 km^2), with varying population densities. The Mountain zone has a dry alpine climate and is situated at the highest altitude (>2500 m), with steep and rugged terrain and short growing seasons. The Hills have a mostly temperate climate (500–2500 m), and the Terai (<500 m) has a mostly subtropical and humid climate (Nepal MoHP 2012). Although the Terai occupies 23 percent of the country's landmass, it hosts almost half of the population (48 percent) and most of the cultivable land (56 percent) (Nepal 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 declined in frequency and increased in intensity (Malla, 2008).

The 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–August) became increasingly hot and wet, and winter months (November–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 data 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 lower birth weights, educational attainment, and adult heights, perhaps as a result of low vitamin D levels during early life (Day et al., 2015). In the United States, 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 the result of selection effects, as Buckles and Hungerman (2013) show in their study of winter births in the United States which occur disproportionately among disadvantaged youths. However, 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 effects of 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 the fall–winter months (Lokshin and Radyakin, 2012). In addition, 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 age five rises during the rainy season, which is also the preharvest 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, and have 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 subsequent stunting (Coffey, 2015) as well as low weight and