First foods: Diet quality among infants aged 6-23 months in 42 countries

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Abstract: Diet quality is closely linked to child growth and development, especially among infants aged 6-23 months who need to complement breastmilk with the gradual introduction of nutrient-rich solid foods. This paper links Demographic and Health Survey data on infant feeding to household and environmental factors for 76,641 children in 42 low- and middle-income countries surveyed in 2006-2013, providing novel stylized facts about diets in early childhood. We find strong support for an infant-feeding version of Bennett's Law, as wealthier households introduce more diverse foods at earlier ages, with additional effects of parental education, local infrastructure and agro-climatic conditions. We also explore the determinants of children's consumption of individual nutrient-rich food groups, and document similar associations with household wealth, parental education and geographic variables. These results reveal systematic patterns in how first foods vary across developing countries, pointing to new opportunities for research towards nutrition-smart policies to improve children's diets.

Key words: Child malnutrition; Child diets; Dietary diversity; Bennett's law

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1. Introduction

Undernutrition limits the growth and development of several hundred million children every year, contributing to poor health and cognition, low educational attainment and reduced lifetime earnings (Glewwe et al. 2001; Horton et al. 2008; Hoddinott 2009). Growth faltering is most severe in the 6-23 month window when infants are first introduced to solid foods (Shrimpton et al. 2001; Victora et al. 2010). At this age, infants have small stomachs relative to their potential growth velocity: they need more dietary energy and larger quantities of high-quality protein, fats and micronutrients than can be provided by breastmilk alone, but they cannot yet digest sufficient volumes of the starchy staples and other foods with low nutrient density typically consumed by older children and adults in low- and middle-income countries (PAHO/WHO, 2003). Black et al. (2013) report strong evidence that improving diet quality in the first two years of life can prevent stunting and micronutrient deficiencies, supported by a wide range of studies regarding the specific foods used to complement breastmilk from 6 to 23 months of age (Arimond and Ruel 2004; Mallard et al. 2014; Headey et al. 2018).

This study describes the month-to-month introduction of solid foods in 42 low- and middle-income countries (LMICs) around the world, using mothers' responses to the infant feeding questions introduced in Phases 5 and 6 of the Demographic and Health Surveys starting in 2003. Our motivation is the monthly pattern of growth faltering and micronutrient deficiency illustrated by Figure 1. The stunting rate, defined as the fraction of children whose length- or height-for-age is more than two standard deviations below the WHO reference distribution for a healthy population, is relatively low and stable from birth through early infancy, then rises sharply around 6 months before stabilizing by two years of age. This pattern has been documented ever since the DHS began measuring heights in the late 1980s (Shrimpton et al.

2001, Victora et al. 2010). Here we add anemia prevalence, which the DHS began measuring in the late 1990s using small samples of blood from infants starting at 6 months of age. Figure 1 shows how month-to-month growth faltering coincides with age pattern of anemia, which peaks around 6 months when the DHS begins measurement and falls sharply after 12 months of age. Both indicators reveal the potential importance of diet quality in very early life, and the precise timing and composition of an infant's first solid foods.

Figure 1. Child growth faltering and anemia, by age in months

Notes: Data shown are mean prevalence rates for stunting (HAZ<-2) and anemia (hemoglobin<11 g/dl), among 67,241 children measured for Phase 5 & 6 of the DHS in 39 countries where hemoglobin tests were done. HAZ is measured using length-for-age from birth to age 2, and height-for-age thereafter, in z score units of standard deviation away from the mean of a healthy population. Anemia is measured using heel-prick blood samples only after 6 months of age. Countries and years for all surveys used are shown in supplemental annex Table A1.

Nutritionists have long recognized the importance of gradually introducing new foods in addition to continued breastfeeding after 6 months of age (WHO/UNICEF 2003), but observations of actual intake by month in LMICs is generally limited to small scale qualitative studies in specific communities (Pak-Gorstein et al., 2009). Population-representative survey data has typically been aggregated into wider age categories, if only because each survey can reach only a few children at each age. Previous studies have also focused on other kinds of differences across populations (Dibley and Senarath 2012; Begin and Aguayo 2017; Galway, Acharya and Jones 2018) or intake of specific food groups (Headey, Hirvonen and Hoddinott, 2018).

In this study we focus on the month-to-month introduction of new foods using nonparametric methods as in Figure 1, to characterize the resulting dietary diversity among food groups fed to infants as they grow. Economics has a long tradition of research on consumer demand for variety in other kinds of goods, showing introduction of new goods and increased diversity in consumption as incomes rise (Senior 1836; Marshall 1890; Jackson 1984). For food in particular, since Bennett (1941) many studies of have confirmed that richer people with higher expenditure levels diversify out of starchy staples into more costly and more nutrient-dense foods, whether using national data on per-capita food supplies (e.g. Choudhury and Headey 2017) or survey data (e.g. Behrman and Deolalikar 1989; Subramanian and Deaton 1996). Recent studies show how the diet diversification process is affected by differences in the relative cost of acquiring different foods, including the many situations in which certain foods are entirely missing from local markets. As shown by Singh, Squire and Strauss (1986), at times and places where people can buy and sell freely at market prices, consumption decisions would be separable from production choices since farm households can raise whatever crops and livestock would generate their highest available living standards. A key insight of this literature is that many nutrient-dense foods such as fruits and vegetables, meat, eggs and milk are not easily stored or traded in underdeveloped rural settings, so they can be included in child diets only when and where they are produced (e.g. Hoddinott et al. 2015). Studies of non-separability typically focus on whether the household's own production is needed for consumption, but trade among villagers could ensure that the more relevant agro-ecological constraint is at the community level. Even when communities are linked through year-round trade, price differentials due to transport and storage costs ensure that local conditions affect relative prices, with more nutritious foods available at lower relative cost at places and times with more favourable agroecological and infrastructural conditions. Previous work has focused primarily on overall diet diversity for households relative to their own production diversity (Sibhatu and Qaim 2018), with more limited research on specific foods and food groups consumed by children at different ages (Mulmi et al. 2017).

This paper aims to provide a comprehensive exploration of the relative roles of wealth, parental knowledge/education, women's empowerment, and community level characteristics such as agroecology and infrastructure, in shaping infant feeding patterns. We make novel use of recent Development and Health Surveys (DHS) from 42 countries, combined with geographic data about the locations of DHS survey clusters as described in Section 2. We use these data to first document infant feeding patterns in our sample, including differences across major developing regions, before presenting econometric models that account for inter-child differences in dietary diversity scores, minimum dietary diversity, and the consumption of eight nutrient-rich food groups. We then provide various extensions to explore the relationship between household and community level factors, to account for regional heterogeneity, and to contrast our results to findings from the existing literature, with potential policy implications and areas for future research.

2. Theory, data and methods

Our work is motivated by household decisionmaking models such as those described in Hoddinott et al. (2015), Behrman and Deolalikar (1989), and Singh, Squire and Strauss (1986). We expect that parents seek to sustain child growth and development through age-specific nutrient intake and non-food goods or services such as healthcare, while also pursuing other objectives against a variety of resource constraints. Child outcomes also depend on intrahousehold bargaining, as each household member makes different contributions and has different preferences (Strauss and Thomas 1995; Behrman 1997; Haddad et al. 1997).

In this framework, if there were perfectly competitive markets for everything, child dietary intake would depend only on the household's full income (including the value of time and things produced at home), relative prices of different foods, and factors affecting preferences such as nutritional knowledge and maternal empowerment. Missing or imperfect markets ensure that the household's own production possibilities and local conditions around each survey site also influence consumption, especially for bulky and highly perishable foods that have high transport and storage costs. These include many of the most important nutrient-dense foods needed for infant feeding, such as dairy products, eggs and many fruits and vegetables. Crop choice and productivity is very sensitive to temperature and climate (Schlenker and Lobell, 2010), which also affect vectors for human and livestock diseases such as the tsetse fly that has long limited availability of dairy products in Africa (Alsan, 2015). In this study we link these local agroecological and also infrastructural factors to infant feeding practices, comparing community characteristics directly to household and other influences on the first foods consumed by infants as they grow.

Data

Our outcome of interest is mothers' responses to the child feeding questionnaire included in 42 countries during Phases 5 and 6 of the DHS (ICF International 2015), which we link to household characteristics from the DHS combined with geographic information from other sources about infrastructure and agroecological conditions around each survey site. The DHS are particularly useful for multi-country analysis due to their standardized methods for study design and interviewer training, as well as careful translation to elicit comparable information about local foods and feeding practices. We include all countries and survey rounds that include the infant feeding model, listed in the supplemental annex as Table A1. Like other studies based on DHS data, most (58%) of our sample is from sub-Saharan Africa, with 24% from Latin America and the Caribbean, 11% from Asia and 7% from the Middle East and North Africa. Other regions are relatively under-represented, with just two countries from the Middle East and North Africa (Egypt and Jordan), and three from Asia (Cambodia, Nepal and Timor-Leste). Despite these limitations, these 42 countries – with several hundred communities surveyed in each country – provide substantial socioeconomic and geographic variation for our analysis.

Our primary measures of diet quality are the dietary diversity score (DDS), defined as the number out of seven food groups consumed by a child in the past 24 hours, and minimum dietary diversity (MDD), defined as whether a child consumed at least four of these seven food groups. DDS and MDD have been linked to child growth (Arimond and Ruel, 2004), and MDD has also been shown to be a strong predictor of micronutrient adequacy in children (FANTA, 2006). In addition to these diversity metrics, we explore consumption patterns of four nutrient-rich vegetal foods and four nutrient-rich animal-sourced foods. The seven food groups included in the DDS and MDD measures are described in Table 1, along with the eight nutrient-rich food groups. Note that we focus on children 6-23 months of age. Data are for older children are not generally recorded in the DHS, and children 0-5 months are not supposed to be fed solid foods.

Table 1. Food group classifications used for diet diversity measurement

Food groups used for dietary diversity scores and minimum diet diversity	Disaggregated food categories used for analysis of nutrient-rich food consumption
(1) Starchy staples	(1) Cereals (excluded) (2) Roots/tubers (excluded)
(2) Legumes and nuts	(3) Legumes and nuts
(3) Vitamin A-rich fruits and vegetables	(4) Vitamin A-rich fruits and vegetables, excluding DGLV (5) DGLV (Dark green leafy vegetables)
(4) Other fruits/vegetables;	(6) Other fruits and vegetables
(5) Dairy products	(7) Dairy products
(6) Eggs	(8) Eggs
(7) Meat, organs, fish.	(9) Meat/organs (10) Fish*

Note: Data on fish consumption are missing for Peru.

The theoretical framework described above emphasizes the importance of budget constraints in shaping food purchases. To capture purchasing power, we use DHS data on the household's ownership of durable consumption goods (radio, TV, refrigerator, motorbike, car) and housing characteristics (floor materials, access to electricity, access to piped water or an improved toilet) that reflect permanent income. Time-varying purchasing power would be reflected in household expenditure, but it is measured with substantial error (Beegle et al. 2012) and asset-based measures are a generally preferred. Following the standard approach we use durable consumption goods to derive a wealth index using principal components analysis, as per Filmer and Pritchett (2001), re-estimating the index over our dataset of 42 countries to derive an internally comparable index using common weights. The results are very highly correlated with separate estimation of asset indexes to compare households within each survey (r=0.97), indicating that these asset categories have similar association with each other and ability to predict the latent concept of households' permanent income, despite differences in relative cost and demand across rural and urban households in various countries (Rutstein et al. 2013).

In addition to wealth, we use several other socioeconomic indicators that we interpret primarily as proxies for nutrition knowledge. Formal education, in particular has been shown to be a strong predictor of nutritional knowledge (Webb and Block 2004, Schneider and Masters 2018). We measure formal education as years of schooling of mothers and their partners (usually the father of the child). Following Alderman and Headey (2017), we pool years of education into different year brackets to allow for non-linear returns to education, whereby 1-6 years approximates "primary education", 7-9 years denote "lower secondary" or "middle school" and 10-plus refer to attending "upper secondary" or receiving some amount of tertiary education. It is also possible that exposure to health services may impart nutritional knowledge relevant to diets and feeding practices. To this end we construct a health access index that equals one if mothers had antenatal check-ups, neonatal care (a medical facility birth) and postnatal care in the form of vaccinations. These three indicators are correlated with each other, and robustness tests revealed that each had similar coefficients. We also use an indicator of whether a child was breastfed within one hour of birth, as recommended by nutritionists, as a proxy for exposure to nutrition-specific counselling. And in addition to knowledge proxies, we also use women's participation in decisions on her own healthcare as a proxy for maternal empowerment, which may be particularly important insofar as mothers are usually directly responsible for feeding young children. We also include the sex of the child to assess whether there are gender differences in child feeding, given evidence of biases in breastfeeding in countries such as India (Jayachandran and Kuziemko, 2009). Robustness tests using a variety of other DHS data as control variables did not alter results and are not reported here.

Our selection of community-level GIS indicators is motivated by the microeconomic theory around missing markets described above. Access to markets through improved infrastructure or inherent geographical advantages may be an important prerequisite for purchasing a greater variety of foods, especially perishable foods that are costly to trade long distances. The DHS records whether a cluster is urban or not, but definitions of urban vary somewhat arbitrarily across countries, so we instead use GIS estimates of travel time to cities to construct a "remote location" dummy variable that equals one if the DHS cluster has more than a one-hour travel time to a town/city of 20,000 people or more. We also use a satellite-based night lights intensity index to capture local economic development and electricity infrastructure (Henderson et al., 2012), as well as distance to coastline (to reflect international costs of importing food), distance to a major inland water body (a 10 km^2 lake or a major river) to reflect access to fisheries and large scale irrigation, and population density of the surrounding area to reflect the thickness of local markets.

In addition to infrastructural and demographic conditions, agricultural conditions can substantially influence which foods are produced in a given community. We focus on three potentially relevant measures: average temperature, average rainfall, and cluster altitude, where temperature and rainfall are measured as 30-year annual averages (1980-2010). We expect that more rainfall increases the array of crops that can be grown, as well as fodder for livestock, while agronomic research shows that high temperatures (e.g. above 29 degrees Celsius) reduce the yields of many crops, and will therefore prevent farmers from even attempting to grow heat-sensitive crops (Schlenker and Lobell, 2010). Temperature patterns and altitude also influence livestock diseases such as tsetse fly which restricts cattle ownership and therefore dairy and meat production.

Methods

Our analysis begins with descriptive evidence on consumption patterns in the full sample and the five major developing regions, before turning to non-parametric local polynomial smoothing regressions to examine the relationships between dietary diversity and various explanatory variables of interest. As there are many non-linear relationships, particularly for the community-level GIS indicators described above, we measure continuous indicators with terciles to flexibly and parsimoniously capture these non-linearities. We then use ordinary least squares regression models and linear probability models to estimate a regression model with DDS, MDD or consumption of a nutrient-rich food group as a function of DHS child and household characteristics (H), community characteristics (C), child age in month (Z), and country-year (survey) fixed effects ($\boldsymbol{\mu_k}$), where *i*, *j*, and *k* respectively denote child, cluster and country identifiers and ε is an error term:

$$\boldsymbol{D_{i,j,k} = \beta_H H_{i,j,k} + \beta_C C_{j,k} + \delta Z_{i,j,k} + \mu_k + \varepsilon_{i,j,k}} \qquad (1)$$

The key parameters of interest in equation (1) are the coefficients captured by the vectors $\boldsymbol{H'\beta}$ and $\boldsymbol{C'\beta}$. Under the strong assumption that individual consumption is separable from home production, the household factors in equation (1) could be interpreted as shifting individuals' demand for each kind of infant food, while community factors capture shifts in market-level supply, demand and trade. In practice separability may not hold, so we interpret these associations as stylized facts that suggests avenues for further research. Since we control for country-year fixed effects, coefficients reflect only cross-sectional variation within each survey.

3. Main Results

Descriptive results

Descriptive statistics for the key variables used in our regressions are reported in Table 2. Child dietary diversity score is low in this sample. Children consumed 2.81 out of 7 food groups, on average, in the past 24 hours, and just 35% of children achieved MDD. Likewise, consumption of nutrient-rich food groups is low. For example, only 39% of children in this sample consumed dairy in the past 24 hours. This is consistent with the generally low levels of development in the sample. Table 2 reports the wealth index scaled from 0-1 to facilitate interpretation, where 1 constitutes ownership of all assets. The average score is just 0.35, suggesting that most households only own a few of the assets that enter in to the wealth index. Moreover, only 39 percent of mothers and 47 percent of fathers have more than a primary level education, while only 27 percent of children have had access to the full measured spectrum of antenatal, neonatal and postnatal health care. We also report the raw measures of the continuous GIS variables, although the regression analysis below uses terciles. There is tremendous geographical variation in this sample of clusters, with a wide variety of agroecologies covered, as well as very different levels of infrastructure development.

Table 2. Descriptive statistics for the full sample of 76,641 children in 42 countries

Variable	Mean	SD	Min	Max
Child feeding indicators from DHS data				
Child dietary diversity score	2.81	1.81	0.00	7.00
Minimum dietary diversity	0.35	0.48	0.00	1.00
Legumes/nuts	0.37	0.48	0.00	1.00
Dark Green Leafy Vegetables (DGLV)	0.29	0.45	0.00	1.00
Vitamin-A rich fruits/vegetables[a]	0.28	0.45	0.00	1.00
Other fruits/vegetables	0.27	0.45	0.00	1.00
Dairy products	0.39	0.49	0.00	1.00
Eggs	0.23	0.42	0.00	1.00
Meat/organs	0.29	0.45	0.00	1.00
Fish[a]	0.21	0.40	0.00	1.00
Child/parent indicators from DHS data				
Wealth index, scaled 0-1	0.35	0.30	0.00	1.00
Maternal primary education (1-6 years)	0.27	0.45	0.00	1.00
Maternal secondary education (7-9 years)	0.15	0.36	0.00	1.00
Maternal tertiary education (10-plus years)	0.24	0.43	0.00	1.00
Paternal primary education (1-6 years)	0.26	0.44	0.00	1.00
Paternal secondary education (7-9 years)	0.15	0.35	0.00	1.00
Paternal tertiary education (10-plus years)	0.32	0.47	0.00	1.00
Healthcare access[b]	0.27	0.44	0.00	1.00
Child was breastfed immediately	0.66	0.47	0.00	1.00
Women can decide on own healthcare	0.62	0.49	0.00	1.00
Child is male	0.51	0.50	0.00	1.00
Geographic characteristics of household locations				
Travel time to 20,000 person city	165.28	264.48	0.00	4854.00
Night lights intensity index	13.28	21.04	0.00	63.00
Population density	735.18	2183.09	0.00	36904.40
Distance to coastline (km)	21.77	22.95	0.00	257.04
Distance to major inland water body (km)	360.53	367.94	0.00	1753.50
Mean rainfall (mm) over 1981-2010	996.01	628.36	0.00	6127.83
Mean temperature (Celsius) over 1981-2010	230.98	53.79	-46.62	302.30
Altitude (meters) by cluster	644.34	800.63	-377.00	4899.00

Note: DHS data are from Phase 5 & 6 surveys for 42 countries listed in supplemental annex Table A1; Geographic characteristics of household locations are computed from data sources described in the text, based on coordinates of DHS enumeration areas that are reported with systematic random error for de-identification.
a. Fish consumption is only available for 70,127 children because of lack of data on fish, and data on Vitamin-A rich fruit consumption is only available for 74,832 children because of missing data for Tanzania.
b. healthcare access is equal to one if a child had prenatal care, was born in a medical facility and had the full set of recommended vaccinations.

Table 3 reports dietary patterns by region, while Appendix Figures A1 and A2 reports mean DDS and MDD by country. Dietary diversity is lowest in sub-Saharan Africa (SSA), where just 22.1% of children achieve MDD. Consumption of most nutrient-rich foods is also low, although we note that fish consumption is exceptionally high by international standards, with one-quarter of African children consuming fish in the past 24 hours, on par with dairy. Among vegetal foods, DGL vegetable consumption is relatively high in Africa. Patterns in the Asian sample are quite similar, with DGL veg also high, and dairy and fish consumed by around one-quarter of Asian children. The other three regions are much more developed. In the Eastern Europe and Central Asia (ECA) region almost half of children achieve MDD and two-thirds consumed dairy and almost half consumed other fruit/veg, though very few consumed DGL or vitamin-A rich fruits/vegetables. Egg and meat consumption is also much higher in this region than in SSA or Asia. Patterns in Latin America and the Caribbean (LAC) and the Middle East and North Africa (MNA) are broadly similar, although DDS and MDD are higher, and there are one two important differences for individual foods. In the small MNA sample, dairy consumption is very high (83.4%) and in LAC vitamin A-rich fruit/veg consumption is relatively high (39.9%). Overall, though, consumption of most nutrient-rich foods is much more prevalent in these three more developed regions than in SSA or Asia, with fish and DGL vegetables the main exceptions.

Table 3. Dietary diversity and intake of 8 food groups for infants 6-23 months of age, by region

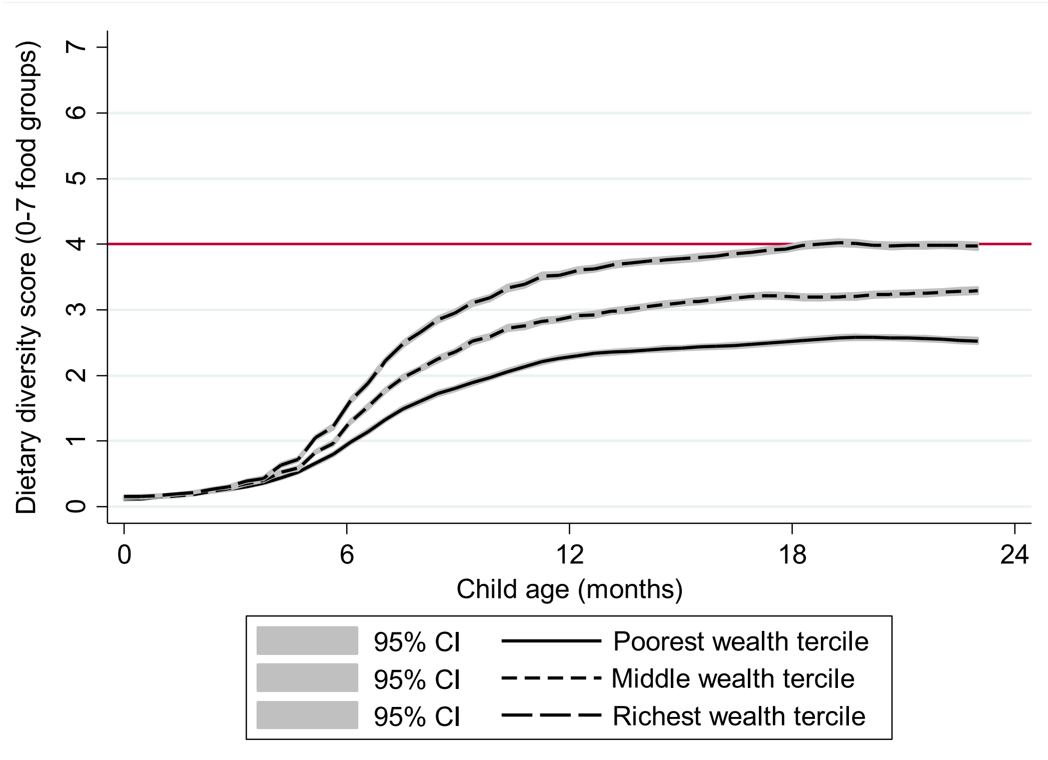
Regions[a]	DDS	MDD	DGL veg	Vit.A-rich F&V[b]	Other F&V	Legumes & nuts	Dairy	Eggs	Meat, organs	Fish[b]
SSA N=42794	2.3	22.1%	32.2%	14.9%	17.5%	24.5%	24.4%	11.7%	17.2%	24.6%
Asia N=7968	2.6	28.2%	42.0%	13.6%	21.4%	18.2%	28.7%	22.9%	21.4%	22.6%
ECA N=2865	3.1	45.2%	13.0%	18.9%	46.6%	15.4%	65.2%	37.0%	40.1%	3.7%
LAC N=17658	4.0	63.9%	17.6%	39.9%	47.5%	40.4%	64.0%	41.7%	55.8%	11.4%
MENA N=5356	3.6	56.3%	18.0%	10.5%	46.2%	28.4%	83.4%	46.5%	38.7%	14.4%
Total N=76641	2.8	35.2%	28.3%	20.1%	27.6%	27.3%	39.2%	22.8%	28.5%	20.4%

Note: Data shown use DHS household survey weights. Regional means other than Africa should be interpreted with caution due to small sample sizes, including just 4 countries for Asia, 3 for Eastern Europe and Central Asia, 7 for Latin America and the Caribbean, and just 2 for the Middle East and North Africa.
a. Regional abbreviations are: SSA=sub-Saharan Africa; Asia refers to South Asia and South-East Asia; ECA = Eastern Europe and Central Asia; LAC = Latin America and the Caribbean; MENA = Middle East & North Africa;
b. Latin America & Caribbean has only 12,963 observations for fish consumption due to missing data for Peru, while sub-Saharan Africa has only 40985 observations for vitamin A-rich fruits due to lack of data for Tanzania.

Graphical results

Figure 2 uses a non-parametric regression to demonstrate patterns of dietary diversity by child age, stratified by the lowest, richest and middle wealth quintiles. Across all three quintiles dietary diversity increases with age. Some children are fed foods prematurely (prior to 6 months), and at 6 months the diversity differences across wealth quintiles are minimal as children are typically introduced to more palatable foods from just one or two groups (e.g. cereals, dairy). By 12 months, however, diversity differences across wealth quintiles become stark and then persist thereafter. It is also notable that even for the richest wealth tercile MDD is only achieved by around 18 months of age (on average).

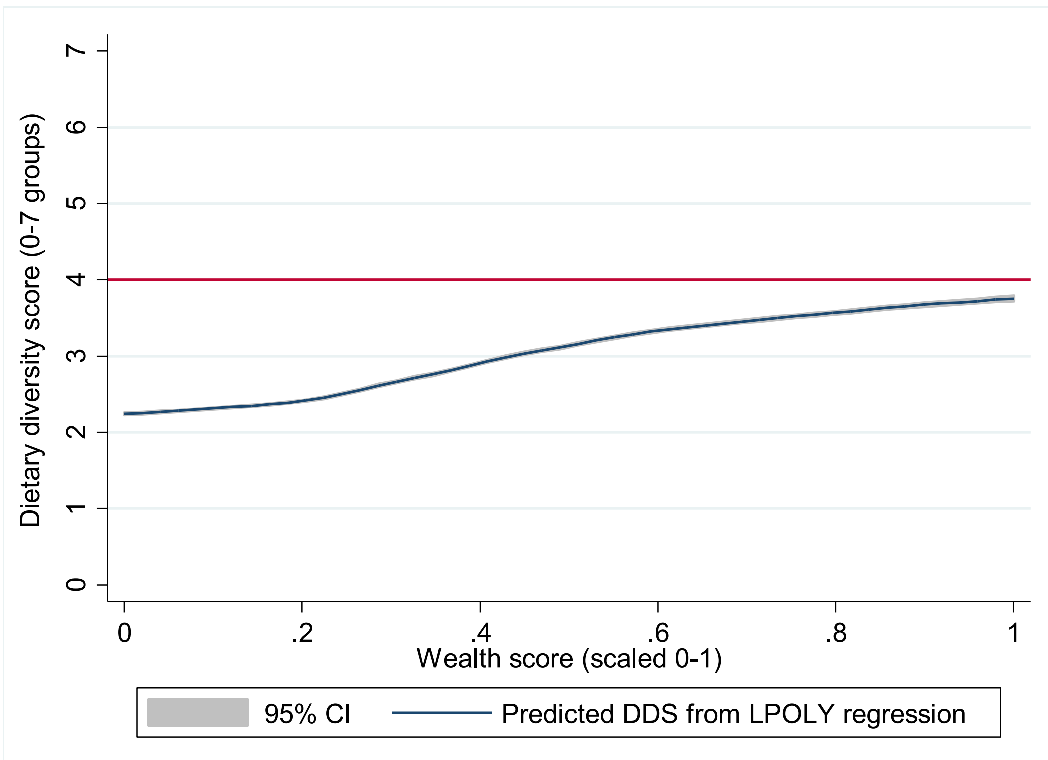
Figure 2. Mean child dietary diversity score at each age in months, by wealth tercile



Note: Data shown are local polynomial smoothing estimates with 95% confidence intervals (CI) for 76,641 infants aged 6-23 months with dietary intake data recorded in the Phase 5 & 6 surveys for 42 countries listed in supplemental annex Table A1, by household wealth computed as described in the text. The red line denotes the cut-off line for minimum dietary diversity (MDD).

Figure 3 shows a mostly linear relationship between dietary diversity and the raw wealth index score, consistent with Bennett's observation that consumers diversify away from starchy staples as their incomes increase. In Figure 3, there is some suggestion that the marginal effect of wealth may eventually decline, but in this relatively poor sample, the diminishing effects are modest. Nevertheless our regression estimates specify wealth terciles to allow for non-linear effects. In Appendix Figure A3 we also observe strong but quite non-linear associations between dietary diversity scores and parental education, with a discrete break between having no education and any education, but also evidence of increasing returns to education with secondary school yielding much greater benefits than primary school (7 years or greater). We also observe a somewhat steeper gradient for maternal education. Both facts are consistent with Alderman and Headey's (2017) analysis of the associations between parental education and stunting.

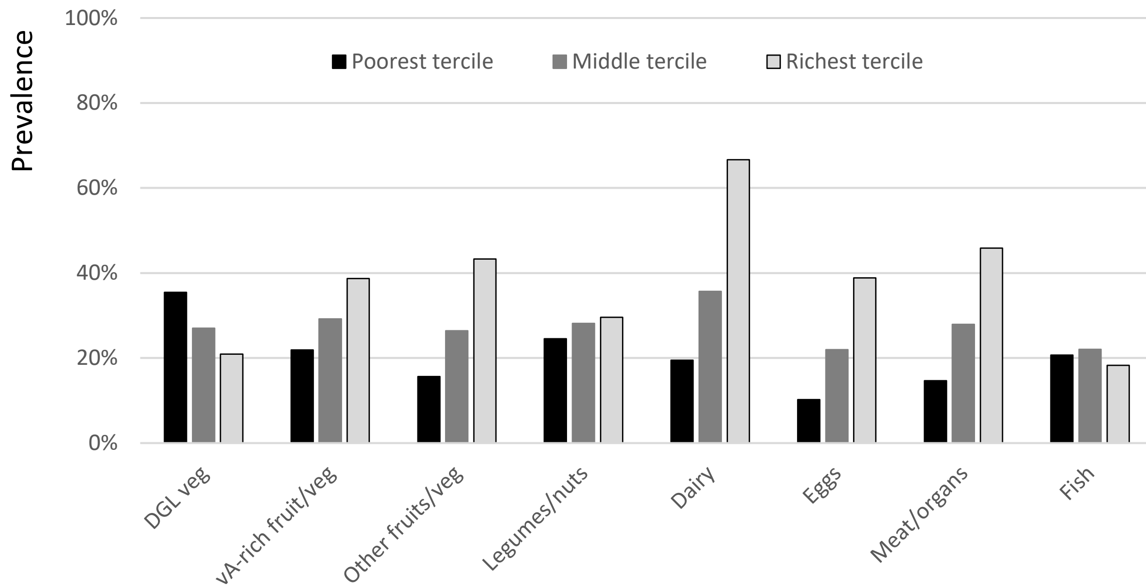
Figure 1. Mean child dietary diversity score by level of household wealth



Note: As for Figure 2.

Figure 4 shows the relationship between household wealth and the consumption of the eight nutrient-rich food groups described above, where wealth is split by terciles. For most nutrient-rich foods, consumption increases markedly with wealth, most strikingly for dairy, eggs, meat/organs and other fruits/veg. However, DGL vegetable consumption declines as wealth increases, suggesting parents regard these as an inferior good. Fish consumption also declines slightly from the middle to richest tercile, and legume/nut consumption increases very slightly with wealth.

Figure 4. Intake of 8 nutrient-rich food groups for children 6-23 months, by wealth tercile



Note: Data shown are unweighted mean consumption prevalence of any food from each group in the past 24 hours by terciles of the household wealth index described in Section 2, for children 6-23 months in 42 countries.

In Appendix Figures A4 and A5 we report locally weighted regressions of the associations between dietary diversity and the community-level GIS indicators. These indicators have strikingly non-linear relationships. For example, being within one hour from a city/town of more than 20,000 people (20K hereafter) is beneficial for dietary diversification, but that these benefits decline rapidly as the travel time extends beyond one hour. Rainfall is positively associated with dietary diversity until approximately 1300mm per year, and thereafter flattens out. Average temperature is negatively associated with dietary diversity, although the relationship is non-linear. Night lights intensity shares a positive association with DDS, but the gradient eventually flattens. Distance to the coastline and to major inland water bodies shows no clear patterns, but population density is positively associated with diversity. These non-linearities prompt us to create a dummy if the cluster is more than one hour from a 20K city/town to address the marked threshold at this cut-off, but to split the other indicators into terciles to capture these non-linearities.

Parametric multivariate regression results

Table 4 presents linear regression analysis of the determinants of DDS and MDD for children 6-23 months of age, as well as 12-23 months of age. This more restrictive sample is used because Figure 2 demonstrated that the dietary benefits of wealth are minimal for infants 6-11 months who have only recently been introduced to solid foods. For the most part both the DDS and MDD results are broadly robust across these two age ranges, although in many cases the coefficients in the 12-23 month sample are larger in magnitude.

Turning to the results, we find clear evidence for Bennett's law applying to child diet diversity: the number of nutritionally-defined food groups fed to children for all ages rises linearly with each tercile. In the 12 - 23 month range, for example, the middle tercile consumes 0.15 food groups more than the poorest tercile, while the highest tercile consumed 0.42 food groups more. The corresponding marginal effects in the MDD regression suggest that children from the richest tercile are 12.3 points more likely to achieve MDD.

While these marginal wealth effects are reasonably large, the regression also indicator that various knowledge proxies also play an equally important role in explaining variation in the dietary diversity of infants. Women with 10 or more years of education are likely to feed their children an extra 0.5 food groups, and 13.3 points more likely to achieve MDD. Interestingly, the corresponding marginal effects for paternal education – though still highly significant – are less than half the size of the maternal education effects. Further indirect evidence of a role for nutritional knowledge is reflected in the coefficient on health access, which is associated with an extra 0.2 food groups and a 5 - 7 point increase in the likelihood of achieving MDD. However, we find no statistically significant coefficients associated with a mother's ability to make her own healthcare decisions.

In addition to household level factors, indicators of geographical and infrastructural characteristics share a number of significant associations with child dietary diversity scores. Interestingly, more remote locations share no sizeable and significant association with dietary diversity once other characteristics are controlled for. In contrast, the night lights intensity index – which is associated with economic development, electrification and urbanization - has a strong association with DDS and MDD. Children in high intensity communities are predicted to consume an extra 0.14 - 0.18 food groups, and 3 - 4 points more likely to achieve MDD. Population density is also significantly associated with MDD and DDS, though the marginal effect sizes are more modest. Coastal access has modest associations with these dietary metrics, as does access to inland water bodies. In contrast, there are clear signs of a significant dietary penalty associated with living in low rainfall communities, since the lowest rainfall tercile is likely to consume 0.11 - 0.14 fewer food groups than middle and high rainfall communities. There is a penalty of similar magnitude for being in cooler locations, but no significant association between altitude and dietary diversity measures.

Table 4. Determinants of dietary diversity scores (DDS) and minimum dietary diversity (MDD), by age

	(1) DDS 6-23 months	(2) DDS 12-23 months	(3) MDD 6-23 months	(4) MDD 12-23 months
Child/household indicators from the DHS				
Household wealth, middle vs low	0.146***	0.171***	0.043***	0.055***
Household wealth, high vs low	0.365***	0.424***	0.100***	0.123***
Maternal 1-6 yrs education vs none	0.127***	0.160***	0.026***	0.038***
Maternal 7-9 yrs education vs none	0.284***	0.342***	0.070***	0.095***
Maternal 10+ yrs education vs none	0.448***	0.518***	0.108***	0.133***
Paternal 1-6 yrs education vs none	0.097***	0.113***	0.016***	0.022***
Paternal 7-9 yrs education vs none	0.141***	0.151***	0.026***	0.030***
Paternal 10+ yrs education vs none	0.183***	0.207***	0.042***	0.051***
Health access vs none	0.218***	0.179***	0.074***	0.051***
Child breastfed immediately vs not	0.034***	0.051***	0.013***	0.016***
Mother decides own healthcare vs not	0.006	0	-0.006	-0.005
Child is male vs female	-0.002	-0.004	0.001	-0.001
Geographic characteristics of household locations				
Remote location vs not remote	-0.031	-0.03	-0.009*	-0.007
Night lights intensity, middle vs low	0.055**	0.056*	0.012*	0.017**
Night lights intensity, high vs low	0.143***	0.180***	0.031***	0.043***
Population density, middle vs low	0.045**	0.045**	0.011**	0.01
Population density, high vs low	0.048*	0.054*	0.013*	0.014*
Distance to coastline, middle vs low	0.03	0.087***	0.014**	0.023***
Distance to coastline, high vs low	-0.013	0.02	0.003	0.004
Distance to water body, middle vs low	0.030*	0.027	0.009**	0.011*
Distance to water body, high vs low	0.028	0.014	0.007	0.005
Mean rainfall, middle vs low	0.122***	0.142***	0.020***	0.026***
Mean rainfall, high vs low	0.120***	0.111***	0.014**	0.016*
Mean temperature, middle vs low	-0.108***	-0.120***	-0.030***	-0.039***
Mean temperature, high vs low	-0.153***	-0.137***	-0.042***	-0.039***
Altitude by cluster, middle vs low	0.031	0.023	0.004	0.005
Altitude by cluster, high vs low	0.011	0.014	-0.002	0.002
Age-in-month dummies included?	Yes	Yes	Yes	Yes
Country-year fixed effects included?	Yes	Yes	Yes	Yes
R-squared	0.356	0.311	0.255	0.251
N	76641	49123	76641	49123

Note: Significance levels shown are estimated using cluster-robust standard errors and are denoted: ***p<0.01, **p<0.05, *p<0.1. Controls included but not reported are child age dummies, country and survey fixed effects.

Table 5 reports results with consumption of various nutrient-rich vegetal foods as the dependent variable. Consistent with Figure 4, DGL vegetable consumption does not rise with wealth, nor does legume/nut consumption. However, children from the richest wealth tercile are 5-6 times more likely to consume vitamin-A rich fruits/vegetables or other fruit/vegetables. Interestingly, however, more educated mothers and fathers are more likely to feed their children all of these foods, though there are no clear signs of increasing returns. Health service access is also associated with modest increases in all foods exception DGL vegetables. Amongst the community-level GIS variables, consumption of fruits and vegetables tends to be higher in communities further away from the coast and from water bodies. For all crops there is a clear penalty to residing in the coolest temperature tercile, but also in the lowest rainfall tercile.

Table 6 reports analogous results for consumption of animal-soured foods. Also consistent with Figure 4, dairy consumption rises starkly with wealth. Children from the highest wealth tercile are 13 points more likely to consume dairy, compared to an 8.6 point increase in meat/organ consumption and a 5.7 point increase in egg consumption. However, fish consumption does not rise with wealth, which again suggests that fish – though often highly nutritious – may be regarded as an inferior good. Indeed, the overall pattern of wealth effects suggest that as households become richer they substitute out of fish and into other ASFs. Parental education is again significantly associated with consumption of nutrient-rich animal-sourced foods, although the effects are stronger for maternal education and highest for dairy. Health access is also associated with consumption of all ASFs, except fish.

Turning to community factors, night lights intensity is against positively associated with greater ASF consumption, except fish. Distance to the coastline and to major water bodies have weak associations in general, although both indicators are strong predictors of fish consumption.

For example, children close to major water bodies are 4-5 points more likely to consume fish. Amongst climate variables, drier conditions are associated with more dairy production, but less egg, meat and fish consumption, while temperature effects vary in sign and magnitude. Altitude generally has modest associations, although children living in low altitude localities are significantly more likely to consume fish and less likely to consume eggs. Overall there is fairly strong evidence that agroecological conditions shape which ASFs children are fed in developing countries.

Table 5. Determinants of intake by vegetal food group, for children 6-23 months

	(1) **DGL Veg**	(2) **vA-rich fruit, veg**	(3) **Other fruit, veg**	(4) **Legumes, nuts**
Child/household indicators from the DHS				
Household wealth, middle vs low	-0.016***	0.013***	0.021***	0.016***
Household wealth, high vs low	-0.009	0.056***	0.057***	0.010
Maternal 1-6 yrs education vs none	-0.007	0.006	0.016***	0.019***
Maternal 7-9 yrs education vs none	0.010	0.029***	0.047***	0.037***
Maternal 10+ yrs education vs none	0.029***	0.057***	0.076***	0.034***
Paternal 1-6 yrs education vs none	0.006	0.007	0.005	0.029***
Paternal 7-9 yrs education vs none	0.008	0.017***	0.017***	0.014**
Paternal 10+ yrs education vs none	0.014**	0.024***	0.024***	0.015***
Health access vs none	-0.002	0.024***	0.048***	0.012***
Child breastfed immediately vs not	0.003	0.007**	0.008**	0.009**
Mother decides own healthcare vs not	0.009**	-0.005	-0.005	0.003
Child is male vs female	0.000	0.000	0.002	-0.001
Geographic characteristics of household locations				
Remote location vs not remote	-0.006	-0.012**	-0.011**	0.002
Night lights intensity, middle vs low	-0.005	0.017**	0.001	-0.017***
Night lights intensity, high vs low	0.000	0.009	0.016**	-0.005
Population density, middle vs low	0.005	0.008	0.024***	0.004
Population density, high vs low	0.01	0.023***	0.026***	0.009
Distance to coastline, middle vs low	0.004	0.006	-0.012**	0.010*
Distance to coastline, high vs low	0.075***	-0.016*	-0.022***	0.007
Distance to water body, middle vs low	0.023***	0.014***	0.011**	0.007
Distance to water body, high vs low	0.029***	0.012**	-0.004	0.020***
Mean rainfall, middle vs low	0.008	0.007	0.033***	0.031***
Mean rainfall, high vs low	-0.015*	-0.012	0.033***	0.030***
Mean temperature, middle vs low	-0.028***	-0.043***	-0.009	-0.020***
Mean temperature, high vs low	-0.058***	-0.057***	-0.030***	-0.044***
Altitude by cluster, middle vs low	0.014**	0.007	0.006	0.005
Altitude by cluster, high vs low	0.022***	-0.013	0.008	0.033***
Age-in-month dummies included?	Yes	Yes	Yes	Yes
Country-year fixed effects included?	Yes	Yes	Yes	Yes
R-squared	0.169	0.144	0.183	0.154
N	76641	76641	76641	76641

Note: As for Table 4.

Table 6. Determinants of intake by animal-sourced food group, for children 6-23 months

	(1) Dairy	(2) Eggs	(3) Meat, organs	(4) Fish[b]
Child/household indicators from the DHS				
Household wealth, middle vs low	0.041***	0.028***	0.031***	0.011***
Household wealth, high vs low	0.131***	0.057***	0.086***	0.000
Maternal 1-6 yrs education vs none	0.014***	0.016***	0.009**	0.041***
Maternal 7-9 yrs education vs none	0.064***	0.033***	0.036***	0.037***
Maternal 10+ yrs education vs none	0.114***	0.055***	0.077***	0.034***
Paternal 1-6 yrs education vs none	-0.005	0.015***	0.005	0.032***
Paternal 7-9 yrs education vs none	0.019***	0.023***	0.021***	0.028***
Paternal 10+ yrs education vs none	0.028***	0.032***	0.020***	0.043***
Health access vs none	0.053***	0.052***	0.050***	0.006
Child breastfed immediately vs not	-0.006	0.017***	0.012***	0.009***
Mother decides own healthcare vs not	-0.016***	0.001	-0.003	0.006*
Child is male vs female	0.007**	-0.004	0.000	0.000
Geographic characteristics of household locations				
Remote location vs not remote	0.012**	-0.005	-0.007	-0.009*
Night lights intensity, middle vs low	0.027***	0.007	0.029***	0.007
Night lights intensity, high vs low	0.069***	0.029***	0.050***	-0.001
Population density, middle vs low	-0.007	-0.004	0.015***	-0.012**
Population density, high vs low	0.000	-0.005	0.006	-0.026***
Distance to coastline, middle vs low	0.014**	0.011**	0.019***	-0.013**
Distance to coastline, high vs low	0.023**	-0.020***	0.017**	-0.037***
Distance to water body, middle vs low	-0.002	0.011***	0.008*	-0.042***
Distance to water body, high vs low	-0.004	0.010**	0.015***	-0.052***
Mean rainfall, middle vs low	-0.044***	0.021***	0.022***	0.045***
Mean rainfall, high vs low	-0.064***	0.044***	0.022***	0.099***
Mean temperature, middle vs low	-0.009	-0.017***	-0.001	0.025***
Mean temperature, high vs low	-0.008	-0.020**	0.024***	0.051***
Altitude by cluster, middle vs low	-0.009	0.021***	0.013**	-0.045***
Altitude by cluster, high vs low	0.001	0.028***	-0.032***	-0.057***
Age-in-month dummies included?	Yes	Yes	Yes	Yes
Country-year fixed effects included?	Yes	Yes	Yes	Yes
R-squared	0.276	0.187	0.232	0.163
N	76641	76641	76641	70137

Note: As for Table 4.

4. Extensions

Sensitivity to the exclusion of household or community level variables

Table 7 gauges the sensitivity of the 12 - 23 month DDS results to the exclusion of household or community level variables. We do this for two reasons. First, previous studies of diets in the DHS, such as Senarath et al. (2012) and Headey et al. (2018), have only used household level indicators from the DHS itself, so it is important to assess the sensitivity of these results to the novel inclusion of GIS indicators. Second, it is probable that many of the community level factors influence diets through household-level factors. For example, one would expect agroecological conditions to be important predictors of household wealth. It is therefore interesting to assess how these factors influence dietary diversity when household level factors are potential mediators.

Table 7 first reports the full model reported in regression (2) of Table 2 as a benchmark, while regressions (2) and (3) in Table 6 exclude community- and household-level factors, respectively. In regression (2) we observe that the exclusion of community-level factors generally has modest impacts on the household-level coefficients, except for the wealth coefficients, which increase quite substantially with the exclusion of GIS variables. The high vs low wealth effect increases from 0.424 to 0.548, for example.

In regression (3) of Table 7 we see that excluding household level factors results in quite large changes in the marginal effects of many GIS indicators. For example, children in remote locations consume 0.14 fewer food groups, and the coefficients on night lights intensity terciles roughly triple in magnitude. Population density coefficients also increase, and children in clusters far away from the coast now consume 0.16 fewer food groups. There are also larger benefits to higher rainfall and greater costs to higher temperatures.

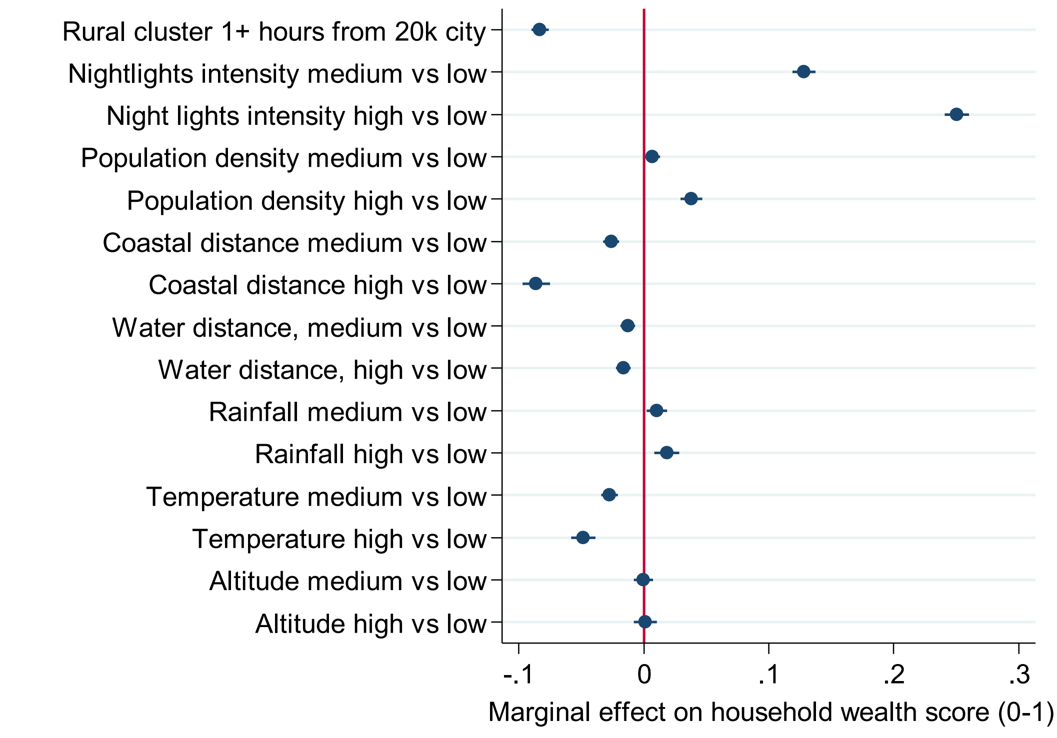
Table 7. Robustness of DDS determinants to exclusion of covariates

	(1) Full model	(2) Household variables only	(3) Community variables only
Child/household indicators from the DHS			
Household wealth, middle vs low	0.171***	0.223***	
Household wealth, high vs low	0.424***	0.548***	
Maternal 1-6 yrs education vs none	0.160***	0.171***	
Maternal 7-9 yrs education vs none	0.342***	0.358***	
Maternal 10+ yrs education vs none	0.518***	0.550***	
Paternal 1-6 yrs education vs none	0.113***	0.128***	
Paternal 7-9 yrs education vs none	0.151***	0.168***	
Paternal 10+ yrs education vs none	0.207***	0.230***	
Health access vs none	0.179***	0.197***	
Child breastfed immediately vs not	0.051***	0.055***	
Mother decides own healthcare vs not	0.000	0.011	
Child is male vs female	-0.004	-0.004	
Geographic characteristics of household locations			
Remote location vs not remote	-0.03		-0.139***
Night lights intensity, middle vs low	0.056*		0.189***
Night lights intensity, high vs low	0.180***		0.459***
Population density, middle vs low	0.045**		0.059***
Population density, high vs low	0.054*		0.103***
Distance to coastline, middle vs low	0.087***		0.035
Distance to coastline, high vs low	0.02		-0.161***
Distance to water body, middle vs low	0.027		0.014
Distance to water body, high vs low	0.014		-0.004
Mean rainfall, middle vs low	0.142***		0.215***
Mean rainfall, high vs low	0.111***		0.251***
Mean temperature, middle vs low	-0.120***		-0.167***
Mean temperature, high vs low	-0.137***		-0.208***
Altitude by cluster, middle vs low	0.023		0.01
Altitude by cluster, high vs low	0.014		0.015
Age-in-month dummies included?	Yes	Yes	Yes
Country-year fixed effects included?	Yes	Yes	Yes
R-squared	0.311	0.308	0.286
N	49123	49123	49123

Notes: Cluster-robust standard errors were used to estimate significance levels denoted: ***p<0.01, **p<0.05, *p<0.1. Controls included but not reported are child age dummies, country and survey fixed effects.

One important explanation of this pattern of results is that many of these GIS-level indicators are reasonably strong predictors of household wealth, parental education and access to health services. To examine this we estimated regressions with household wealth as the dependent variable and the various GIS indciators as explanatory variables. Coefficient plots with 95% confidence intervals are reported in Figure 5. Most striking, but not unexpected, is the strong association between night lights intensity and household wealth. Indeed, a regression of wealth against night lights intensity, without any other controls, explains around two-thirds of the variation in household wealth. Yet many other GIS variables explain household wealth. Populations that are more remote from cities and the coastline are poorer, as are populations in warmer and drier places.

Figure 5. Association of geographic characteristics with household wealth



Notes: Data shown are coefficient plots from a regression of the household wealth score, scaled to vary between 0 and 1, on all GIS community variables and country-year fixed effects.

Next, Table 8 examines the ability of the different variables in regressions (1) and (2) of Table 7 to predict variation in child DDS. To do this we conduct a simple regression-decomposition between groups, as in previous analyses of decompositions of nutrition change over time (Headey et al., 2015) or space (Cavatorta et al., 2015). Here we decompose the DDS differences between nine high-diversity countries with MDD prevalence of 40% or higher (the top nine countries in Appendix Figure A2) and the remaining 33 low-diversity countries with MDD prevalence of 33% or less. In effect, the regression decomposition asks what the change in DDS would be if the low diversity countries had the mean levels of household level variables (***H***) or community-level variables (***C***) that the high diversity country have. Hence the predicted difference in DDS between high and low diversity countries due to any specific variable is just the product of the relevant regression coefficient and the difference in means across the two samples:

$$\Delta \boldsymbol{D}_{i,j,k} = \boldsymbol{\beta}_H \Delta \boldsymbol{H}_{i,j,k} + \boldsymbol{\beta}_C \Delta \boldsymbol{C}_{j,k} \qquad (2)$$

Table 8. Using regression decomposition at variable means to explain differences in dietary diversity scores

	(1) Full model	(2) Child & household variables only
	Predicted difference in DDS	
Wealth	0.16	0.23
Parental education	0.20	0.25
Health access	0.05	0.04
Night lights	0.06	NA
Climate variables	0.03	NA
	Predictive power	
Actual difference in DDS between high and low diversity countries	1.57	1.57
Total explained difference between high and low diversity countries (% of actual)	0.49 (31.2%)	0.53 (33.5%)

Notes: High diversity countries are those where MDD prevalence is greater than 40%. This includes Peru, Dominican Republic, Albania, Bolivia, Honduras, Colombia, Jordan, Guyana and Egypt (see Figure A2 for MDD prevalence by country). The table reports a decomposition at means. In column (1) the predicted change in DDS is the product of coefficients reported in regression (1) of Table 6 and the difference in means between a sample of low diet diversity countries and sub-sample of high dietary diversity countries. Column (2) uses the coefficients from regression (2) of Table 6, which excludes community level variables.

The results in Table 8 allow us to gauge the predictive importance of individual variables but also the accuracy of the model as a whole. In column (1) we see that inter-group differences in wealth account for a 0.16 difference in DDS, while parental education accounts for 0.20, with health access, night lights and climate variables explaining a further 0.14 difference collectively. This sums to a 0.40 difference in DDS, which is around one-third of the actual difference in DDS across sample. In column (2) we conduct a decomposition based on regression (2) in Table 7 where community-level factors were omitted. This increases the contribution of wealth differences to 0.23 and education differences to 0.25, with health access still making only a small contribution, and the model as a whole still accounting for one-third of the inter-group difference. Two important conclusions therefore stem from Table 7. First, the model as a whole clearly does not fully explain why these nine countries have substantially more dietary diversity than the remaining country; and country-specific factors likely play an important role. Second, household wealth is not the paramount driver of dietary diversification that it is often assumed to be (at least, by economists); parental education is at least as important in a purely statistical sense.

Regional heterogeneity

Next we exploit the substantive geographical coverage in our data to explore heterogeneity of the DDS results across regions. Results across the two least developed regions, SSA and Asia, are relatively similar, although there are somewhat larger marginal effects for paternal education and health access in Asia. Wealth and maternal education effects in LAC are somewhat larger in magnitude, but the coefficients on paternal education in this region are not statistically different from zero. In MNA and ECA, wealth effects are insignificantly different from zero, and there are many fewer significant coefficients in general, perhaps reflecting higher standards of living in these regions.

For the GIS indicators there are limits in the number of clusters in most regions that likely restrict the ability of these regressions to accurately identify community-level effects, so we focus the discussion here on SSA, which has a large sample size and ample geographic variation in these indicators. In SSA we again observe positive associations between night lights intensity and DDS, but also that areas further from the coast have somewhat higher DDS. Given the region's vulnerability to climate change, the sensitivity of DDS to rainfall and temperature is particularly striking. We also note that Appendix Tables A2 and A3 report SSA-specific results for determinants of the eight nutrient-rich food groups. These regressions also confirm that low rainfall and high temperatures restrict dietary diversity, reducing intake of the various fruits and vegetables, legumes/nuts, eggs and meat/organs, though not fish or dairy products. We note that we also experimented with an alternative measure of climate, the length of the growing season, which is strongly correlated with rainfall (r=0.79). This variable yielded similarly strong results, with lengthier growing periods generally associated with greater dietary diversity and increased consumption of vegetal foods, in particular (results not shown).

Table 9. Heterogeneity in determinants of dietary diversity scores by region
Panel A: Child/household indicators

	(1) Sub-Saharan Africa	(2) Asia	(3) Latin America & Caribbean	(4) Middle East & North Africa	(5) East Europe & Central Asia
<u>Child/household indicators from the DHS</u>					
Middle wealth vs low	0.032***	0.052***	0.077***	-0.075	0.065
Upper wealth vs low	0.082***	0.092***	0.147***	0.052	0.06
Maternal primary education	0.011**	0.043***	0.090***	0.057**	0.066
Maternal secondary education	0.052***	0.065***	0.151***	0.072**	0.027
Maternal tertiary education	0.091***	0.101***	0.176***	0.132***	0.042
Paternal primary education	0.013**	0.033**	0.018	0.019	0.008
Paternal secondary education	0.021***	0.059***	0.022	0.006	-0.019
Paternal tertiary education	0.043***	0.100***	0.02	0.044*	-0.004
Health access	0.061***	0.112***	0.057***	0.026	0.059***
Child was breastfed immediately	0.016***	0.011	0.007	0.008	0.023
Mother can decide on own healthcare	-0.012**	0.026**	0.01	-0.026	-0.015
Child is male	-0.003	0.008	0.007	-0.002	-0.017

Table 9 (continued)

Panel B: Geographic characteristics

	Sub-Saharan Africa	Asia	Latin America & Caribbean	Middle East & North Africa	East Europe & Central Asia
Geographic characteristics of household locations					
Remote location vs not remote	-0.006	-0.031**	-0.016	0.013	0.003
Night lights intensity, middle vs low	0.009	-0.004	0.005	0.088	0.024
Night lights intensity, high vs low	0.048***	0.014	-0.017	0.176**	0.042
Population density, middle vs low	0.002	0.026	0.039***	0.021	-0.009
Population density, high vs low	0.011	0.023	0.041***	0.005	-0.017
Distance to coastline, middle vs low	0.033***	-0.014	0.034***	-0.044***	
Distance to coastline, high vs low	0.034***	-0.035	-0.043**		
Distance to water body, middle vs low	0.009	0.026*	-0.001	0.014	-0.036
Distance to water body, high vs low	0.005	0.003	-0.005	0.073***	-0.048
Mean rainfall, middle vs low	0.022***	0.087	0.018		-0.069
Mean rainfall, high vs low	0.055***	0.041	-0.006		
Mean temperature, middle vs low	-0.038***	-0.059**	-0.009	0.023	
Mean temperature, high vs low	-0.022*	-0.039	-0.051***	-0.012	
Altitude by cluster, middle vs low	-0.005	-0.009	0.005	0.046	-0.074
Altitude by cluster, high vs low	0.025*	-0.050**	-0.039***	0.067*	-0.112**
Age-in-month dummies included?	Yes	Yes	Yes	Yes	Yes
Country-year fixed effects included?	Yes	Yes	Yes	Yes	Yes
R-squared	0.165	0.131	0.204	0.114	0.099
N	27336	5140	11448	3404	1795

Notes: Cluster-robust standard errors were used to estimate significance levels denoted: ***p<0.01, **p<0.05, *p<0.1. Controls included but not reported are child age dummies, country and survey fixed effects

Comparisons to previous studies

Lastly, we sought to compare our results on child-level demand for food to more conventional economic estimates of household level demand for food. If children are typically fed the foods that the household as a whole is consuming, one would expect these patterns to be similar. One three-country study found that the diets of children and their mothers are very similar (Nguyen et al., 2013), though a study in Bangladesh found that milk was disproportionately fed to young children (Sununtnasuk and Fiedler, 2017). Other more qualitative studies also find that there are often norms that prohibit feeding certain nutritious foods to young children, particularly eggs (Pak-Gorstein et al., 2009).

In Table 10 we compare the wealth effects estimated from food group regressions for Africa (SSA plus Egypt) to the median income elasticities reported in a recent meta-analysis of these parameters for Africa (Colen et al., 2018). The regression specifications used to derive our child-level results are very different to those used in household food consumption studies that populated the Colen et al. meta-analysis, meaning that the coefficients in question cannot be directly compared in magnitude. Nevertheless, the patterns of coefficient magnitudes are actually very similar. The correlation between middle vs low wealth effects and the Colen et al. median income elasticities is 0.67, while the corresponding correlation for high vs low wealth effects is 0.86. In both sets of results, income/wealth effects for vegetal foods are generally low (and mostly statistically insignificant from zero in our regressions), while income/wealth elasticities for ASFs are generally high. However, our results also point to the need to look at more disaggregated food groups. As we saw above, wealth effects on DGL vegetables are actually negative, while the wealth effect on fish consumption is about one-fifth of the high versus low wealth effect estimated for meat, and one third of the corresponding effect for eggs. This is a potentially important finding given that fish is the most commonly consumed ASF in SSA, and in some parts of Asia, and that fish are rich in protein and a range of micronutrients.

Table 10. Comparing income elasticities with wealth effects, by food group in Africa

	Household-level income elasticity (Colen et al. 2018)	Child-level middle vs low wealth effect (this study)	Child-level high vs low wealth effect (this study)
Tubers	0.32	0.022***	0.017**
Cereals	0.36	-0.003	-0.006
Legumes and nuts	0.46	-0.002	-0.007
Fruits and vegetables	0.61	0.000	0.018*
DGL vegetables	Not available	-0.025***	-0.048***
Dairy	0.81	0.032***	0.176***
Meat/organs, fish, eggs	0.80	0.058***	0.108***
Meat/organs		0.036***	0.099***
Eggs		0.021***	0.075***
Fish	Not available	0.019***	0.021**
Correlation with household-level income elasticity		*0.67*	*0.86*

Notes: The household level income elasticities are the median elasticities for sub-Saharan Africa reported in Appendix Table C2 in Colen et al. (2018). The child-level high vs low wealth effects refers to regressions of child consumption of each food group against DHS child and household level factors, excluding GIS community variables, for sub-Saharan Africa only.

5. Conclusions

Economic analysis of food choice and diet quality is largely confined to purchases by households. We overcome past data constraints on infant feeding by combining data from 42 countries covered by the DHS with a rich array of GIS-based community level data that capture economic and infrastructural development as well as exogenous agricultural conditions. This extensive dataset allows us to document diverse child feeding patterns across regions and economic strata, to estimate household and community level determinants with precision and flexibility, and to explore heterogeneity in these associations across developing regions.

In this section we flag some of the most important findings from our results, and discuss their implications for new research and for nutrition-smart policies designed to improve child feeding.

Wealth, nutritional knowledge and dietary diversification

We estimate precise and essentially linear associations between DDS/MDD and household wealth, providing strong support for Bennett's law. Perhaps surprisingly, however, the marginal effects of household wealth on dietary diversity are not obviously paramount; the marginal effects associated with 10+ years of maternal education are commensurately large and explain at least as much of the difference between low and high dietary diversity countries. It is possible that maternal education represents unobserved wealth, and likely that it partly reflects her empowerment, but also probable that associations with dietary diversity are substantially driven by nutritional knowledge. Similarly, health access might partly reflect wealth insofar as health services are income-elastic but might also proxy for parents accessing health/nutrition information, as could breastfeeding in the first hour after birth. We also note that the strong and non-linear associations between women's education and child dietary diversity score are consistent with the results on stunting reported in Alderman and Headey (2017).

Community-level characteristics and child nutrition

We offer novel evidence that indicators of geographic, demographic and infrastructural characteristics – as well as night lights (which likely reflects broader local economic development) – have significant and reasonably large associations with child dietary diversity scores. Night lights intensity is strongly associated with household wealth, suggesting it is indeed much more a general indicator of economic prosperity (Henderson et al., 2012) than an indicator of specific electricity infrastructure. In terms of urbanization and other geographical factors, proximity to a city had only weak associations with dietary diversity but population density had moderately strong associations, while distances to the nearest coast and major inland water body were associated with increased consumption of some specific foods (especially fish), but not with overall dietary diversity.

Of significant policy relevance in the context of a rapidly warming climate, we find strong relationships between climate indicators and dietary diversity, as infants in the lowest tercile of temperatures and highest tercile of rainfall have the most diverse diets. This is consistent with a wide range of previous research suggesting that more temperate conditions facilitate agricultural growth and broader development (e.g. Masters and McMillan 2001), and that individual crop yields are highly sensitive to extreme heat during the growing season, specifically temperatures in excess of 29 degrees Celsius for many cereals such as maize, wheat, sorghum and millet (Schlenker and Lobell, 2010). Though poorly documented, and therefore an area for future research, production of many fruits and vegetables are often more heat- and rain-sensitive than staple crops. Certainly, our evidence on vegetable foods is consistent with this hypothesis: children in the hottest temperature tercile are 3-6 points less likely to consume a fruit, vegetable, or legume. This raises the possibility that future climate change will further reduce consumption of nutrient-rich vegetal products.

For livestock, the climate situation is less clear. Dairy consumption is not associated with temperature in any consistent fashion, perhaps because pastoralist populations in arid climate depend so heavily on milk production and consumption. Egg, meat and fish consumption all increase with rainfall, but fish consumption is also somewhat higher in warmer locations.

Children's consumption of specific nutrient-rich foods

A subtle but important finding of our research is that while overall dietary diversity increases with wealth (and parental education), children's consumption of specific nutrient-rich foods is highly variable. At one extreme, dairy consumption rises sharply with household wealth and night lights intensity. The wealth gradient for meat is also relatively steep, while the gradient for eggs is more modest again, while fish consumption seems largely invariant to increases in wealth and quite prevalent even among the lowest wealth tercile. In terms of vegetal foods, vitamin A-rich fruits and vegetables and other fruit/vegetables have modest wealth gradients similar to egg consumption, with children from the wealthiest tercile about 5.7 times more likely to consume these products than children from the poorest tercile of household wealth. However, legume/nut consumption is largely invariant to wealth, and DGL vegetable consumption seems to decline with wealth.

The fact that some highly healthy foods, such as DGL vegetables and fish, decline with wealth perhaps suggests a nutritional knowledge constraint, although given the implicit substitution into other healthy foods (e.g. substation from fish to eggs, meat or dairy) it is difficult to assess whether there is a net nutritional penalty. It may be, however, that parents should be encouraged to keep these healthy foods in the diet, especially if they are affordable, even as wealth increases. Again, studying the evolution of diets in developing countries, particularly as they pertain to children, seems an important area for future research.

Strengths and limitations

All results in this study are purely observational, intended to establish novel stylized facts from a dataset of unprecedented size and scope. Our focus is on observing associations between the diversification of children's diets and both household and community level factors, in light of economic evidence on food demand that is largely confined to household diets in specific countries. Key limitations include data quality, such as the limited recall and dichotomous nature of child dietary data in the DHS, use of a relatively simple wealth index, no direct measures of nutritional knowledge or exposure to programs designed to improve that knowledge. Our analysis also spans many countries in which the relationships between diets and the explanatory factors of interest may vary; we examine heterogeneity across regions, however, and do find evidence of some important heterogeneity at this level of aggregation.

These limitations aside, this study has several strengths. Most studies of dietary diversification have focused on single country analyses of household level consumption data. Diets, however, are an intrinsically individual concept, and the diets of young children are particularly important for their longer term physical and cognitive development, as well as human capital accumulation (Glewwe et al. 2001; Horton et al. 2008; Hoddinott 2009). No previous study of which we are aware has extensively examine both household and geographical predictors of infant food consumption at a global scale, although Galway, Acharya and Jones (2018) and Headey, Hoddinott and Hirvonen (2018) do address more specific questions around children's diets.

Overall, our findings have important implications for future research and policy design, especially for countries with the highest burdens of malnutrition. Our results suggest that while wealth accumulation is indeed an important driver of diversification, there are strong grounds to also invest heavily in women's education. There may also be benefits to expanding basic health care, although further research is needed on whether the associations reflect the potentially bidirectional relationship between exposure to health services and nutritional knowledge. Moreover, it is likely that the health access benefits could be further strengthened by improving the nutritional messaging of conventional health services (Menon et al. 2015). Future studies might also examine the impacts of rural-urban migration and other structural transformation processes on dietary change, and the associations between climate and dietary diversification are striking and warrant further investigation of the impacts of climate changes on nutrient-rich food production and dietary diversity.

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Appendix

Table A1. Countries, years and sample sizes of DHS surveys, phase 5 and 6

Survey	N	Survey	N
Sub-Saharan Africa (SSA)		**Asia**	
Benin 2011/2012	2,907	Bangladesh 2011/2011	2,293
Burkina Faso 2010/2010	1,843	Cambodia 2010/2010	1,080
Burundi 2010/2010	965	Nepal 2006/2006	1,515
Cameroon 2011/2011	1,423	Nepal 2011/2011	664
Comoros 2012/2012	541	Timor-Leste 2009/2010	2,416
Cote d'Ivoire 2011/2012	788		
Ethiopia 2011/2011	2,473	**Eastern Europe and Central Asia (ECA)**	
Gabon 2012/2012	664	Albania 2008/2009	370
Ghana 2008/2008	695	Kyrgyz Republic 2012/2012	1,203
Guinea 2012/2012	919	Tajikistan 2012/2012	1,292
Lesotho 2009/2009	144		
Liberia 2013/2013	748	**Latin America & Caribbean (LAC)**	
Madagascar 2008/2009	1,176	Bolivia 2008/2008	2,065
Malawi 2010/2010	1,415	Colombia 2010/2010	3,952
Mali 2012/2013	1,317	Dominican Republic 2007/2007	1,881
Mozambique 2011/2011	2,546	Dominican Republic 2013/2013	596
Namibia 2006/2007	597	Guyana 2009/2009	282
Namibia 2013/2013	200	Haiti 2005/2006	671
Nigeria 2008/2008	2,654	Haiti 2012/2012	1,039
Nigeria 2013/2013	7,563	Honduras 2011/2012	2,477
Rwanda 2010/2010	923	Peru 2004/2008	1,990
Senegal 2010/2011	1,083	Peru 2009/2009	2,705
Senegal 2012/2013	1,571		
Sierra Leone 2008/2008	505	**Middle East & North Africa (MENA)**	
Sierra Leone 2013/2013	1,101	Egypt 2008/2008	3,070
Swaziland 2006/2007	359	Jordan 2007/2007	568
Tanzania 2010/2010	1,809	Jordan 2012/2012	1,718
Uganda 2006/2006	608		
Uganda 2011/2011	543		
Zambia 2007/2007	1,448		
Zimbabwe 2010/2011	1,266	**Total**	**76,641**

Figure A1. Mean dietary diversity scores by country

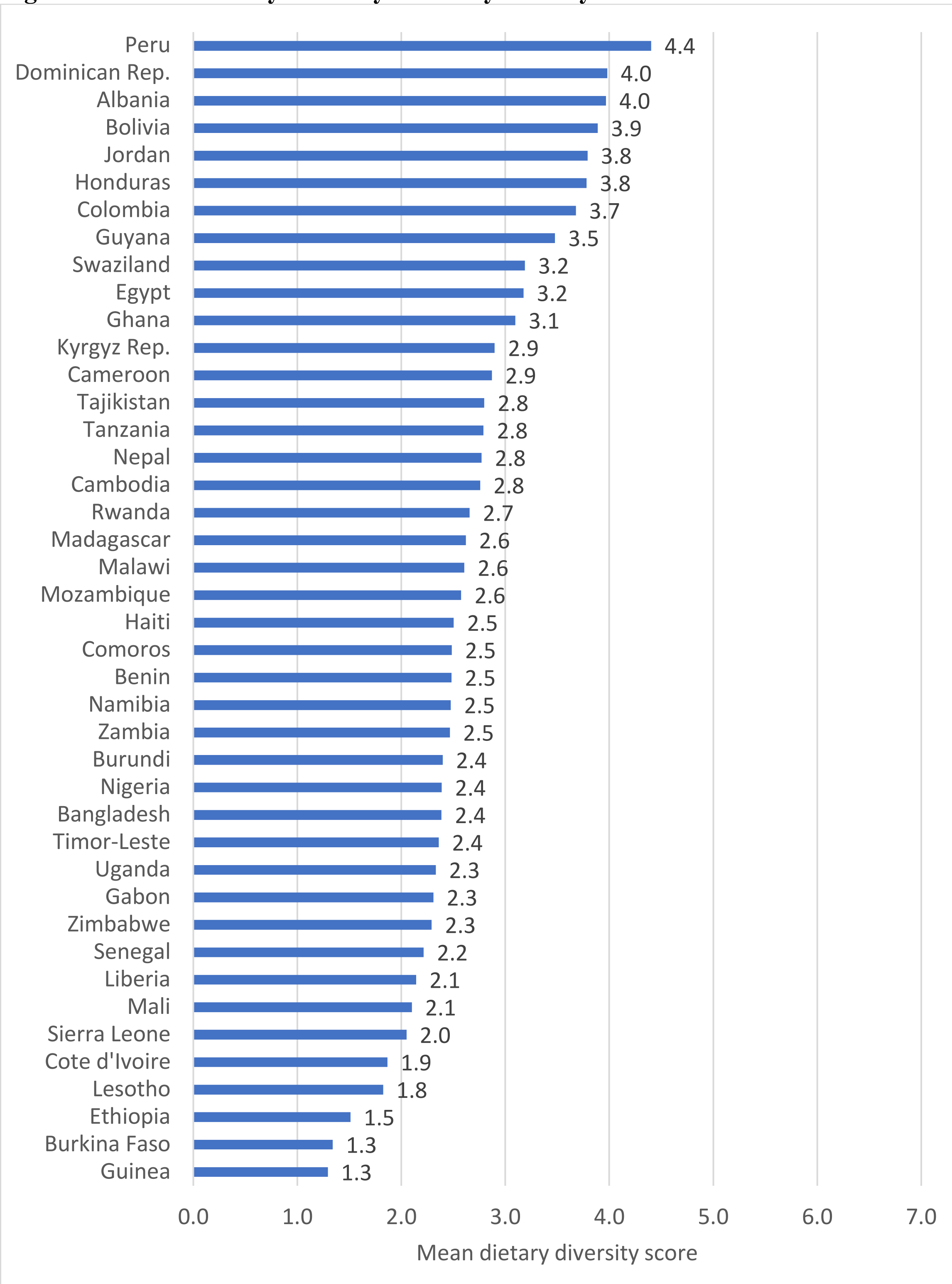


Figure A2. Mean minimum dietary diversity prevalence by country

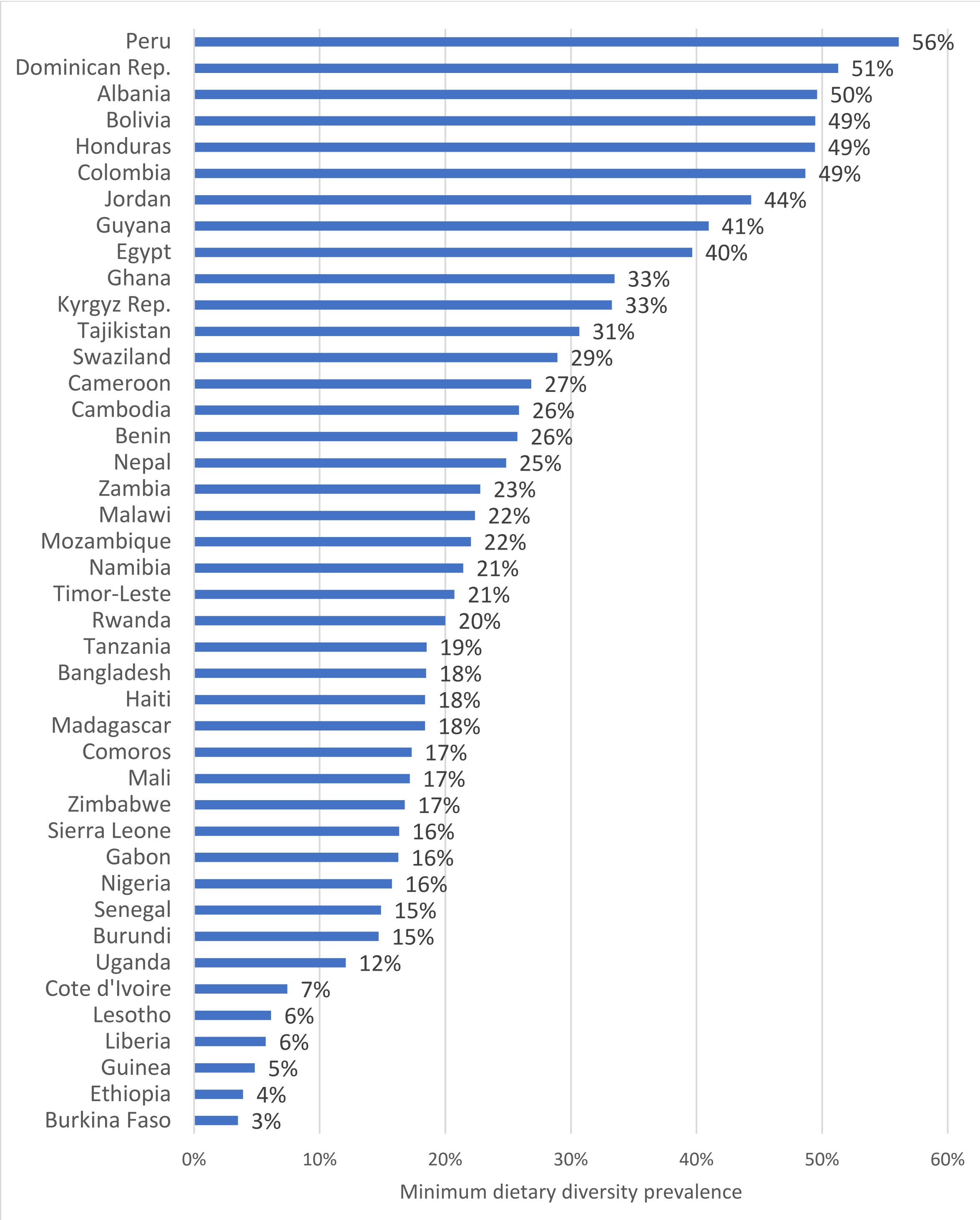
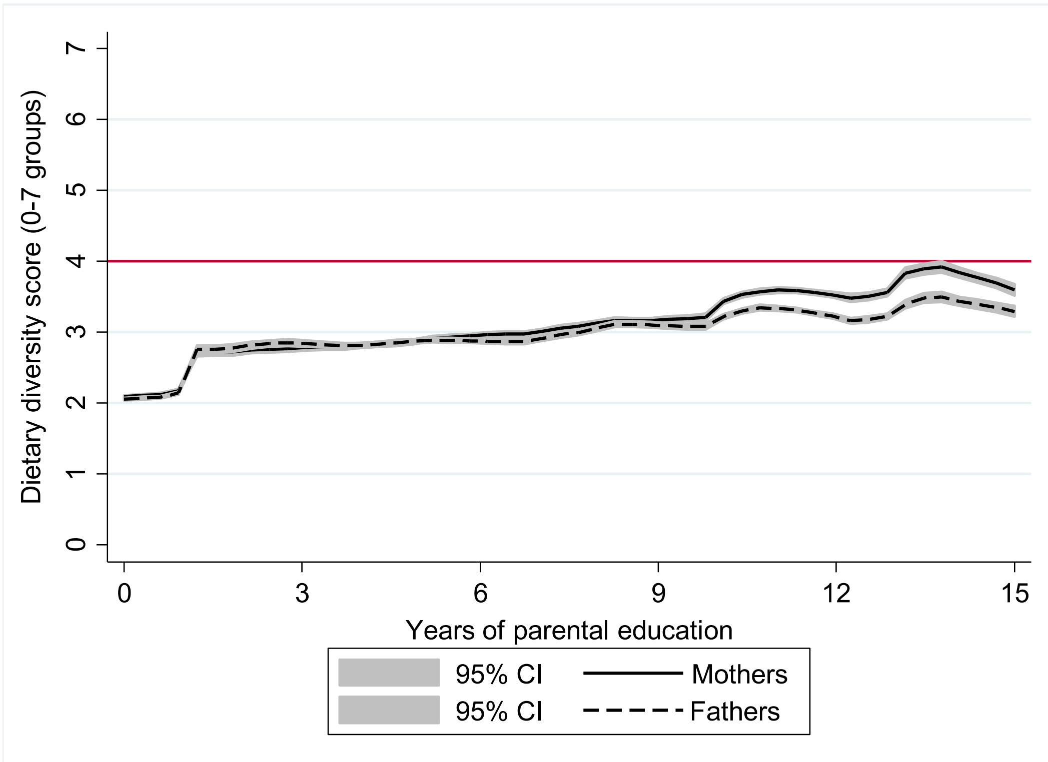
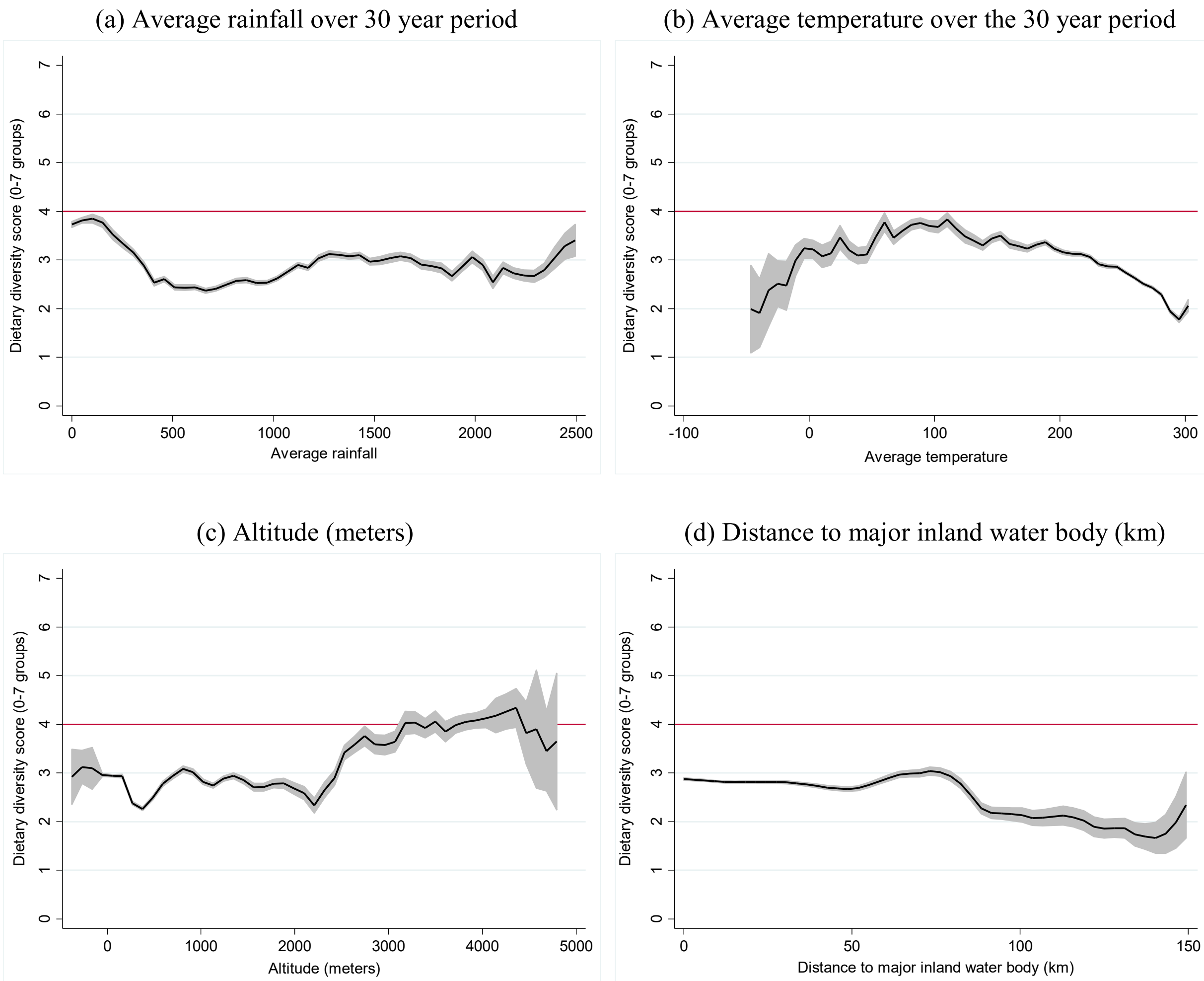


Figure A3. Nonparametric estimates of the relationship between child dietary diversity score and years of parental education



Source: Phase 5 & 6 DHS data for 42 countries. These are local polynomial smoothing estimates with 95% confidence intervals (CI)

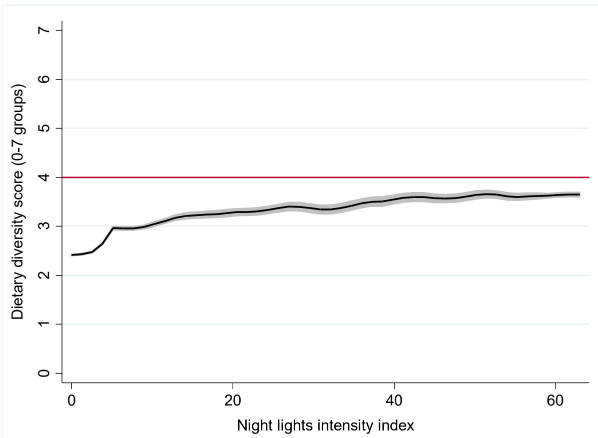
Figure A4. Dietary diversity scores and GIS-based agro-ecological indicators (LPOLY plots with 95% CIs)



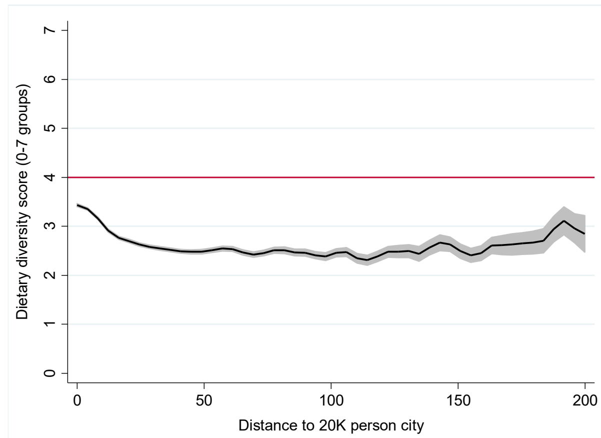
Source: Phase 5 & 6 DHS data for 42 countries. These are local polynomial smoothing estimates with 95% confidence intervals (CI)

Figure A5. Dietary diversity scores and GIS-based infrastructural indicators

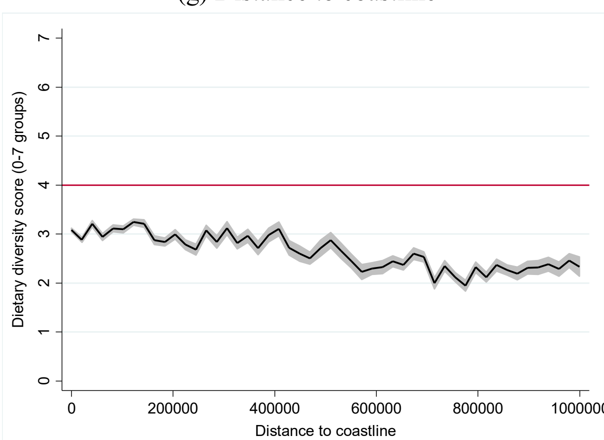
(a) Night lights intensity index



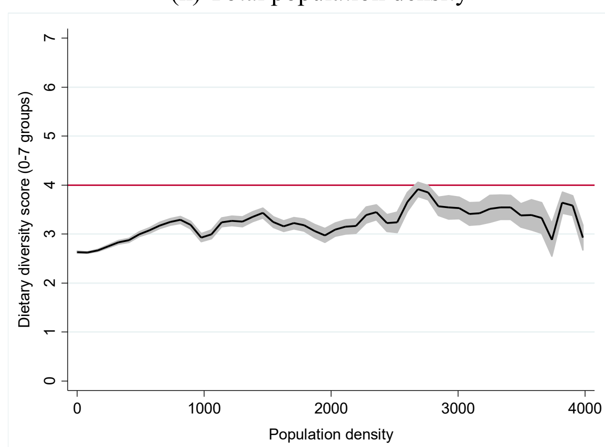
(a) Travel time to cities greater than 20k population



(g) Distance to coastline



(h) Total population density



Source: Phase 5 & 6 DHS data for 42 countries. These are local polynomial smoothing estimates with 95% confidence intervals (CI)

Table A2. Determinants of nutrient-rich vegetal food consumption by infants in Africa

	(1) DGL Veg	(2) vA-rich fruit, veg	(3) Other fruit, veg	(4) Legumes, nuts
DHS child/household indicators				
Household wealth, middle vs low	-0.015**	0.020***	0.022***	-0.003
Household wealth, high vs low	-0.030***	0.043***	0.040***	-0.012
Maternal 1-6 yrs education vs none	0.001	0.013**	0.008	0.007
Maternal 7-9 yrs education vs none	0.017**	0.020**	0.030***	0.036***
Maternal 10+ yrs education vs none	0.009	0.029***	0.051***	0.043***
Paternal 1-6 yrs education vs none	0.008	0.020***	0.019***	0.023***
Paternal 7-9 yrs education vs none	0.004	0.014*	0.024***	0.023***
Paternal 10+ yrs education vs none	0.001	0.026***	0.030***	0.026***
Health access vs none	0.020***	0.030***	0.039***	0.018***
Child breastfed immediately vs not	0.008	0.020***	0.010**	0.007
Mother decides own healthcare vs not	0.003	-0.011**	-0.007	0.006
Child is male vs female	0.001	-0.002	0.004	0.001
Geographic characteristics of household locations				
Remote location vs not remote	0.01	-0.006	-0.006	0.002
Night lights intensity, middle vs low	0.002	0.01	0.004	-0.013
Night lights intensity, high vs low	-0.009	0.007	0.028***	0.015
Population density, middle vs low	-0.008	-0.003	0.019***	0.005
Population density, high vs low	0.007	0.023**	0.032***	0.009
Distance to coastline, middle vs low	0.019*	0.021*	0.003	-0.001
Distance to coastline, high vs low	0.123***	0.023*	-0.008	0.016
Distance to water body, middle vs low	0.022***	0.017**	0.011*	0.018***
Distance to water body, high vs low	0.025***	0.012*	-0.002	0.031***
Mean rainfall, middle vs low	0.039***	0.022***	0.012**	0.035***
Mean rainfall, high vs low	0.065***	0.034***	0.044***	0.039***
Mean temperature, middle vs low	-0.007	-0.056***	-0.029***	-0.048***
Mean temperature, high vs low	-0.016	-0.031**	-0.045***	-0.063***
Altitude by cluster, middle vs low	0.021*	0.003	-0.003	-0.002
Altitude by cluster, high vs low	0.060***	-0.006	0.008	0.046***
Age-in-month dummies included?	Yes	Yes	Yes	Yes
Country-year fixed effects included?	Yes	Yes	Yes	Yes
R-squared	0.167	0.093	0.11	0.13
N	42794	42794	42794	42794

Notes: Cluster-robust standard errors were used to estimate significance levels denoted: ***p<0.01, **p<0.05, *p<0.1. Controls included but not reported are child age dummies, country and survey fixed effects.

Table A3. Determinants of animal-sourced food consumption by infants in Africa

	(1) Dairy	(2) Eggs	(3) Meat	(4) Fish[b]
DHS child/household indicators				
Household wealth, middle vs low	0.041***	0.028***	0.031***	0.011***
Household wealth, high vs low	0.131***	0.057***	0.086***	0.000
Maternal 1-6 yrs education vs none	0.014***	0.016***	0.009**	0.041***
Maternal 7-9 yrs education vs none	0.064***	0.033***	0.036***	0.037***
Maternal 10+ yrs education vs none	0.114***	0.055***	0.077***	0.034***
Paternal 1-6 yrs education vs none	-0.005	0.015***	0.005	0.032***
Paternal 7-9 yrs education vs none	0.019***	0.023***	0.021***	0.028***
Paternal 10+ yrs education vs none	0.028***	0.032***	0.020***	0.043***
Health access vs none	0.053***	0.052***	0.050***	0.006
Child breastfed immediately vs not	-0.006	0.017***	0.012***	0.009***
Mother decides own healthcare vs not	-0.016***	0.001	-0.003	0.006*
Child is male vs female	0.007**	-0.004	0	0
Geographic characteristics of household locations				
Remote location vs not remote	0.012**	-0.005	-0.007	-0.009*
Night lights intensity, middle vs low	0.027***	0.007	0.029***	0.007
Night lights intensity, high vs low	0.069***	0.029***	0.050***	-0.001
Population density, middle vs low	-0.007	-0.004	0.015***	-0.012**
Population density, high vs low	0.000	-0.005	0.006	-0.026***
Distance to coastline, middle vs low	0.014**	0.011**	0.019***	-0.013**
Distance to coastline, high vs low	0.023**	-0.020***	0.017**	-0.037***
Distance to water body, middle vs low	-0.002	0.011***	0.008*	-0.042***
Distance to water body, high vs low	-0.004	0.010**	0.015***	-0.052***
Mean rainfall, middle vs low	-0.044***	0.021***	0.022***	0.045***
Mean rainfall, high vs low	-0.064***	0.044***	0.022***	0.099***
Mean temperature, middle vs low	-0.009	-0.017***	-0.001	0.025***
Mean temperature, high vs low	-0.008	-0.020**	0.024***	0.051***
Altitude by cluster, middle vs low	-0.009	0.021***	0.013**	-0.045***
Altitude by cluster, high vs low	0.001	0.028***	-0.032***	-0.057***
Age-in-month dummies included?	Yes	Yes	Yes	Yes
Country-year fixed effects included?	Yes	Yes	Yes	Yes
R-squared	0.276	0.187	0.232	0.163
N	76641	76641	76641	70137

Notes: Cluster-robust standard errors were used to estimate significance levels denoted: ***p<0.01, **p<0.05, *p<0.1. Controls included but not reported are child age dummies, country and survey fixed effects