Animal sourced foods and child stunting

December, 2017

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Abstract

Stunting affects 160 million pre-school children around the world, and imposes significant costs on a child's health, cognitive development, schooling and economic performance. Stunting in early childhood has been linked to poor dietary diversity, notably low intake of animal-sourced foods (ASFs) rich in high quality protein and other growth-stimulating nutrients. Surprisingly, however, very little economic research has focused on ASFs and child growth. In this paper we redress this omission through an analysis of 112,553 children aged 6-23 months from 46 countries. We first document distinctive patterns of ASF consumption among children in different regions, particularly highly variable patterns of dairy consumption, low consumption of eggs and meat, and surprisingly frequent consumption of fish in several poor regions of Africa and Asia. We then examine how ASF consumption is associated with child stunting in multivariate models saturated with control variables. We find strong associations with a generic ASF consumption indicator as well as with fish and dairy consumption. Finally, we explore why ASF consumption is low but also so variable. We show that non-tradable ASFs (fresh milk, eggs) are a very expensive source of calories in low income countries, and that caloric prices of these foods are strongly associated with children's consumption patterns. A host of other demand-side factors are also important, but the strong influence of prices implies an important role for agricultural policies – in production, marketing and trade – to improve the accessibility and affordability of ASFs in poorer countries.

Key words: Animal-sourced foods; dietary diversity; nutrition; stunting; livestock; fisheries.

JEL codes: Q18, O15, I15

Word count: 9,166

Number of Tables: 11

Number of Figures: 3

Acknowledgements: This paper was funded by The Bill and Melinda Gates Foundation under the project *Advancing Research on Nutrition and Agriculture (ARENA), Phase II*, as well as the CGIAR program on Agriculture for Nutrition and Health (A4NH). We thank Marie Ruel for comments and suggestions. The usual disclaimer applies.

Introduction

Approximately 160 million children under the age of 5 and living in developing countries are considered chronically undernourished (de Onis and Branca, 2016); that is, their height is at least two standard deviations less than the median height of a well-nourished child of the same age and sex. Nutritional status is a component of health and thus reducing chronic undernutrition has intrinsic value. In addition, chronic undernutrition in early life is causally linked to a whole host of adverse later life outcomes including reduced schooling, poorer cognitive skills, lower earnings and a higher likelihood of living in poverty (Hoddinott, et al., 2013). For this reason, reducing chronic undernutrition has instrumental value too.

Most stunting (or chronic under-nutrition) manifests in the first 1000 days of life (Victora, et al., 2009). In many countries children are born small, partially protected from infections and low nutrient diets by predominant breastfeeding in the first few months after birth, but then subject to accelerated growth faltering from 6-24 months. Several things need to happen in this 6-24-month period to ensure that growth faltering does not take place. First, since breast milk can no longer provided all nutrients required for healthy growth and development starting around the age of 6 months of age, children need to be introduced to complementary foods that need to be fed frequently (because of small gastric capacity), and fed a nutrient-rich diet (or fortified complementary foods) to ensure that they meet their nutrient requirements. Second, because young children's immune systems are in development, they need to be protected from both acute and chronic infections through preventative measures (e.g. improved water, sanitation, hygiene, food safety, immunization) and optimal use of health services for timely treatment. After 24 months further growth faltering is less commonplace as immune systems strengthen, but there is also little evidence of systematic catch-up growth in the first 5 years of life, and stunting tends to be highly persistent at a population level (Leroy, et al., 2014). This suggests that nutritional interventions should indeed be prioritized in the first 1000 days of life, a so called "window of opportunity" (Victora, et al., 2009).

While there is broad agreement on the important general interplay between diets, health and care practices, academic thinking on the importance of ASFs specific nutrient dimensions of child undernutrition has evolved over time.

Amongst biological nutritionists, there was substantial emphasis on protein deficiency as one of the main causes of undernutrition in low income countries in the 1950s and 1960s (Semba, 2016), but an influential article by McLaren (1974) argued that if a child consumed an adequate amount of calories, it was likely that they would also consume adequate amounts of protein. Coinciding with the 1974 global food (calorie) crisis, McLaren's arguments prompted a much greater emphasis on improving calorie availability. This also suited the emphasis of economists and agronomists on increasing the productivity of calorie-dense staple crops through the Green Revolution. In recent years, however, biological research has argued that the essential amino acids in ASFs – "essential" because they cannot be synthesized from scratch within the human body – act as catalysts that regulate cellular processes such as growth and differentiation (anabolic processes), including bone and skeletal muscle growth (Semba 2016). But in addition to protein, ASFs are dense in a wide range of micronutrients linked to growth and cognitive development (iron, B12, choline), and cow's milk is uniquely rich in calcium and its ability to stimulate the secretion of insulin-like growth factor I (IGF-I), a hormone that stimulates bone and tissue growth (Dror and Allen, 2011).

In addition to biological theory, empirical evidence from developing countries has also lent support to the important role of ASFs in child nutrition. In terms of pure ASF consumption interventions, there are remarkably few interventions that test supplementation of infants (0-24 months) with an ASF relative to the usual diet (though there are many experiments with some sort of protein supplementation in infant formula or complex fortified infant foods).[1] Walker, et al. (1991) provided a high-protein milk-based supplement to stunted children aged 9-24 months in Jamaica, finding after 12 months that the

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[1] Still other studies review relationships between ASF intake and growth, but not among pre-school children, and only in a mix of high and low-income countries (de Beer, 2012, Hoppe, et al., 2006).

growth in length was 0.89 cm higher in the treatment group. Tang, et al. (2014) conducted a cluster-randomized controlled trial in rural China that provided a daily 60g-portion of minced pork to a treatment group while the control group received rice. The growth in length was 0.26 cm higher in the treatment group. In a recent study in rural Ecuador, Iannotti, et al. (2017) randomly assigned 6-9 month old children into treatment that provided one egg per day for a 6 month period and a control that followed a usual diet. The effects were large: length-for-age z score increased by 0.63 SD[2] and stunting prevalence decreased by 47% ($p < 0.01$) relative to the control group. Nutrition-sensitive livestock interventions conceptually only offer much more indirect evidence of growth impacts, but many of these do show some impact on growth (Leroy and Frongillo, 2007), particularly dairy interventions (Iannotti, et al., 2013). Likewise, several observational analyses of household surveys show that children from cow-owning households are 0.3 to 0.6 standard deviations taller than children whose households do not own cows (Choudhury and Headey, 2017, Hoddinott, et al., 2015, Rawlins, et al., 2014). Some research argues poultry ownership has potential dietary benefits for young children, but may also impose significant health risks because of fecal contamination or zoonotic respiratory diseases (Headey and Hirvonen, 2016).

Finally, historical evidence shows strong correlations between per capita livestock holdings and adult heights. Data from 19th century Bavaria show how statures were greater in regions that had higher levels of per capita milk production (Baten, 2009, Baten and Murray, 2000).[3] Similarly, per capita cattle holdings is found to be an important predictor of within-country differences in female stature in post-colonial Africa (Moradi and Baten, 2005). Grasgruber, et al. (2016) analyze more recent data on adult male heights from 105 countries, which they link to dietary proxies from the FAO Food Balance Sheets and genetic markers linked to lactose intolerance. They show that male adult male heights are most highly

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[2] Using the WHO (2006) growth standards, this translates into 1.63 cm gain in length relative to the control group.

[3] The absence of technology to refrigerate inhibited trade and meant that local production and consumption of dairy were highly correlated. In the United States, mechanical refrigeration technology started to spread in the late 19th century facilitating market integration of perishable foods such as dairy (Goodwin, et al., 2002). Craig, et al. (2004) estimate that the adoption of refrigeration post-1890s United States increased annual dairy consumption and annual protein intake by 1.7 % and 1.25 %, respectively. The authors further estimate that a large fraction of the improvement in adult statures in 1890s were due to refrigeration.

correlated with animal-sourced protein intake, which is in turn strongly associated with more lactose-tolerant genetic profiles. Takahashi (1984) argues that the post-war improvements in child heights in Japan are strongly linked to the introduction of dairy into the Japanese diet.

The common implication of these different strands of research is that ASF intake could be a limiting factor for linear growth in developing countries, including growth in the first 1,000 days of life. Despite this, the linkages between ASF consumption and child growth in contemporary developing countries are still poorly understood. The evidence on the linear growth impacts of ASF intake is very limited, often focused on older children or adults, and often focused on dairy consumption even though the importance of dairy in children's diets is far from universal. Indeed, few studies have systematically analyzed how ASF consumption patterns vary across countries and regions, and why this is the case.

In light of these knowledge gaps, this paper offers three contributions. The first is descriptive. Using an unusually large agglomeration of Demographic Health Surveys (DHS), encompassing 112,553 children aged 6-23 months living in 46 developing countries with generally high levels of stunting, we document complex regional patterns of ASF intake in 24-hour recall data. Second, we use these rich surveys to conduct an age-disaggregated multivariate analysis of the associations between children food consumption patterns and linear growth in models saturated with a host of relevant control variables; that is assessing whether these associations are consistent with the biological, historical and programmatic evidence referenced above.

Third, we explore why ASF consumption is low, but also so variable across countries and regions, even those at similar levels of development. We link DHS data to national level data on "cereal-relative caloric prices" that tell us how expensive a source of calories each ASF is relative to the cheapest staple cereal in each country. Combined, these data can shed light on why consumption of ASFs various across countries and households.

The paper is organized as follows. Section 2 provides an overview of the data and methods used in this paper. Section 3 presents descriptive evidence on children diets in different regions. Section 4 presents results on the associations between child stunting and ASF consumption. Section 5 examines results that help explain why ASF consumption is low and variable in developing countries. Section 6 concludes.

2. Methods

We use multi-country household survey data from phases 5 and 6 of the Demographic Health Surveys (DHS), covering surveys conducted between 2006 and 2014 (ICF International, 2015). The DHS are widely used in analyses of child nutrition, including the main dependent variables in our analysis, child stunting, which is defined as a height-for-age Z-score less than 2 standard deviations below the WHO (2006) growth standards. Since the mid-2000s (Phase 5) the DHS has implemented a highly standardized dietary module in which mothers are asked to recall which of 12 disaggregated food groups their youngest child (0-24 months of age) consumed in the past 24 hours. These 12 food groups are conventionally aggregated into a 7-food group dietary diversity score (DDS). Table 1 lists the 7 aggregated food groups in the left-hand column and the 12 more disaggregated groups in the right-hand column. Three of the 7 aggregated food groups are ASFs (dairy, eggs, flesh foods).

Previous research recommended that a threshold of 4 out of the 7 aggregated food groups be defined as minimum dietary diversity (MDD) for two reasons since this threshold was effective in predicting micronutrient adequacy and virtually guaranteed inclusion of at least one ASF (in our data set over 97% of children 6-23 months who achieved 4/7 food groups consumed at least 1 ASF). This MDD indicator is now a standard WHO infant and young child feeding (IYCF) target (WHO, 2008), and DDS or MDD if often used in both experimental research (as an outcome indicator) and observational research. In terms of the latter, nutritionists have assess whether dietary diversity scores or MDD is associated with a reduced risk of stunting, conditional on age and breastfeeding status. Early studies found substantial evidence of significant associations (Arimond and Ruel, 2004, Ruel and Menon, 2002), though subsequent studies with larger samples of countries have tended to find that these results are often not robust s(Jones, et al., 2014; Onyango, et al., 2014).

However, these studies are also subject to several criticisms.

First, heterogeneity in the associations between DDS/MDD and stunting could be driven by differences in the composition of diets, particularly variation in consumption of ASFs. Indeed, one early study in this literature suggested that dairy consumption may be driving some of the association between dietary metrics and child stunting in Latin America (Ruel, 2003).

Second, the use of 24-hour recall in DHS consumption indicators, which are potentially a poor proxy for usual diets, creates imprecision and attenuation bias (Thorne-Lyman, et al., 2014). These problems are also compounded by sample size problems. The DHS only collects dietary data for the youngest child, typically in the 0-24 months range. Moreover, younger children in this 0-24 month range are not relevant to any analysis of stunting since: (a) most children 0-5 months are not consuming any complementary foods; and (b) one would not expect to see any instantaneous growth benefits from a recent introduction of complementary foods (e.g. in the 6-11-month range). Instead, the benefits of an improved diet would be expected to accumulate throughout the first two years of life, consistent with the growth faltering patterns observed in Victora, et al. (2009). Hence the most relevant sample for any analysis of stunting is likely to be children reaching the end of the first 1000 days of life (e.g. 18-23 months), provided that there is a reasonably high degree of persistence in children diets (i.e. their dietary patterns from the past 24 hours roughly reflect dietary patterns from 12 months ago).

A third issue with country-specific analyses is that some countries have exceptionally poor dietary patterns throughout the country, which may result in sufficient variation in the right-hand side variables of interest. To take an extreme example, just 3 percent of Burkinabe children achieve MDD, and less than 10% consume dairy products in the past 24 hours.

A fourth issue is the obvious problem with confounding factors. Many factors that might determine ASF consumption might also affect nutrition through other channels, including wealth and nutrition knowledge.

To combat these limitations in the data we take several steps.

First, we go beyond DDS and MDD to test associations with an ASF indicator (equal to 1 if a child consumed dairy, egg or a flesh foods) and more disaggregated dietary indicators from the DHS (e.g. separate indicators of meat, fish, eggs and dairy). The strong overlap between ASF consumption and MDD suggests it might be ASFs primarily driving the observed associations with stunting, yet many children who do not achieve MDD still consume at least 1 ASF, which allows us to test for significant associations between child growth and ASF consumption even among children classified as having inadequate diets.

Second, we use an expansive dataset covering 112,553 children aged 6-23 months from 46 countries in five regions designed to encompass broadly similar nutritional and dietary profiles, and to ensure reasonable region-specific sample sizes (see Supplementary Table S1 for a full list of countries):

(1) Latin America & Caribbean (5 countries, 20,846 children)
(2) North Africa & Western Asia (4 countries, 13,623 children)
(3) Central, South and South-East Asia (9 countries, 22,706 children)
(4) West and Central Africa (16 countries, 33,343 children)
(5) Eastern and Southern Africa (13 countries, 22,035 children)

This sample has excellent coverage of children from sub-Saharan Africa and South Asia, with India, Pakistan, Bangladesh and Nepal comprising over 70% of the 9-country Asian sample. Unlike most previous studies we focus on pooled results for the total sample of 46 countries and these five region-subsamples, rather than country-specific samples – although our models always control for country-year fixed effects through the inclusion of binary variables for each survey.

Third, the availability of a much larger dataset allows us to conduct a more age-disaggregated analysis using both non-parametric and parametric regressions. We first run local polynomial regressions (LPOLY) on stunting against age to gauge the extent of growth faltering in the 6-23 period in which complementary foods are first introduced. We then use similar LPOLY graphs to show ASF consumption patterns over child age. Finally, we plot stunting against child age for separate dietary sub-samples such as MDD and non-MDD children and ASF and non-ASF children. We do these particular LPOLY graphs without controls, but also first use parametric regressions on a full set of control variables and survey dummies (described in Table 2) to derive residual stunting estimates that are then plotted against child age for these dietary subsamples.

Fourth, a concern with an associational exploration such as ours is the potential for correlation between ASF consumption and the disturbance term. Note, however, that our large sample allows the possibility of a relatively strong placebo test. Suppose we observe in our data a correlation between ASF consumption and child height at age six months. Biologically, this correlation makes no sense as ASF consumption should not have any instantaneous effect on child growth at 6 months, when solid foods are first introduced, since growth is a cumulative process. If the addition of controls to the model eliminates these associations at 6 months then this suggests that the control variables are relatively effective in purging the regressions of correlation between ASF consumption and the disturbance term.

For our parametric regression analysis, we estimate linear probability models that always include the full sets of controls listed in Table 2 – mostly drawn from (Danaei, et al., 2016) – as well as age-in-month as well as survey dummy variables.[4] The inclusion of the latter means that the regression coefficients always represent within-survey associations with stunting. Our results are not population-weighted, but the coefficients do reflect implicit weights based on sample size and on within-survey variation in stunting and dietary variables (that is, countries with less stunting or less variation in dietary

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[4] Our results are robust to using a Probit model instead of linear probability model.

indicators will get less weight).[5] Moreover, our region-based regressions give a feel for parameter heterogeneity across regions with different nutritional and dietary profiles. For our parametric results we omit children 6-11 months (since one would not expect to see sizeable growth benefits from ASF consumption amongst children who have just begun to consume complementary foods), and run separate regressions for children 12-14, 15-17, 18-20 and 21-23 months. Our expectation is that the associations between dietary indicators and stunting are stronger for older age groups.[6]

In the final part of the analysis, we supplement DHS data with national level data on cereal-relative calorie prices (CCPs) from Headey, et al. (2017). The underlying price data pertain to nationally averaged prices of 200 standardized food products collected by national statistical agencies for 177 countries under the auspices of The International Comparison Program (ICP) coordinated by the World Bank. These weight-based prices were then converted to prices per calorie. Specific foods were then allocated into groups (see Table 3), and in each country the cheapest staple cereal was selected as a numeraire. CCPs were then constructed by taking the ratio of the cheapest food in each group to the cheapest staple cereal in a country. As an example, the CCP for eggs in Bangladesh is the ratio of the price of 1 calorie of an egg relative to 1 calorie of rice. Table 3 indicates that most ASF categories involve good coverage of a range of specific food items, although there is insufficient coverage of local varieties of freshwater fish (though tilapia is priced in most developing countries and is typically a relatively cheap fish variety). Coverage of fresh and processed dairy products is good (6 products), as is eggs (medium and large).

We use these national level price data in linear probability regressions where consumption of individual ASFs is modelled as a function of child and household characteristics from the DHS – including important predictors of ASF consumption such as household wealth and parental education –

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[5] In an extreme case, if no dairy were consumed in a particular survey, then that survey would not contribute any variation to the coefficients of interest since this would be absorbed by the survey dummy.

[6] We also note one idiosyncrasy: Peruvian DHS do not provide any disaggregated data on flesh foods, with fish and meat/organs aggregated together.

and national level prices. The inclusion of time-invariant prices for 2011 means that these regressions necessarily omit survey/country dummies, but we include a series of additional national-level control variables that might influence ASF prices and simultaneous determine ASF consumption patterns through other mechanisms. These variables are sourced from the World Bank and include GDP per capita, cereal yields, and a conflict dummy variable for whether there were battle-related deaths during the period in question.

3. Dietary patterns among young children

Table 4 reports nutrition and dietary indicators for children from the five major regions in our sample, while Table 5 reports consumption patterns of more disaggregated food groups by region. Stunting rates are high in this sample of children (31.9%). The regional disaggregation shows that stunting is much higher in the two sub-Saharan African regions and South-Central and South-East Asia – where roughly a third of children in this age range are stunted – than in the two predominantly middle-income regions (Table 4). Dietary diversity scores follow a similar pattern. Sampled children in the Latin America and Caribbean region have relatively good dietary diversity, with a mean score of 4.0 (equal to the MDD threshold) and 84 percent of sampled children consuming an ASF in the past 24 hours. Moreover, even among children failing to achieve MDD we observe that two thirds consumed as ASF in the past 24 hours. Table 5 shows that consumption levels among different ASFs are broadly similar in Latin America. Slightly over half consume dairy and meat/fish, while almost half consumed eggs in the past 24 hours.

Relative to levels of wealth/income, diets in the North African and Western Asian samples are surprisingly undiversified, with mean DDS of just 2.9 and only 37% achieving MDD. Dairy is overwhelmingly the most important ASF for children in this sample, with almost two-thirds consuming dairy in the past 24 hours, and a further 11 percent consuming infant formula. Around 80% of children who did not achieve MDD consumed at least 1 ASF.

In the other Asian region – where India comprises over half the sample – dietary diversity is very low and just over 20% of children achieved MDD. However, 60% of children not achieving MDD in this region still consumed at least 1 ASF in the last 24 hours. The most commonly consumed ASF is dairy, although these regional aggregates mask substantial diversity in this region. In India, Pakistan, Nepal, Kyrgyzstan and Tajikistan around half of children consumed dairy in the past 24 hours, but dairy is much less common in Bangladesh (roughly one quarter) and in Cambodia just 6 percent of children consume dairy. In these last two countries fish is a much more important ASF, with roughly one half of children in these countries having consumed fish in the last 24 hours. Egg consumption is prevalent in Bangladesh, Pakistan, Kyrgyzstan and Tajikistan (around one-quarter), but in India and Cambodia less than 10% of children consumed eggs in the previous day.

In the two African regions dietary diversity is very low, with just 16-17% of sampled children achieving MDD. Among children not achieving MDD roughly half consumed ASF in the previous day in both of these regions. Consumption levels of specific foods also show broadly similar patterns, with low consumption of dairy products (~20%), eggs (~12%) and red meat (~16%). One significant difference is the predominance of fish consumption in Western and Central Africa where almost a third of children consumed fish in the previous day, making it easily the most common ASF in this region. Indeed, in the more tropical and coastal countries in this region around half of children consumed fish in the past 24 hours. Fish consumption is relatively common in most of Eastern and Southern Africa (~20%), with the major exceptions being Ethiopia and Zimbabwe where dairy is more common. Egg consumption in both African regions is universally low despite the fact that poultry ownership is widespread in Africa, with over half of households owning poultry (Headey and Hirvonen, 2015).

Figure 1 plots stunting against child age for 46 countries. Just after birth roughly 18% of the sample is stunted, but this changes little for the first few months of life when most infants are predominantly breastfed. Yet from 4-5 months onwards stunting rates increase precipitously until about

20 months of age where they level off at just over 40%. Regional data show similar patterns of accelerated growth faltering during the 6-20 months period (Figure S1).

The fact that most growth faltering occurs over this 4-20-month period suggests that poor feeding practices might play an important role in influencing child growth outcomes. Figure 2 plots consumption of any ASF (red) and some specific ASFs by child age. Dairy is the most commonly consumed ASF in this sample. While dairy products are only recommended to be introduced at 12 months because of potentially adverse side effects on fragile infant digestive systems (FAO, 2013), in this sample about 20% of children 6 months of age consumed dairy products on the previous day. This rises to 40% by 18 months. Consumption of eggs, meat and fish are all less common that dairy and are characterized by similar levels of consumption at all ages. Thus, while almost 60% of children in this sample consumed at least one ASF in the previous day, diversity in ASF consumption is also low, and it would appear that most children fail to consume a non-dairy ASF on a daily basis.

4. Associations between stunting and animal sourced foods

Non-parametric evidence

The cumulative nature of stunting implies that the benefits of improved diets are likely to materialize as children age. LPOLY plots of stunting by age for diet-stratified sub-samples are an effective way to explore this idea. Figure 3 report LPOLY plots of where the vertical axis measures either the raw stunting variable or stunting residuals where the variation in stunting due to all the control variables listed in Table 1 (except age) is purged. Panel A separates stunting rates for children achieving and not achieving MDD. In Panel B the adjusted stunting residuals show no significant different until approximately 14 months, suggesting that the control variables are doing a good job of purging these relationships of confounding factors. After 14 months the difference between MDD=1 and MDD=0 children rises until approximately

21 months of age and then stabilizes, consistent with the cumulative benefits of an improved diet. At 23 months the point estimate difference in stunting prevalence between the two groups is approximately 8 percentage points.

In Panels C and D, we split the sample by ASF and non-ASF children. The patterns are similar, with significant differences again emerging from 14 months onwards in Panel D. Differences between ASF and non-ASF children are approximately 7 percentage points at age 23 months in Panel D.[7]

Finally, Panels E and F restrict the sample of children to those with inadequate diets (MDD=0), and then splits by ASF and non-ASF children. Even among children with inadequate diets there is a significant difference in stunting prevalence between ASF and non-ASF children. This difference again emerges at around 14 months and tends to peak at approximately 21 months at around 5 percentage points.

Parametric evidence

All parametric regressions control for the variables listed in Table 2 as well as fixed country-year characteristics through survey dummies. Table 6 provides parametric evidence on the relationships described in Figure 3. Regressions (1) through (4) provide a parametric replication of Panel B from Figure 3 with the sample split by four age brackets spanning the 12-23-month range. Consistent with Figure 3, results from the 12-14 month and 15-17-month range shows small and marginally significant differences between MDD and non-MDD children. In the 18-20-month range, however, this difference becomes a highly significant 3.3 percentage points, and in the 21-23-month sample it becomes 5.1 percentage points.[8] Relative to other determinants of stunting this point estimate on MDD is large in magnitude. Moving from the lowest to richest wealth tertile implies an 8.6-point reduction in stunting, for

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[7] Considering the stunting rate of about 40 percent in this age group (Figure 1), this 7-percentage point difference translates into about 17.5 percent difference in stunting prevalence.

[8] Considering the stunting rate of about 40 percent in this age group (Figure 1), this 5.1 percentage point difference translates into about 13 percent difference in stunting prevalence.

example, and moving from no education to a mother with 10+ years of education implies a 5.7-point reduction.

Table 7 reports stunting regressions for relatively aggregated food groups, including any ASF on the arguably strong assumption that the growth benefits of different ASFs are similar in magnitude. Regressions (1) through (4) again disaggregate by age. Consistent with results above, the coefficients on "Any ASF" become highly significant in the 18-20 and 21-23-month samples, with the coefficient implying ASF consumption reduces stunting by 3.7 or 3.8 percentage points. Regressions (5) through (8) restrict the sample to MDD=0 children, as in Panels E and F of Figure 3.[9] The coefficients on ASF remain highly significant in the 18-20 and 21-23-month categories, implying stunting reductions of 4 and 2.6 percentage points respectively. [10]

In Table 8 we disaggregate further into individual food groups. In regressions (1) through (4) we aggregate fish and meat into one category to accommodate Peru, while regressions (5) through (8) exclude Peru in order to tests for different coefficients on meat and fish. Regressions (1) through (4) again tend to show more significant coefficients in the 18-20 and 21-23-month samples. In the 21-23 month sample the coefficients on dairy and meat are significant at the 1% level and relative large in magnitude (3.6 and 2.6 points), while the coefficient on eggs is only marginally significant and relatively small in magnitude, imply a 1.7-point reduction in stunting. Interestingly, coefficients on both Vitamin A-rich fruit and other fruit are both significant in the 18-20 and 21-23-month samples, while vitamin-A rich fruit is also significant in the 12-14-month sample.

Unlike other ASFs, the coefficients on meat are significant across all age brackets in regressions (1) through (4). However, when we disaggregate into separate meat and fish categories in regressions (5) through (8), with Peru now excluded, we observe that the coefficients on fish are robust across age

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[9] It is important to note that dropping MDD=1 children from these regressions changes the regional composition of the sample, with fewer children from Latin America and the Caribbean, for example.

[10] We also note that the 'Any legume/nut' variable appears with a significant and *positive* coefficient in column 8. However, this counter-intuitive result is not robust to the inclusion of subnational fixed effects to the model; see Table S3 in the Supplement.

ranges, varying between 2-point differences and 3.8-point differences. In contrast, the coefficient on meat is only significant in the 18-20-month sample. In regression (8) the coefficient on fish is significantly larger than the coefficient on meat at the 2% level, but in all other regressions the differences are not statistically significant.

Table 9 disaggregates by region. In Latin America and the Caribbean, where children appear to regularly consume multiple ASFs on a daily basis, we observe a large point estimate on dairy (4.4 points) and fish/meat (5.6 points). In North African and Western Asia none of the ASF coefficients are significant. We note, however, that these anomalous results on the food consumption variables extend to wealth and parental education, the coefficients on which are all statistically insignificant. Indeed, previous research has also noted the surprising insignificance of these variables in explaining stunting in Egypt (Alderman and Headey, 2017), which accounts for almost two-thirds of this region's sample. In South, Central and Eastern Asia the coefficients on dairy consumption are significant, albeit with a large point estimate of 4.8 percentage points. In Western and Central Africa where fish is the most commonly consume ASF the coefficient on fish is highly significant and large in magnitude, implying a 4.3-point reduction in stunting. Consumption of eggs is also significantly associated with stunting, implying a 3.1-point reduction. The coefficient on dairy, which is not as widely consumed in this region, is highly insignificant. In contrast, the coefficient on dairy consumption, which is more common in parts of this region (such as Ethiopia, Uganda, Rwanda and Zimbabwe), is highly significant and very large in magnitude, implying a 7.1-point reduction in stunting. The coefficient on fish consumption is also marginally significant.

The supplement reports a full set of alternative results to those reported above, which include subnational fixed effects instead of survey dummies. There are few material differences in most of the key results on ASFs as an aggregate category, but several results for specific foods are weakened, particularly for fish. This suggests, not implausibly, that consumption of specific foods is strongly associated with spatial factors, such as access to coasts, inland water ways and climatic factors.

5. Constraints to ASF consumption in developing countries

Why is consumption of ASFs among young children so low in developing countries, but also so variable across products, as we observed in Section 3?

One perceived barrier is lack of nutritional knowledge. Many nutritional programs have attempted to improve nutritional knowledge, albeit it with mixed success and substantive concerns on sustainability (Dewey and Adu-Afarwuah, 2008, Menon, et al., 2015). Consistent with knowledge constraints, parental education has been strongly linked to nutrition outcomes and dietary diversity even when applying methods to reduce endogeneity bias (Alderman and Headey, 2017). Gender bias and low levels of maternal empowerment are also widely cited constraints (Jayachandran and Pande, 2015), as are food taboos (Pachón, et al., 2007, Zerfu, et al., 2016). Additionally, many studies show that consumers diversify away from starchy staple foods as incomes rise as per Bennett's law (Choudhury and Headey, 2017), opting for more expensive sources of calories as incomes rise (Subramanian and Deaton, 1996), including strong demand for ASFs (Melo, et al., 2015). If incomes constrain ASF consumption, this suggests they may be a very expensive source of calories in low income countries. Certainly, many ASFs are imperfectly tradable, especially in environments with underdeveloped value chains (e.g. poor transport, lack of cold storage, and low levels of processing). Highly perishable foods also have associated food safety risks, with semi-commercialized dairy systems a notable example in both contemporary developing economies (Gizachew, et al., 2016) and early 20th century industrialized societies (Gordon, 2016, p. 81-83). In turn, this draws attention to the price of ASFs as a factor constraining children's consumption of these foods, something that has received surprisingly little attention.

Table 10 reports data on the price of ASFs and other foods relative to the price to a country-specific numeraire, the cheapest staple cereal (e.g. rice, wheat, and maize products). For example, the value 6.1 for fish in Eastern & Southern Africa tells us that it costs 6.1 times more to consume a calorie from a fish product than it does a calorie from a staple cereal. Across all regions, roots and tubers are very cheap sources of calories. Strikingly, vitamin-A rich fruits and vegetables and "other fruit" are also relatively affordable, partly because many such fruits are highly suitable to tropical conditions, and because of some (e.g. mangos, papayas) are relatively easy to store and transport. By contrast, vegetables – highly perishable and low in calorie density – are an expensive source of calories. Legumes – which are reasonably high in lower quality protein – are a very affordable source of calories in most regions, but less so Africa.

Price ratios on ASFs, however, reveal striking differences across income levels and regions. Both perishable fresh milk and highly storable processed milk are relatively cheap sources of calories in high income countries but also in Latin America and the Caribbean. In North Africa processed milk is cheap, but fresh milk is very expensive. It is notable that in both these middle-income regions consumption of dairy products among infants and young children is widespread, with well over half consuming dairy in the past 24 hours (Section 2). By contrast, fresh milk is moderately expensive in South, Central and South-East Asia (though relatively cheap in India, where dairy consumption is high) and extremely expensive in sub-Saharan Africa. In Western and Central Africa, for example, fresh milk is 16.5 times as expensive as the cheapest cereals. Processed milk is highly storable, so it is little surprise that it is more affordable in all regions.

Price variation for eggs is even more striking. Eggs are a very cheap source of calories and protein in high income countries (Iannotti, et al., 2014). Yet in North Africa and Asia they are at least 6 times as expensive as staple cereals, and in Africa 9-10 times as expensive. This provides *prima facie* evidence that the highly perishable nature of eggs and the low productivity of egg production in lower income countries would appear to account for the low levels of egg consumption observed in section 2.

The price story on flesh foods is quite different. Both red/white meat and fish are relatively tradable, either because of the scope to trade live animals, or the ability to freeze, dry, smoke or salt meat. Meat and fish are again notably cheap in high income countries and in Latin America and the Caribbean, but also – compared to other AFSs - relatively affordable in sub-Saharan Africa where meat/fish calories are 5-6 times as expensive as staple cereals. Fortified baby cereals are extremely expensive in all regions except high income countries and Latin America and the Caribbean, with information asymmetries a likely explanation for these market failures (Masters, et al., 2016).

Table 11 reports linear probability models explaining children's consumption of four different ASFs. Own prices are always significantly and negatively associated with consumption of each specific ASF. Dairy and egg consumption are especially strongly associated with prices. In the case of dairy, a doubling of the price ratio for fresh milk – for example, the difference between dairy prices in the US and India – would reduce dairy consumption by around 10 percentage points. The association for eggs is even stronger, suggesting the very high prices of eggs in most regions (Table 10) provides one explanation for why egg consumption is not common among infants and young children in poorer countries. Meat and fish consumption share somewhat more modest associations with their own price ratios. In the case of fish this may be the result of some attenuation bias, as the ICP only measures a few fish varieties relevant to lower income countries.

Amongst other national factors there are some interesting associations. Dairy and meat consumption have strong associations with GDP per capita, but in the case of dairy there is also an association with household level wealth that is much stronger than the corresponding associations for other ASFs. Fish consumption is negatively associated with GDP per capita and with household wealth, reflecting high levels of consumption in much of sub-Saharan Africa as well as countries like Cambodia and Bangladesh. The national urbanization rate is very strongly associated with egg and fish consumption, but negatively associated with meat consumption. These results might indicator that more commercialized large-scale low-cost poultry production systems tend to emerge when large urban agglomerations give rise to concentrated centers of demand.

Overall, the results suggest that there are multiple barriers to ASF consumption that are consistent with the existence of important supply-side constraints resulting in high prices of ASFs

6. Conclusions

Despite plausible biological mechanisms linking ASF intake to child growth there is a surprising dearth of evidence on this relationship in developing countries, and little previous work has systematically documented patterns of ASF consumption among young children, or attempted to explain why these patterns exist.

In this paper we first documented that ASF consumption among young children is relatively low in sub-Saharan Africa and most of Asia, but also characterized by some distinctive patterns. Most notable are: (i) low levels of dairy consumption in most lowland areas of Africa and much of Asia (Bangladesh, Cambodia), but relatively high levels of fish consumption; (ii) low levels of egg and red/white meat consumption in Africa and Asia. We then demonstrated strong associations between ASF consumption and child growth, particularly for fish and dairy products, and in some instances for eggs and meat also. Finally, we show that high relative prices of ASF calories are a critical constraint restricting consumption of these foods, particularly for highly perishable products such as fresh milk and eggs.

These findings are based on admittedly limited 24-hour dietary recall and on statistical associations rather than causal impacts. That said, our non-parametric analysis suggests that our saturated regression models do a good job of purging the results of obvious biases. There is also an important reason to suspect that we may be underestimating the impact of ASF consumption on stunting: the 24-hour recall is likely to be an imperfect proxy for usual diets (i.e. within-person error) leading to an attenuation bias. This may also be more problematic for some ASFs than others since some (e.g. dairy) may be consumed in larger quantities than others (e.g. flesh foods, eggs). While much more experimental evidence on ASF consumption and child nutrition, as well as cognitive measures, is needed, the evidence presented here is strongly indicative of important nutritional benefits from ASF consumption.

For the agriculture and nutrition communities these findings are of clear importance. Nutritionists have long promoted interventions designed to improve nutritional knowledge on feeding practices, and/or to increase homestead production of ASFs (Dewey and Adu-Afarwuah, 2008, Leroy and Frongillo, 2007). The extremely high prices of ASFs suggests these interventions could have limited impacts, however. One reason is that high ASF prices provide strong incentives for producers to sell ASFs rather than feed them to their own children. Behavioral change interventions are used to encourage households to resist the financial rewards of selling ASFs, but doing so is costly and potentially unsustainable, and will still fail to increase ASF consumption among non-producers. Potentially a more cost-effective and sustainable strategy is to employ larger scale investments in the livestock and fisheries sector and its associated value chains, and/or appropriate trade policies, to reduce the prices of ASFs for all consumers.

In the case of eggs – a highly non-tradable product – investments in domestic production are clearly crucial. However, egg production is characterized by sizeable economies of scale, suggesting that investments in village production systems are unlikely to be economically efficient. India, for example, has seen rapid growth in egg production stemming from medium and large-scale scale firms (Mehta and Nambiar, 2007). Moreover, a growing body of research also suggests scavenging poultry systems are also hazardous to the health of young children (Headey and Hirvonen, 2016, Ngure, et al., 2013). For dairy, the issue is much more complex, since dairy powder is highly tradable but not obviously a close substitute for fresh milk, nor highly desirable in contexts where water quality is a major concern. Many populations in tropical regions also have little tradition of consuming milk, suggestion there may be significant cultural issues to be overcome (FAO, 2008). Meat and fish are also complex sectors characterized by both intensive and extensive production modalities and some degree of tradability. The importance of fish in many African and Asian diets – even those of young children – and its strong associations with child growth make it a particularly interesting sector for future research and investment. One concern is that extensive systems are facing major over-fishing problems in Africa especially, although more sustainable fish farming systems have experienced explosive growth in much of Asia and parts of Africa (Béné, et al., 2015).

Finally, the importance of ASFs for child nutrition has important ramifications for agricultural development efforts. The vast proportion of agricultural research and development expenditures for lower income countries has been directed towards staple crops, with livestock and fisheries accounting for less than 12% of CGIAR spending. [11] Potentially this funding portfolio makes sense from a poverty and food security (calorie) perspective, but from a nutritional perspective this allocation appears skewed. If the international agricultural development community is to make a more meaningful contribution to reducing undernutrition then greater investment in livestock and fisheries sectors will be essential, as will more nutritionally oriented trade strategies.

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[11] The CGIAR is the Consultative Group for International Agricultural Research. This estimate of 12% of CGIAR spending allocated to livestock was provided by David Laborde at IFPRI, and is an estimate for the share of total CGIAR spending (excluding IFPRI) accounted for y ILRI and World Fish from 1997 to 2012. It is potentially an underestimate insofar as other centers may have some funding devoted to livestock, although we believe that the true share would not be much higher than 12%. As for national agricultural expenditures, we suspect that in many cases the share of the total agricultural budget devoted to livestock would not be any higher than 12%. In some extreme cases, such as Malawi, almost the entire agricultural budget is devoted to crops.

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Tables and Figures

Table 1. Food groups listed in Phases 5 and 6 of the Demographic Health Surveys (DHS)

Aggregated food groups in DDS (7 groups)	**Disaggregated food groups (12 groups)**
(1) Starchy staples	(1) Grains; (2) Roots/tubers
(2) Legumes/nuts	(3) Legumes/nuts
(3) Vitamin-A rich fruits/vegetables	(4) Vit-A rich fruits; (5) Vit-A rich vegetables
(4) Other fruits/vegetables	(6) other fruits (7) dark green leafy vegetables, (8) other vegetables
(5) Dairy	(7) Fresh/powdered cow's milk; (8) Infant formula
(6) Eggs	(9) Eggs
(7) Flesh foods	(10) Meat/organs; (11) Fish
	(12) Fortified infant cereals

Table 2. Descriptive statistics for the DHS sample of children 6-23 months in 46 countries

	Variable	Obs	Mean	St. Dev.
Nutrition & dietary indicators	Stunting	112,553	0.32	0.47
	Diet diversity score (0-7)	112,553	2.57	1.76
	Min. diet diversity (MDD)	112,553	0.29	0.45
	Animal sourced food (ASF)	112,553	0.62	0.49
	No food yesterday	112,553	0.11	0.31
	Grain/root/tuber	112,553	0.77	0.42
	Legume/nut	112,553	0.26	0.44
	Vit A fruit/veg	112,553	0.45	0.50
	Dark green fruit veg	112,553	0.29	0.45
	Other fruit	112,553	0.28	0.45
	Breastfed	112,553	0.79	0.40
	Fortified infant cereals	112,553	0.09	0.29
	Infant formula	112,553	0.09	0.28
	Dairy	112,553	0.36	0.48
	Eggs (0/1)	112,553	0.37	0.48
	Any meat/fish	112,553	0.23	0.42
	Meat (red/white, organs)	112,553	0.20	0.40
	Fish* (0/1)	100,791	0.22	0.41
Additional control variables	Diarrhea	112,553	0.23	0.42
	Fever	112,553	0.27	0.44
	Antenatal care (4+ visits)	112,553	0.60	0.49
	Medical facility birth	112,553	0.60	0.49
	Child born small	112,553	0.19	0.39
	Short birth interval	112,553	0.13	0.34
	Father absent	112,553	0.10	0.30
	Mother 3-4 children	112,553	0.29	0.45
	Mother 5-plus children	112,553	0.24	0.43
	Teenage mother	112,553	0.16	0.36
	Mother underweight	112,553	0.13	0.34
	Mother <145cm tall	112,553	0.05	0.22
	mother 145-150cm tall	112,553	0.14	0.35
	Mother 150-155cm tall	112,553	0.25	0.44
	Improved toilet	112,553	0.29	0.46
	Unimproved toilet	112,553	0.43	0.49
	Improved water	112,553	0.62	0.48
	Wealth, middle tercile	112,553	0.41	0.49
	Wealth, upper tercile	112,553	0.28	0.45
	Woman 9+ yrs education	112,553	0.33	0.47
	Rural	112,553	0.66	0.47
	Boy	112,553	0.51	0.50
	Child age	112,553	14.10	5.10

Note: These are DHS data from 46 countries listed in Supplement Table S1. *Fish consumption data are not available for Peru.

Table 3. Classification of cereals and specific ASF products in the ICP 2011 data

Food group	# products	Specific products used to construct minimum price
Cereals	13	Rice (5 types), bread products (5 types), maize flour, maize, tortilla
Cow's milk, fresh	2	Pasteurized fresh milk, unskimmed or low-fat
Cow's milk, long-life	3	Condensed milk, powdered milk, UHT
Meat, fresh	20	Whole chicken (2 types), chicken breast, chicken leg; Beef/veal (7 varieties), Lamb/mutton (4 varieties), Pork (4 varieties), Goat (1 variety); all unprocessed.
Chicken eggs, fresh	2	Large brown eggs, medium brown eggs
Fish, fresh	5	Fresh Carp, Mackerel or Tilapia; canned Sardines or canned Tuna

Source: Headey, et al. (2017).

Table 4. Unweighted means of stunting and various dietary indicators by region, children 6-23 months of age

	Stunting (%)	Diet diversity score (0-7 groups)	Minimum diet diversity (4+ groups)	Children consuming at least 1 ASF	MDD=0 children consuming at least 1 ASF	MDD=1 children consuming at least 1 ASF
Latin America & Caribbean	23.6%	4.0	63.6%	84.3%	66.7%	99.2%
North Africa & Western Asia	25.8%	2.9	37.0%	76.6%	81.2%	99.4%
South, Central & South-East Asia	37.1%	2.3	21.1%	57.9%	59.7%	96.7%
Western & Central Africa	32.5%	2.0	16.6%	52.4%	54.9%	95.4%
Eastern & Southern Africa	37.3%	2.2	16.9%	49.1%	47.3%	91.7%
All	31.9%	2.6	28.8%	61.8%	47.4%	97.3%

Notes: Data pertain to 112,553 children 6-23 months of age from DHS surveys from 46 countries. See Supplement Table S1 for a list of countries and sample sizes.

Table 5. Dietary patterns by region, children 6-23 months of age

	Latin America & Caribbean	North Africa & West Asia	South, Central & SE Asia	Western & Central Africa	Eastern & Southern Africa	Total
No food yesterday	3.9%	10.6%	13.6%	17.9%	11.1%	12.5%
Breastfed	76.5%	64.2%	85.1%	80.5%	84.6%	79.6%
Infant formula	8.3%	11.1%	12.4%	5.9%	7.2%	8.5%
Fortified cereals	8.8%	9.4%	14.5%	6.8%	8.4%	9.3%
Cereals, roots, tubers	89.8%	78.8%	76.8%	72.2%	71.3%	77.0%
Legumes/nuts	46.3%	24.1%	16.9%	20.5%	24.1%	25.8%
Vit A-rich fruit & veg	55.1%	28.5%	41.0%	40.9%	53.6%	44.5%
Dark green fruit & veg	18.8%	15.4%	28.6%	30.9%	43.0%	28.7%
Other fruit & veg	51.4%	34.8%	24.6%	18.1%	20.0%	28.1%
Dairy	57.5%	64.9%	38.4%	20.8%	18.7%	36.2%
Eggs	47.3%	30.9%	15.8%	12.2%	13.0%	21.9%
Meat/fish	56.3%	30.9%	23.2%	39.7%	33.6%	37.1%
White/red meat*	53.1%	24.1%	13.6%	15.5%	17.1%	23.4%
Fish*	NA	8.0%	12.8%	31.5%	21.1%	19.9%

Notes: Data pertain to children 6-23 months of age from DHS surveys from 46 countries. See Supplement Table S1 for a list of countries and sample sizes.

Table 6. Least squares regressions of stunting against minimum diet diversity (MDD), with disaggregation of MDD by animal sourced food (ASF) status

	(1)	(2)	(3)	(4)
Age range (months)	12-14	15-17	18-20	21-23
MDD	-0.014*	-0.014*	-0.033***	-0.051***
	(0.008)	(0.008)	(0.008)	(0.009)
Observations	20,454	18,997	17,761	15,912
R-sq	0.109	0.125	0.141	0.150

Notes: Clustered robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 7. Least squares regressions of stunting against aggregated food groups for the full sample of children and MDD=0 children

	(1)	(2)	(3)	(4)
Age range (months)	12-14	15-17	18-20	21-23
Dietary range	Full	Full	Full	Full
Any ASF	-0.010	-0.005	-0.037***	-0.038***
	(0.008)	(0.008)	(0.009)	(0.010)
Any fruit	-0.021***	-0.012	-0.032***	-0.031***
	(0.007)	(0.008)	(0.008)	(0.008)
Any vegetable	-0.003	0.001	0.001	-0.005
	(0.007)	(0.007)	(0.008)	(0.008)
Any legume/nut	-0.004	-0.007	-0.002	0.006
	(0.007)	(0.008)	(0.008)	(0.008)
Observations	20,454	18,997	17,761	15,912
R-squared	0.109	0.125	0.143	0.150
	(5)	(6)	(7)	(8)
Age range (months)	12-14 months	15-17 months	18-20 months	21-23 months
Dietary range	MDD=0	MDD=0	MDD=0	MDD=0
ASF	-0.010	-0.007	-0.040***	-0.026**
	(0.009)	(0.010)	(0.011)	(0.012)
Any fruit	-0.030***	-0.028***	-0.037***	-0.018
	(0.009)	(0.011)	(0.011)	(0.012)
Any vegetable	-0.007	0.001	0.004	-0.005
	(0.009)	(0.010)	(0.010)	(0.011)
Any legume/nut	-0.003	-0.013	-0.004	0.030**
	(0.011)	(0.013)	(0.013)	(0.014)
Observations	14,388	12,613	11,231	9,554
R-sq	0.100	0.107	0.123	0.116

Notes: Clustered robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 8. Least squares regressions of stunting against individual food groups (including fish)

	Meat & fish aggregated (including Peru)			
	(1)	(2)	(3)	(4)
Age range (months)	12-14	15-17	18-20	21-23
Legumes/nuts	-0.003	-0.006	-0.001	0.010
	(0.007)	(0.008)	(0.008)	(0.009)
Vitamin A-rich veg	-0.005	-0.003	0.007	-0.016*
	(0.009)	(0.009)	(0.009)	(0.010)
Dark green leafy veg	-0.005	0.006	-0.001	-0.001
	(0.008)	(0.008)	(0.008)	(0.008)
Vitamin A-rich fruit	-0.023***	-0.008	-0.021**	-0.016*
	(0.009)	(0.009)	(0.009)	(0.010)
Other fruit	-0.009	-0.004	-0.015*	-0.022***
	(0.007)	(0.008)	(0.008)	(0.009)
Dairy	0.003	0.001	-0.020**	-0.036***
	(0.008)	(0.008)	(0.009)	(0.009)
Eggs	0.004	-0.004	-0.007	-0.017*
	(0.008)	(0.008)	(0.009)	(0.009)
Meat	-0.017**	-0.026***	-0.040***	-0.026***
	(0.007)	(0.008)	(0.008)	(0.008)
Observations	20,454	18,997	17,761	15,912
R-squared	0.110	0.126	0.143	0.151
	Meat & fish disaggregated (excluding Peru)			
	(5)	(6)	(7)	(8)
Age range (months)	12-14	15-17	18-20	21-23
Meat	-0.006	-0.014	-0.026***	0.000
	(0.009)	(0.009)	(0.009)	(0.010)
Fish	-0.020**	-0.022**	-0.038***	-0.029***
	(0.009)	(0.009)	(0.010)	(0.010)
Observations	18,372	17,037	15,760	13,960
R-squared	0.105	0.118	0.132	0.137

Notes: Clustered robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 9. Regressions of stunting against individual food groups by region, for children 18-23 months of age

	(1) Latin America & Caribbean	(2) North Africa & Western Asia	(3) South, Central & Eastern Asia	(4) Western & Central Africa	(5) Eastern & Southern Africa
Legumes/nuts	0.003	-0.009	-0.024*	0.010	0.012
	(0.010)	(0.017)	(0.014)	(0.013)	(0.014)
Vit A-rich veg	0.014	-0.000	-0.017	0.005	-0.004
	(0.011)	(0.027)	(0.015)	(0.016)	(0.016)
Vit A-rich fruit	-0.028**	-0.038	-0.019	0.002	-0.023
	(0.012)	(0.024)	(0.015)	(0.014)	(0.016)
Other fruit	-0.011	0.001	-0.028**	-0.024*	-0.027*
	(0.011)	(0.017)	(0.013)	(0.013)	(0.015)
Dark green leafy veg	-0.003	0.037*	-0.008	-0.002	-0.006
	(0.013)	(0.019)	(0.012)	(0.011)	(0.013)
Dairy	-0.044***	-0.002	-0.048***	0.007	-0.066***
	(0.014)	(0.019)	(0.013)	(0.013)	(0.016)
Eggs	-0.017	0.009	-0.025	-0.031**	-0.001
	(0.011)	(0.016)	(0.015)	(0.015)	(0.018)
Fish/Meat	-0.056***				
	(0.012)				
Meat		-0.016	-0.005	-0.011	-0.029*
		(0.016)	(0.016)	(0.013)	(0.016)
Fish		-0.036	-0.025	-0.043***	-0.022
		(0.025)	(0.017)	(0.011)	(0.014)
Observations	6,626	3,544	6,881	9,314	6,625
R-squared	0.227	0.130	0.159	0.086	0.082

Notes: Clustered robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 10. Cereal-relative calorie price ratios for various foods, by region

	Vegetal sourced food prices					
	Roots & tubers	Vit A-rich fruit and veg	Dark green leafy veg.	Other veg.	Other fruit	Legumes
High income	1.6	3.0	9.0	3.3	1.7	1.2
Latin America & Caribbean	1.2	1.9	5.6	6.5	1.3	2.2
North Africa & Western Asia	2.1	2.5	6.1	5.3	3.3	2.1
South, Central & South-East Asia	1.5	1.9	6.2	6.0	3.1	2.0
Western & Central Africa	1.0	2.3	11.5	11.6	3.1	7.5
Eastern & Southern Africa	1.7	3.1	7.3	11.4	3.2	8.7
	Animal sourced foods & fortified baby cereal prices					
	Cow's milk, fresh	Cow's milk, processed	Chicken eggs	Meat	Fish	Fortified baby cereal
High income	3.2	2.2	3.0	2.0	4.3	5.0
Latin America & Caribbean	3.9	3.0	4.9	3.2	3.4	9.6
North Africa & Western Asia	10.1	3.1	6.1	6.2	6.0	16.1
South, Central & South-East Asia	7.8	3.8	6.2	6.5	5.3	16.4
Western & Central Africa	16.5	4.0	9.9	5.3	5.0	23.4
Eastern & Southern Africa	13.9	5.8	9.1	5.6	6.1	18.6

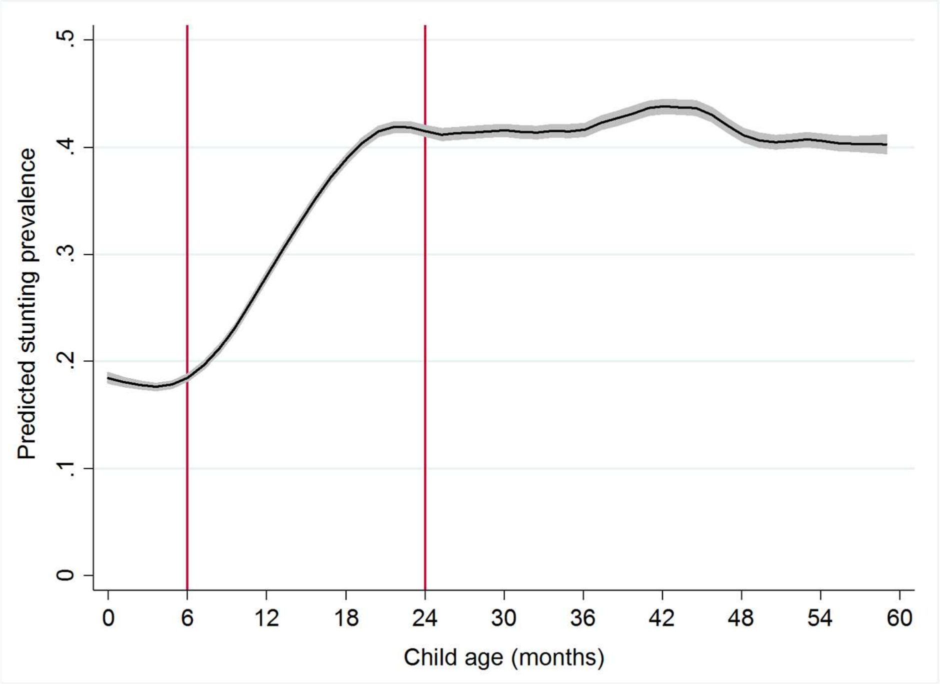
Notes: Caloric prices are the ratio of the price of 1 calorie of a given food (e.g. eggs) relative to 1 calorie of the cheapest staple cereal in each country (e.g. rice, wheat, and maize products). See Headey et al. (2017) for details.

Table 11. Linear probability model regressions of consumption of ASFs by children 6-23 months as a function of calorie price ratios, and various child, household, community and national level characteristics

	(1) Dairy consumption	(2) Egg consumption	(3) Meat consumption	(4) Fish consumption
Log own price[d]	-0.103*** (0.005)	-0.153*** (0.006)	-0.066*** (0.005)	-0.052*** (0.004)
Log cereal yields[d]	0.066*** (0.005)	0.015*** (0.004)	-0.081*** (0.004)	-0.064*** (0.005)
Log GDP per capita[d]	0.075*** (0.004)	-0.029*** (0.004)	0.065*** (0.004)	-0.084*** (0.005)
Log urbanization rate[d]	-0.002 (0.007)	0.204*** (0.006)	-0.062*** (0.007)	0.114*** (0.009)
Conflict dummy[d]	0.008 (0.005)	-0.070*** (0.004)	-0.053*** (0.004)	0.041*** (0.004)
Wealth, middle tercile[b]	0.063*** (0.004)	0.053*** (0.003)	0.024*** (0.003)	0.001 (0.004)
Wealth, upper tercile[b]	0.162*** (0.006)	0.077*** (0.005)	0.066*** (0.005)	-0.040*** (0.006)
Mother 9+ yrs of school[b]	0.030*** (0.004)	0.032*** (0.004)	0.044*** (0.004)	0.005 (0.004)
Father 9+ yrs of school[b]	0.009** (0.004)	0.004 (0.003)	0.012*** (0.003)	0.023*** (0.004)
Open defecation, village[c]	-0.019*** (0.006)	-0.061*** (0.004)	-0.042*** (0.004)	-0.010* (0.006)
Unimproved water, village[c]	-0.049*** (0.006)	-0.028*** (0.004)	-0.012*** (0.004)	+0.028*** (0.005)
Women's autonomy[b]	0.018*** (0.004)	0.012*** (0.004)	-0.005 (0.004)	-0.013*** (0.004)
Currently breastfed[a]	-0.078*** (0.004)	-0.008** (0.004)	-0.050*** (0.004)	-0.013*** (0.004)
Rural[c]	0.000 (0.004)	0.008** (0.004)	-0.022*** (0.004)	-0.027*** (0.004)
Father absent[b]	0.055*** (0.007)	-0.033*** (0.005)	-0.039*** (0.005)	0.016*** (0.006)
Hospital/clinic access[b]	0.020*** (0.004)	0.034*** (0.003)	0.012*** (0.003)	0.046*** (0.004)
Observations	98,840	100,991	91,793	89,896
R-squared	0.177	0.146	0.104	0.115

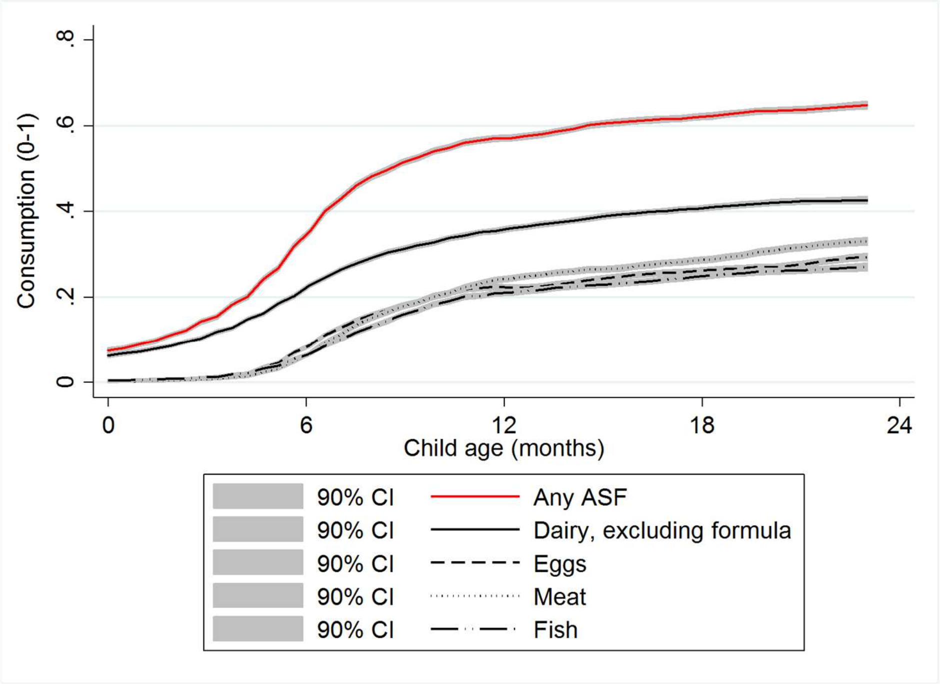
Notes: Clustered robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. a. Child level indicators; b. household level indicators; c. community/cluster level indicators; d. national level indicators. Regressions also control for short birth interval, number of children, teenage motherhood, child sex. These coefficients had small and often insignificant coefficients.

Figure 1. Stunting prevalence by child age for children form 46 countries



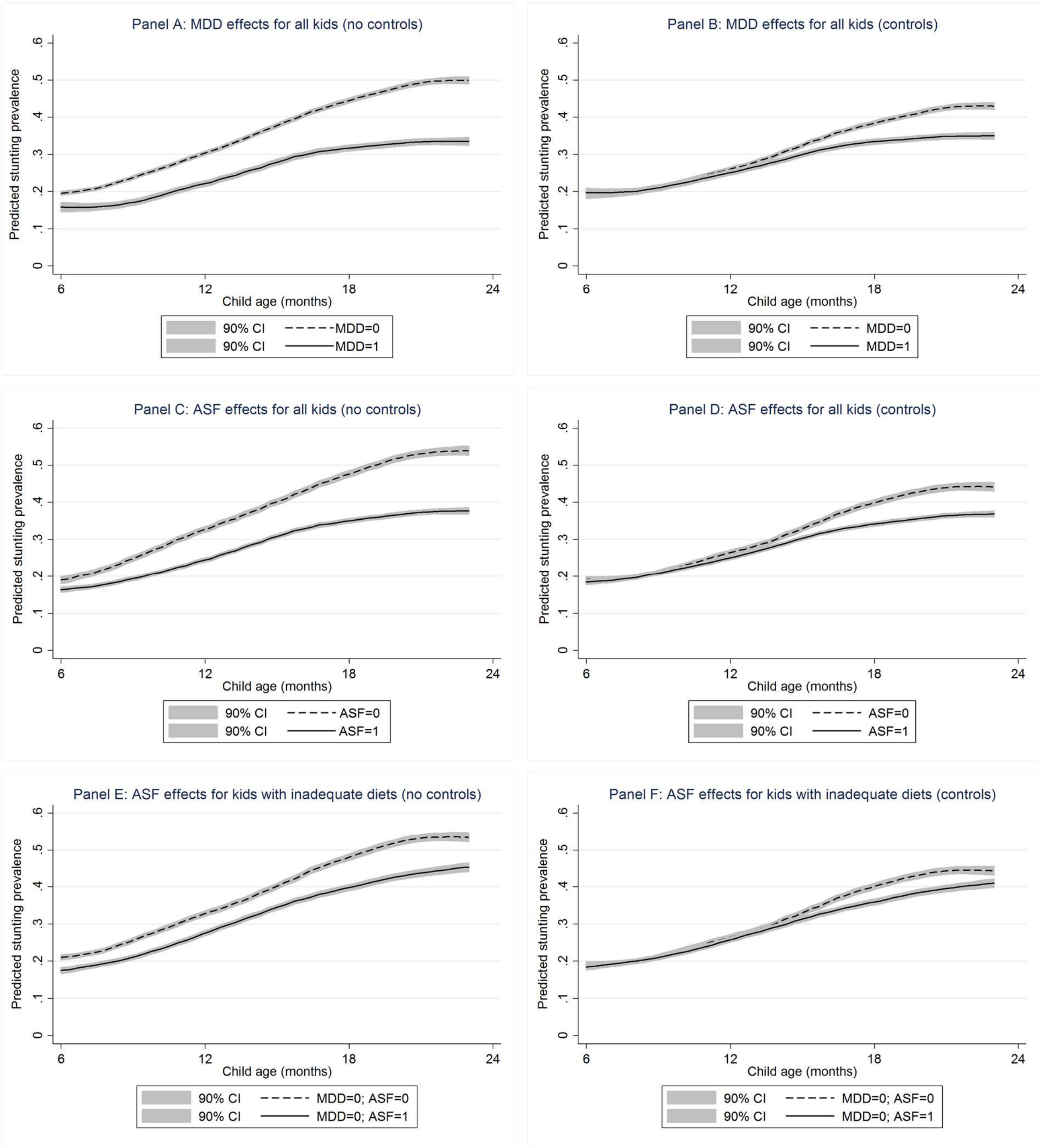
Notes: These are local polynomial plots of stunting against child age, with 90% confidence intervals, for 296,370 children aged 0-59 months.

Figure 2. Consumption of any ASF and specific ASFs, by child age



Notes: These are local polynomial plots of ASF consumption indicators against child age, with 90% confidence intervals, for 147,521 children aged 0-23 months.

Figure 3. Stunting-age patterns by MDD and ASF status, with and without control variables



Panel A: MDD effects for all kids (no controls)

Panel B: MDD effects for all kids (controls)

Panel C: ASF effects for all kids (no controls)

Panel D: ASF effects for all kids (controls)

Panel E: ASF effects for kids with inadequate diets (no controls)

Panel F: ASF effects for kids with inadequate diets (controls)

Notes: These are local polynomial plots of stunting against child age, with 90% confidence intervals, for 112,553 children aged 6-23 months. The control variables listed in Table 1 are incorporated into a first stage parametric regression, though Panels D and F also control for non-ASF foods. The residuals are then adjusted to have the same stunting level at age 6 months ("intercept"), and then plotted separately for different dietary groups.

Supplemental Tables and Figures

Table S1. Observations by region and country

Eastern & Southern Africa

country	Freq.	Percent
Burundi	996	4.52
Ethiopia	560	2.54
Comoros	2,571	11.67
Lesotho	487	2.21
Madagascar	1,321	6
Malawi	1,361	6.18
Mozambique	2,737	12.42
Namibia	1,558	7.07
Rwanda	1,101	5
Swaziland	625	2.84
Uganda	1,356	6.15
Zambia	4,762	21.61
Zimbabwe	2,600	11.8
Total	22,065	100

South, Central and South-East Asia

country	Freq.	Percent
Bangladesh	2,045	9.01
Cambodia	1,086	5
India	11,644	51
Kyrgyz Republic	1,224	5
Maldives	645	2.84
Nepal	2,102	9
Pakistan	796	3.51
Tajikistan	1,266	6
Timor-Leste	1,898	8.36
Total	22,706	100

Western & Central Africa

country	Freq.	Percent
Benin	2,648	7.94
Burkina Faso	1,973	5.92
Cameroon	1,612	4.83
Congo, Rep.	1,280	3.84
Congo, Dem. Republic	2,267	6.8
Cote d'Ivoire	918	2.75
Gabon	942	2.83
Ghana	744	2.23
Guinea	942	2.83
Liberia	2,040	6.12
Mali	1,171	3.51
Niger	1,275	3.82
Nigeria	12,469	37.4
Sao Tome and Principe	403	1.21
Senegal	1,072	3.22
Sierra Leone	1,587	4.76
Total	33,343	100

Latin America & Caribbean

country	Freq.	Percent
Dominican Rep.	906	4.35
Guyana	368	1.77
Haiti	2,009	9.64
Honduras	5,467	26.23
Peru	12,096	58.03
Total	20,846	100

North Africa & Western Asia

country	Freq.	Percent
Azerbaijan	422	3.1
Egypt	7,731	56.75
Jordan	1,709	12.54
Yemen	3,761	27.61
Total	13,623	100

Figure S1. An LPOLY of stunting by child age for five major regions

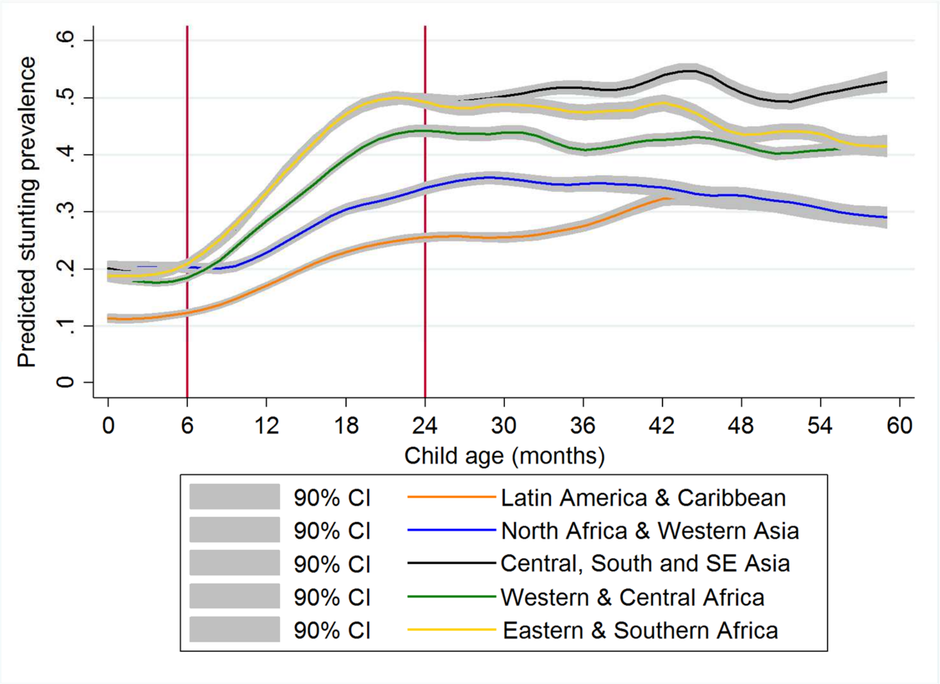


Table S2. Least squares regressions of stunting against minimum diet diversity (MDD), with disaggregation of MDD by animal sourced food (ASF) status, with subnational fixed effects

	(1)	(2)	(3)	(4)
Age range (months)	12-14	15-17	18-20	21-23
All control variables?	Yes	Yes	Yes	Yes
Survey dummies?	Yes	Yes	Yes	Yes
MDD	-0.009	-0.012	-0.027***	-0.045***
	(0.008)	(0.008)	(0.009)	(0.009)
Observations	20,454	18,997	17,761	15,912
R-sq	0.148	0.165	0.180	0.191
	(5) 12-14 months	(6) 15-17 months	(7) 18-20 months	(8) 21-23 months
MDD, with ASF	-0.009	-0.010	-0.028***	-0.045***
	(0.008)	(0.008)	(0.009)	(0.009)
MDD, no ASF	-0.007	-0.057	-0.012	-0.035
	(0.034)	(0.037)	(0.035)	(0.038)
Observations	20,454	18,997	17,761	15,912
R-sq	0.148	0.165	0.180	0.191

Notes: Clustered robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table S3. Least squares regressions of stunting against minimum diet diversity (MDD), with disaggregation of MDD by animal sourced food (ASF) status, with subnational fixed effects

	(1)	(2)	(3)	(4)
Age range (months)	12-14	15-17	18-20	21-23
Dietary range	Full	Full	Full	Full
ASF	-0.006	-0.010	-0.042***	-0.037***
	(0.008)	(0.009)	(0.009)	(0.010)
Any fruit	-0.013*	-0.010	-0.027***	-0.026***
	(0.007)	(0.008)	(0.008)	(0.008)
Any vegetable	-0.008	0.004	0.002	-0.006
	(0.007)	(0.007)	(0.008)	(0.008)
Any legume/nut	-0.004	-0.010	-0.002	0.005
	(0.007)	(0.008)	(0.008)	(0.009)
Observations	20,454	18,997	17,761	15,912
R-squared	0.148	0.165	0.181	0.191
	(5)	(6)	(7)	(8)
Age range (months)	12-14	15-17	18-20	21-23
Dietary range	MDD=0	MDD=0	MDD=0	MDD=0
ASF	-0.007	-0.013	-0.050***	-0.027**
	(0.009)	(0.010)	(0.011)	(0.012)
Any fruit	-0.024**	-0.029***	-0.036***	-0.021*
	(0.010)	(0.011)	(0.011)	(0.012)
Any vegetable	-0.013	0.004	0.005	-0.002
	(0.009)	(0.010)	(0.011)	(0.012)
Any legume/nut	-0.007	-0.014	-0.010	0.022
	(0.012)	(0.013)	(0.013)	(0.015)
Observations	14,388	12,613	11,231	9,554
R-sq	0.146	0.158	0.176	0.174

Notes: Clustered robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table S4. Least squares regressions of stunting against individual food groups (including fish), with subnational fixed effects

	Meat & fish aggregated (including Peru)			
	(1)	(2)	(3)	(4)
Age range (months)	12-14	15-17	18-20	21-23
Legumes/nuts	-0.005	-0.009	-0.002	0.007
	(0.008)	(0.008)	(0.008)	(0.009)
Vit A-rich veg	-0.008	-0.008	0.001	-0.021**
	(0.009)	(0.009)	(0.010)	(0.010)
Vit A-rich fruit	-0.016*	-0.009	-0.015	-0.010
	(0.009)	(0.009)	(0.009)	(0.010)
Dark green leafy veg	-0.010	0.011	0.002	-0.002
	(0.008)	(0.008)	(0.008)	(0.008)
Other fruit	-0.006	-0.005	-0.012	-0.023***
	(0.008)	(0.008)	(0.008)	(0.009)
Dairy	-0.000	-0.004	-0.023**	-0.038***
	(0.008)	(0.009)	(0.009)	(0.010)
Eggs	0.010	-0.001	-0.005	-0.011
	(0.008)	(0.008)	(0.009)	(0.009)
Meat	0.000	-0.011	-0.027***	-0.012
	(0.007)	(0.008)	(0.008)	(0.009)
Observations	20,454	18,997	17,761	15,912
R-squared	0.148	0.165	0.181	0.192

	Meat & fish disaggregated (excluding Peru)			
	(5)	(6)	(7)	(8)
Age range (months)	12-14	15-17	18-20	21-23
Meat	-0.002	-0.010	-0.026***	0.007
	(0.009)	(0.009)	(0.010)	(0.010)
Fish	0.006	0.004	-0.018*	-0.009
	(0.009)	(0.010)	(0.010)	(0.011)
Observations	18,372	17,037	15,760	13,960
R-squared	0.143	0.158	0.172	0.179

Notes: Clustered robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table S5. Regressions of stunting against individual food groups by region, for children 18-23 months of age, with subnational fixed effects

	(1) Latin America & Caribbean	(2) North Africa & Western Asia	(3) South, Central & Eastern Asia	(4) Western & Central Africa	(5) Eastern & Southern Africa
Legumes/nuts	0.002	-0.011	-0.026*	0.013	0.002
	(0.011)	(0.017)	(0.015)	(0.013)	(0.015)
Vit A-rich veg	0.003	-0.007	-0.017	0.003	-0.006
	(0.011)	(0.028)	(0.015)	(0.016)	(0.017)
Vit A-rich fruit	-0.021*	-0.031	-0.008	0.003	-0.021
	(0.012)	(0.025)	(0.016)	(0.014)	(0.016)
Other fruit	-0.007	0.038**	-0.000	-0.008	0.003
	(0.013)	(0.019)	(0.013)	(0.011)	(0.013)
Dark green leafy veg	-0.010	0.003	-0.035***	-0.015	-0.023
	(0.011)	(0.017)	(0.013)	(0.013)	(0.016)
Dairy	-0.042***	0.001	-0.051***	0.002	-0.064***
	(0.014)	(0.019)	(0.014)	(0.013)	(0.017)
Eggs	-0.018*	0.006	-0.011	-0.027*	-0.008
	(0.011)	(0.016)	(0.015)	(0.015)	(0.018)
Fish/Meat	-0.047***				
	(0.013)				
Fish		-0.019	0.009	-0.009	-0.033**
		(0.016)	(0.016)	(0.013)	(0.016)
Meat		-0.026	-0.013	-0.013	-0.022
		(0.026)	(0.018)	(0.012)	(0.015)
Observations	6,626	3,544	6,881	9,314	6,471
R-squared	0.250	0.140	0.184	0.125	0.109

Notes: Clustered robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.