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Keywords
Cognitive skills, Learning, Adolescent, Food insecurity, India, Education inequality, Human capital, Longitudinal, Education, Lifecourse

JEL Codes
I24, I29, I39, H52

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We investigated inequalities in learning achievements at 12 years by household food insecurity trajectories at ages 5, 8 and 12 years in a longitudinal sample of 1,911 Indian children. Estimates included extensive child and household controls, and lagged cognitive scores to address unobserved individual heterogeneity in ability and early investments. Overall, household food insecurity at any age predicted lower vocabulary, reading, maths and English scores in early adolescence. Adolescents from households that transitioned out from food insecurity at age 5 to later food security, and adolescents from chronically food insecure households had the lowest scores across all outcomes. There was heterogeneity in the relationship between temporal occurrence of food insecurity and cognitive skills, based on developmental and curriculum-specific timing of skill formation. Results were robust to additional explanations of the "household food insecurity gap", i.e. education and health investments, parental and child education aspirations, and child psychosocial skills.

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1. Introduction

Following the large expansion in primary and secondary educational access called for in the Millennium Development Goals, equitable learning has become the new imperative in the Sustainable Development Goal education agenda (World Bank, 2018). Inequalities in child and adolescent learning achievements may have long-lasting effects on individual lifecourse income, productivity, health, and intergenerational transmission of poverty, undermining a country's overall economic and social development (Behrman et al., 2017; Hanushek, 2013).

Policymakers in low- and middle-income countries (LMICs) are increasingly considering the role of household food security - a situation of unstable access to enough, safe and nutritious food - in children's accumulation of educational capital in order to devise multi-sectoral strategies for child learning, so that synergies with the social protection, health and food systems can be reaped (Bundy et al., 2017). Research on children's experiences of food insecurity at home in high-income countries—particularly the US—has suggested that food insecurity has wide-ranging implications for child school participation, learning and broader development (Alaimo, Olson, & Frongillo, 2001; Howard, 2011; Jyoti, Frongillo, Jones, & Al, 2005). However, there is a serious dearth of research on the learning consequences of food insecurity in LMIC settings, where the global burden of food insecurity is greatest and research on the linkages between food insecurity and early childhood undernutrition dominates much of the discourse (Chandrasekhar, Aguayo, Krishna, & Nair, 2017; Reis, 2012). Yet, returns from education, socio-demographic factors, and structure of the social protection, food and education systems—all of which have the potential to impact on household food insecurity, as well as to moderate the association between food insecurity and cognitive achievements— vary widely from higher-income contexts.

In this paper, we investigate inequalities in adolescent learning achievements by household food insecurity trajectories. We do this by relying on rich longitudinal data following children at early childhood, mid-childhood and adolescence in India, the second largest country in the world and a leading emerging economy. The country is currently home to a third of the global adolescent and youth population, and the Indian Government has recently identified inequalities in young people's human capital as a major challenge to reap the demographic dividend (Ministry of Statistics and Programme Implementation Government of India, 2017).

The need for robust evidence of inequalities in cognitive skills formation by household food insecurity trajectories is particularly pressing in India, which is in the midst of what has been defined as a "learning crisis" (World Bank, 2018). Since the 2000s, the country achieved impressive expansion in school participation but increases in learning levels have not followed: in rural India, only a quarter of Grade 3 students were at "grade-level" in reading and in maths in 2016[1] (ASER Centre, 2017). While a large body of literature has decomposed learning disparities by gender, caste, household wealth, place of residence, and private schooling (Alcott & Rose, 2017; ASER Centre, 2017; Dercon & Singh, 2013a; A. Singh, 2015), we are not aware of work focusing on household food insecurity. This is especially surprising in this context, as the country bears the largest burden of food insecurity and malnutrition globally (Headey, Hoddinott, & Park, 2016; Vellakkal et al., 2015) (also see Section 2.2).

Despite recent UNICEF estimates highlighted that at least 590 million children under age 15 live in moderately or severely food insecure households (Pereira, Handa, & Holmqvist, 2017), very few studies have addressed this topic in LMICs contexts, partially due to lack of data. Through this article, we aim at starting to fill this key evidence gap for policy-makers in those settings. The data we used are particularly suitable for examining this issue, as they simultaneously collected information on household food security and cognitive development during three critical periods of skills formation. Further, the longitudinal dimension allowed for the estimation of "value-added" models of adolescent learning by including measures of early childhood cognition that control for early-life heterogeneity in children's ability and household investments, thus increasing the robustness of our identification strategy (Andrabi, Das, Khwaja, & Zajonc, 2011). This way, we could investigate the extent to which the 'household food security gaps' in adolescent learning could be accounted for early-life differences in cognition and educational investments.

We hope to add to the literature in three main ways: first, we provide robust evidence on the relationship between timing and duration of household food insecurity and adolescent learning in a key emerging economy. Evidence from the US suggested that, as in the case of income poverty, household food security is more often a transient

[1] In Andhra Pradesh and Telangana, the settings for our study, only 22% and 18% respectively of Grade 3 students were at the grade-level in reading, and 48% and 40% in Maths (ASER Centre, 2017).

rather than a permanent condition, with the majority of households moving in and out of food insecurity over time (Burke et al., 2017; Howard, 2011; Perez-Escamilla & Pinheiro de Toledo Vianna, 2012). Whether a similar dynamic pattern holds in India—where, proportionally speaking, the scale and depth of food insecurity is greater—and what the implications of this dynamics for adolescent learning are, has been, so far, unclear. Second, as adolescents were assessed in multiple learning domains, including child receptive vocabulary, reading in the local language, maths, and English, we were able to investigate skill-based heterogeneity in the predictive power of household food insecurity. This aspect has also been relatively under-researched so far. We expect some degree of heterogeneity by cognitive achievement, due to variation in developmental periods in which different skills are usually acquired and curriculum-based variation in the age in which different skills are taught. Finally, we hypothesise and test a number of potential explanations that could account for adolescent learning disparities instead of household food insecurity trajectories. Thanks to the richness of our data, we could consider a wider set of possible pathways than previous studies, including education investments, health and psychosocial skills.

The rest of the paper is organised as follows: Section 2 presents the background; Sections 3 and 4 present the methods and results respectively. Finally, Section 5 discusses the results and concludes.

2. Background

2.1. Household food access and child education: theoretical pathways

Food insecurity is a multidimensional concept, ranging from the access to stable access to safe, nutritious and socially-acceptable food to individual nutritional outcomes (Burchi & De Muro, 2016). Arising from this complexity, the measurement of food insecurity includes assessing multiple dimensions. In this paper, we focus on a single domain: a household's capability to access adequate and nutritious food consistently over time, which, for simplicity, we refer to as "food security". Household food access is usually measured through experience-based access scales. These were first introduced in the US in the early 1990s and later validated for global comparisons (Ballard, Kepple, & Cafiero, 2013). Additional methodological details are presented in Section 3.2.

Due to the long-standing use of such scales in the US and Canada, most of the existing literature is set in those contexts (Gee, 2018; Howard, 2011; Johnson & Markowitz, 2017; Jyoti et al., 2005; Perez-Escamilla & Pinheiro de Toledo Vianna, 2012). Exceptions are studies set in China focusing on maths and language achievements (Hannum, Liu, & Frongillo, 2014) and in Ethiopia on enrolment and grade attainment (Belachew et al., 2011). However, while the literature differs widely in terms of measurement of household food insecurity, educational achievement metrics, periods of skills formation, and methodology, all studies consistently find negative associations between household food insecurity as measured by access scales and child learning.

There are multiple hypothesized mechanisms through which food insecurity at home may be associated with lower learning. First, faced with food insecurity, households may prioritise the purchase of basic foodstuffs as compared to non-food items, and consequently may invest less in educational inputs (e.g. school fees, private tuition, educational materials, uniforms).Second, children from food insecure families may be more likely to work within or outside the household as part of the family's responses to food insecurity, which may lead to increased absenteeism, less time to study, and earlier dropout (Aurino & Morrow, 2015; Belachew et al., 2011).

A further channel is health-related: hunger and morning fasts have adverse effects on cognition, particularly through slower working memory, fatigue and distraction (Pollitt, Cueto, & Jacoby, 1998). Lower dietary quality and variety may also affect cognition via micronutrient deficiencies (Dave, Evans, Saunders, Watkins, & Pfeiffer, 2009). Undernutrition, particularly stunting, has long-term effects on educational outcomes (Maluccio et al., 2009). Hunger and micronutrient deficiencies may impair cognition well before undernutrition is manifest (i.e. stunted growth), highlighting the value added of focusing on household food insecurity rather than exclusively on nutritional outcomes. While the effects of malnutrition on cognition may be more pronounced in the first three years of life, when the brain structure is developing at a faster rate, research has shown that food insecurity in the preschool years (3 to 5 years) may undermine child behaviours and cognitive development in the same way as in the infancy period, thus interfering with a child's readiness to learn (Johnson & Markowitz, 2017).

Fourth, household food insecurity may affect both children and parental psychosocial skills, through increased anxiety, irritability, and shame (Heflin, Siefert, & Williams, 2005; Howard, 2011; Johnson & Markowitz, 2017; Jyoti et al., 2005). Howard (2011) found that in the US, children who transitioned from food insecurity in first grade to food security in third grade had large impairments in non-cognitive skills that persisted through the fifth grade. Decreased child and parental psychosocial skills may in turn affect learning though lower-quality interactions with parents, teachers and peers, and distraught class-room behaviour.

Importantly, there may be variation in the relationship between household food insecurity and learning based on what specific skills are being developed. However, evidence documenting such heterogeneity has been modest at best. The formation of different learning competencies is not fixed across skills, and depends on a child's developmental stage, the organisation of the educational curriculum, and type of school. For instance, early childhood household food insecurity may be particularly detrimental for language development. This is a foundational ability for school readiness and the development of additional cognitive, academic and socio-emotional skills. Usually, language development is formed in early life at home and then is consolidated in the preschool years (3 to 6 years) (Jalongo & Sobolak, 2011). If household food insecurity is associated with lower quality of parent-child interactions and/or with decreased access to quality early education, developmental delays in this domain may have in turn negative implications for the learning of other subjects through less motivation or increased difficulty to learn. By contrast, household food insecurity during mid-childhood or early adolescence may be more predictive of skills that children start to learn only at later stages (e.g. foreign languages).

Adding further complexity, the persistence of household food insecurity constitutes a critical additional issue to consider. While some resilience may be possible in the short-term, long-term resilience to the negative effects of chronic food insecurity may be more elusive (Burke et al., 2017). Not only does long-term food insecurity increase the risk of food insecurity occurring during critical periods for skills formation, but it may also erode the educational foundations that are fundamental for later learning. For example, a child who misses school occasionally due to short-term food insecurity may be able to make-up for missed lessons; a child with a long-term pattern of absenteeism may find it more difficult to catch-up on missed work, which will in

turn make mastery of higher-order skills more difficult and increase the chances of falling behind or dropping-out. This may be particularly salient for maths, for which some degree of catch-up may be more challenging due to the cumulative nature of the curriculum. However, evidence on both the interactions between timing of food insecurity and learning, and on the cumulative effects of chronic food insecurity have been relatively limited so far.

In summary, the relationship between food insecurity and child learning is complex and may vary based on the interaction between timing and persistence of food insecurity, as well as child, household and community level factors such as availability of learning support to children that are lagging behind, as well as accessibility of social protection programmes that tackle poverty and food insecurity.

2.2. Food insecurity in India

The enduring food security challenge in India is a clear policy priority, as evidenced by the 2013 National Food Security Act (Narayanan, 2015). The prioritisation of food security in the policy agenda is reflected in a number of food programmes, such as the Public Distribution Scheme, the Midday-Meal Scheme (the largest school feeding program in the world), and the Mahatma Gandhi National Rural Guarantee Act Scheme. As has been well-documented starting from the pioneering work of Drèze and Sen in the late 1980s, the Indian food security problem does not arise from constrained food supply, but rather to its inequitable distribution, and the lack of an "enabling" environment apt to convert food into adequate nutrition and the capability to be food secure over time (Burchi & De Muro, 2016; Sen & Dreze, 1999). Despite decades of persistent economic growth and increases in food production, sustained access to adequate and diverse food continues to be a challenge for large shares of the Indian population. This "entitlement failure" is partly due to the shrinking of agrarian and informal sector incomes and structural patterns of inequalities, which were recently coupled by inflationary trends in food and non-food prices (Vellakkal et al., 2015). On the other hand, insufficiency of support-led measures (in terms of both policy framing and implementation) to combat the multiple dimensions of poverty (including income, education, water and sanitation, and so on) strengthened these trends leading to persistent malnutrition and food insecurity outcomes.

2.3. The educational landscape

Since the Independence in 1947, Indian education policies have focused primarily on expanding basic education, infrastructures and resources. Today, the country has dramatically increased access, with almost universal gross primary enrolment and about 80% gross secondary enrolment. However, learning levels have not followed these positive trends, with the country being at considerable disadvantage in international learning comparisons, including with other middle-income countries (Kingdon, 2007; R. Singh & Mukherjee, 2017).

Following the 2009 Right to Education Act, education in India is mandatory between ages 6 and 14 years, or up to Grade 8. Recently, there has been a substantial expansion in the enrolment of children in private schooling in Andhra Pradesh (where our study is based), with the risk of marginalising the poorest children to government schools (R. Singh & Mukherjee, 2016). One of the appeals of private schools for Indian parents is the use of English as medium of instruction from preschool, which is considered as a considerable advantage in the labour market. This contrasts with Government schools, which use the local language until about 8 or 9 years of age[2]. The quality of English teaching in the Government schools is variable, as the teachers who provide English instruction are mostly from Non-English disciplinary backgrounds.

A number of policies have been enacted to sustain equitable access and learning outcomes. One that received considerable attention is the national school feeding programme, also known as the Midday-Meal Scheme. The programme provides a free cooked meal to all children in compulsory education in government and aided schools. In Andhra Pradesh[3], coverage is almost universal. A midday-meal is also provided in preschool centres as part of early childhood support. Recent evidence has demonstrated the programme's positive impact on learning (Chakraborty & Jayaraman, 2016) and on mitigating the effects of early shocks on preschool nutritional status (A. Singh, Park, & Dercon, 2014). However, alone, it may not be sufficient to completely protect

[2] Since 2011, English started to be taught as a separate discipline from Grade 1 since 2011. However, this change did not affect our sample, as in 2011 children should have been in Grade 3 or 4.

[3] The State divided into Andhra Pradesh and Telangana in 2014. Together, the two States have a population of85 million people, making it the fourth largest State of India. We will refer to Andhra Pradesh throughout for simplicity, also in the light that the data we used were collected when the two States were still united.

children's education from the negative effects of food insecurity such as being involved in work, lower dietary quality and intakes, or decreased psychosocial well-being.

3. Methods

3.1. Data

We draw on the Andhra Pradesh sample of Young Lives, a multi-country study of childhood poverty (Barnett et al., 2013). The study recruited 2000 children aged ~1. Survey data were subsequently collected in 2006, 2009 and 2013[4]. In round 1, food insecurity data were not collected, therefore we use data from rounds 2, 3 and 4, where children were aged about five, eight and 12 years respectively.

The sampling approach was multistage and "pro-poor". First, 20 sentinel sites through oversampling more disadvantaged areas were selected. Later, 50 households were randomly selected. While the sample is not nationally representative, comparison in key child and household indicators with representative surveys show similar variation (Barnett et al., 2013). At 4.5%, attrition between Rounds 1 and 4 was extremely low for a study of this nature due to exceptional tracking efforts. We present findings from children that were present in all three rounds of the data used here. Comparison of baseline characteristics between households that were successfully tracked and lost-to-follow-up showed that there were no differences in child and household covariates between these two groups, with the exception of a few instances (Appendix 1): specifically, households that were lost to follow-up were more likely to be from other castes and less from backward castes, and had slightly higher wealth. The few covariates that predict attrition, together with the overall low prevalence of attrition rate, attenuates concerns for attrition bias.

3.2. Measurement of household food insecurity

Food insecurity access measures hinge on the notion that the experience of food insecurity is associated with behavioral responses that can be assessed and summarized through a scale (Coates et al., 2007). Responses include: anxiety over the food supply, perceptions that food is of insufficient quantity and quality, reported reductions in food quantity and quality, skipping meals; and, in the most extreme cases, going all day and/or night without food. Experience-based scales differ from other metrics of

4 An additional round of data was collected in 2016 but data are not publicly available.

food insecurity (e.g. anthropometrics or caloric availability) by directly measuring the prevalence and severity of households' failure to access food. In India, different scales have been used in different contexts (for a review, see: (Sethi, Maitra, Avula, Unisa, & Bhalla, 2017)).

In Round 2 (2006) household food security was assessed through an adaptation of the standard US measure (Bickel et al., 2000). In Rounds 3 and 4, the Household Food Insecurity Access Scale (HFIAS) (Coates, Swindale, & Bilinsky, 2007) was instead used. HFIAS is a validated measure of food access in LMICs. For each round, we coded a dichotomous indicator of food insecurity following the approach in Humphries et al (2015). Households were coded as food insecure in Round 2 if they answered yes to any food insecurity question, except eating less-preferred foods. In Rounds 3 and 4, we coded households as food insecure if they were classified as moderately or severely food insecure by the HFIAS.

We then generated a categorical variable aiming to reflect household food security trajectories. This variable assumed the following values: 0 if the child's household has never been food insecure across the three survey rounds; 1 if the household was food insecure when the child was 5 years old but then became food secure at 8 years or 12 years; 2 if the household became food insecure when the child was aged 8 years and remained so until the child was 12 years old; 3 if the household became food insecure when the child was aged 12 years; 4 for any other situation of household food insecurity, which we refer as to "transitory food insecurity"; and 5 if the household was food insecure in all the observations points (chronic household food insecurity). Table 1 summarises the values assumed by the variable based on household food insecurity status at each round.

As a robustness check, we created an alternative measure of household food insecurity restricted to only the common items between the scale used in 2006 and the one used in subsequent rounds. Excluding the question on eating less preferred foods, the common items were: limiting portion size; skip meal and skip eating for a whole day and going to bed hungry. The alternative measure ranges from 0-3; we coded households as food insecure if they responded yes to at least one of these indicators. Starting from this, we constructed the food security trajectories as in the case of our

standard measure (food insecure at age 5, 8, 12, chronic food insecurity, transitory food insecurity, never food insecure).

Table 1. Coding of household food insecurity trajectory variable by survey round

	Whether Household Food Insecure		
	Round 2 (Age 5, 2006)	**Round 3** (Age 8, 2009)	**Round 4** (Age 12, 2013)
Household never food insecure (=0)	No	No	No
Household food insecure when child age 5 (=1)	Yes	No	No
	Yes	Yes	No
Household food insecure when child insecure age 8 (=2)	No	Yes	Yes
Household food insecure when child insecure age 12 (=3)	No	No	Yes
Transitory household food insecurity (=4)	No	Yes	No
	Yes	No	Yes
Chronic household food insecurity (=5)	Yes	Yes	Yes

3.3. Measures of adolescent learning

Adolescent learning at 12 years was assessed through a number of tests, which were designed by education experts and adapted to relate to the formal curriculum of Andhra Pradesh. These included: a version of the Peabody Picture Vocabulary Test (PPVT), a measure of vocabulary development; a reading test in the local language (Telugu); and a maths and English tests. We also employed two measures of cognitive development at 5 years: the PPVT score and a Cognitive Development Assessment (CDA), a measure of children's grasp of basic numeracy concepts. All cognitive scores were collected at home in order to include out-of-school children. They were standardised to have a mean of zero and a standard deviation of one.

3.4. Empirical strategy

There are three potential sources of bias in the estimation of the OLS parameters in the relation between household food insecurity and learning. First, unobserved child and parental heterogeneity may drive "selection" into food insecurity: as these characteristics may be also associated with child learning achievements, endogeneity bias for household food insecurity may be present[5]. Also, potential mis-measurement of test scores may lead to measurement bias in the estimates. We tackle these issues through the adoption of "value-added models of achievement" (Andrabi et al., 2011; Todd & Wolpin, 2003). These models include prior cognitive scores as a summary statistics of the history of household and school inputs for learning, as well as of individual variation in ability (Koedel, Mihaly, & Rockoff, 2015). Although it is arguable that there may be still some degree of unobserved individual heterogeneity and measurement error, estimates from these models have shown to be unbiased when compared with experimental estimates (Angrist, Pathak, & Walters, 2013; A. Singh, 2015). For this reason, value-added models are commonly considered as the most robust approach in face of potential biases stemming from missing data on endowments and educational inputs in observational data.

Second, there may be unobserved characteristics of the local food, health and educational environments (e.g. availability and quality of services, prices) that may be correlated with both a household food security status and with children's learning, potentially leading to omitted variable bias (Howard 2011). We address this concern by relying on a community-fixed effect approach, which sweeps out those characteristics that are common to all children living in the same community.

Finally, if adolescents were tested at school, there may be potential selection biases based on school attendance. This was not a key concern in our case as all learning assessments were conducted at home.

[5] A related issue is the mismeasurement of household food security. Gundersen and Ribar (2011), for instance, reported that a large share of food insecurity is underreported in the US, particularly among households at the lower end of the consumption distribution. This may bias downwards the coefficient related to household food insecurity: when this bias is taken into account, the effect of food security on child outcomes is even larger than previously thought (Gundersen & Kreider, 2009).

Despite our emphasis on addressing potential sources of bias in our identification, causal claims are not tenable. However, we are confident that the combination of value-added estimation with a rich set of child and household covariates should provide robust estimates of the predictive role of household food insecurity dynamics on adolescent learning outcomes.

In econometric terms, the "value-added" model is represented in Equation 1:

$$y_{it,j} = \beta_0 + \beta_1 FI_{it,j} + \beta_2 X_{ij,t} + \beta_3 y_{ij,t-2} + \varphi_j + \varepsilon_{it,j} \qquad (1)$$

Where $y_{it,j}$ relates to the test score for child i at time t living in community j; $X_{ij,t}$ is a vector of child, caregiver and household controls; $y_{ij,t-2}$ is a vector of measures of previous cognitive achievements; φ_j are community characteristics and $\varepsilon_{it,j}$ is the error term. The term $FI_{it,j}$ represents a categorical variable related to household food security trajectories (as described in Section 3.2). The basic vector of controls included: child age in months, gender, caste, child is first born, caregiver's age, caregiver's education, household size, number of boys aged 0-12 years, number of girls aged 0-12 years, number of boys aged 13-17 years, number of girls aged 13-17 years, female head of the household, wealth index, household is urban at Round 4, and three dichotomous dummies related to change of community between rounds.

We then extend the value-added model to obtain Equations 2-4 through the inclusion of three sets of contemporaneous factors that may contribute to explain (alone and in combination) the food insecurity gaps in early adolescent learning outcomes, as per our conceptual framework: (i) investments in adolescent education; (ii) investments in adolescent health: (iii) caregiver and adolescent psychosocial outcomes.

$$\begin{aligned} y_{it,j} = {} & \beta_0 + \beta_1 FI_{it,j} + \beta_2 X_{ij,t} + \beta_3 y_{ij,t-2} + \varphi_j + \varepsilon_{it,j} && (1) \\ & + \beta_4 Educational\ Inputs_{ij,t} && (2) \\ & + \beta_5 Health\ Inputs_{ij,t} && (3) \\ & + \beta_6 Psychosocials_{ij,t} && (4) \end{aligned}$$

Where $Edu\ Inputs_{ij,t}$ includes a dichotomous variable of whether or not the adolescent was enrolled in school and type of school (private/Government)[6]. $Health\ Inputs_{ij,t}$ was summarised by adolescent's height-for-age z-scores (HAZ), a summary measure of all the health investments up to 12 years. $Psychosocials_{ij,t}$ is a vector of caregiver's and adolescent psychosocial skills. These included: a dichotomous variable of whether parents aspired for the adolescent to attain at least a secondary school education (Grade 12); a dichotomous variable of whether the adolescent aspired to attain at least a secondary education; adolescent's self-efficacy and self-esteem scores. Both educational aspirations and psychosocial traits like self-efficacy (a person's belief about one's own ability) and self-esteem (one's own assessment of self-worth) interact with previous cognition in the formation of human capital and influence schooling decisions (Cunha, Heckman, & Schennach, 2010; Dercon & Singh, 2013). Self-esteem and self-efficacy were measured through a set of questions capturing the adolescent degree of agreement/disagreement with statements related to her sense of pride and shame and of agency respectively. Both scores where standardized in order to have mean of 0 and standard deviation of 1 (see Dercon & Sánchez 2013 for details). Descriptive statistics of all controls are presented in Appendix 2.

4. Results

4.1. Descriptive statistics

Household food insecurity was largely a dynamic phenomenon (Figure 1): only 2% of the full sample households were food insecure in all the three rounds of data collection, while only a little over half (53%) were always food secure. The remaining households, about 45% of the sample, were characterized by variation in the timing in which they first became food insecure, as well as in the length of their food insecurity experience. The stratification of household food insecurity trajectories by wealth quartiles (a commonly used indicator of socioeconomic status) pointed to a partial overlap between household food insecurity and wealth, with only 34% of households from the lowest wealth quartile always food secure as compared to 83% of households in the top wealth quartile. Further, while 5% of the households in the lowest quartile

[6] Although the data allowed for the inclusion of additional educational variables such as school attendance, time in school/study or household educational expenditures, we opted for a succinct vector of educational inputs. This was because, although endogeneity may be present across all intermediate outcome considered in the extended models, this problem may be particularly salient in the case of the educational inputs.

were chronically food insecure, virtually no household from the top quartile was food insecure at all rounds. Wealthier households, however, also experienced transitory episodes of food insecurity in some instances.

Figure 1. Household food insecurity trajectories between Round 2 (2006, age 5 years) and Round 4 (2013, age 12 years), overall and by wealth quartile in 2013

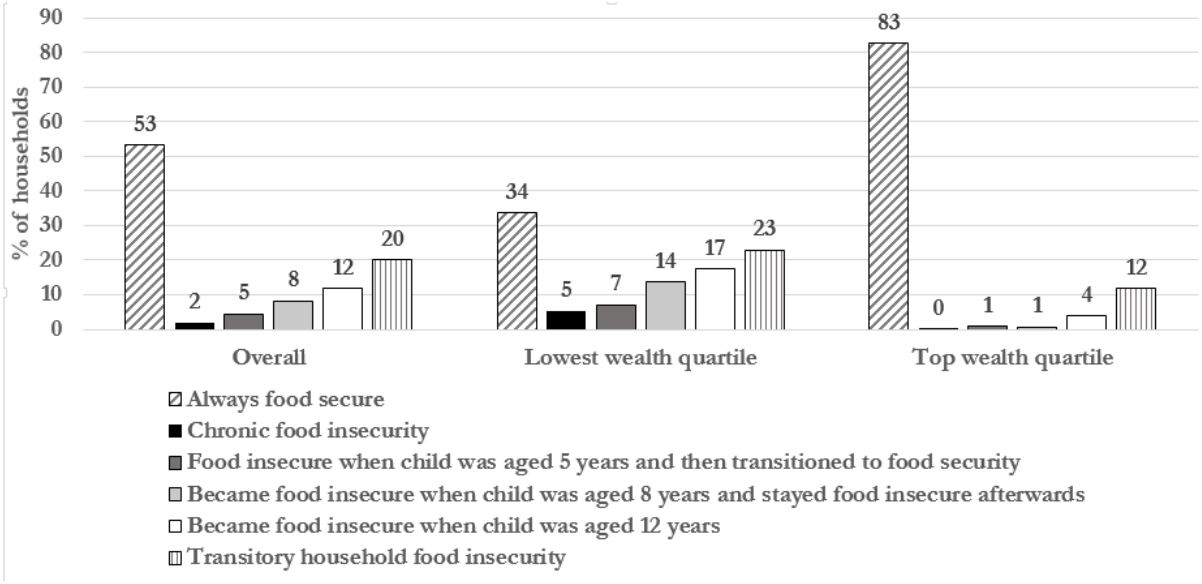
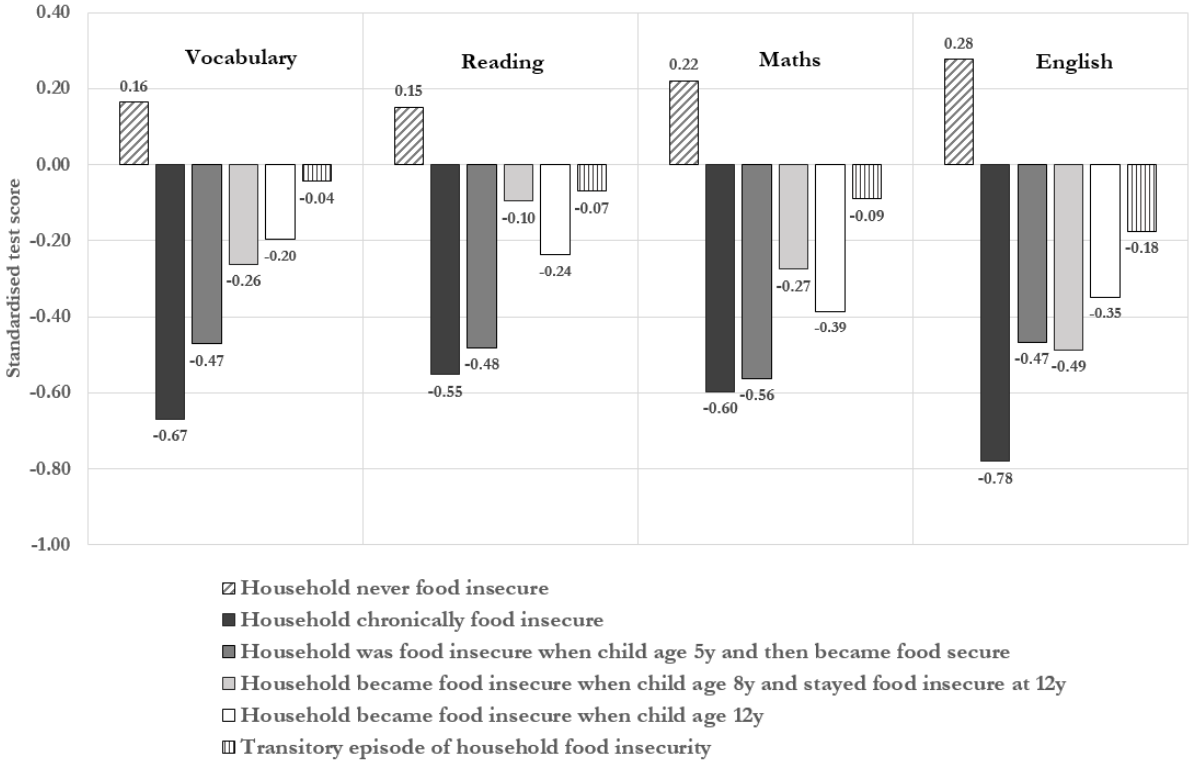


Figure 2 provides the standardized learning scores for adolescents at age 12 based on their households' food insecurity trajectories across the four tests. Children in households that were never food insecure perform approximately 0.2 standard deviations above the sample mean across all metrics. Children experiencing transitory household food insecurity were near the mean on PPVT and reading scores, though somewhat further below the mean on maths and English. The descriptive data suggest a general gradient in educational achievement by household food insecurity trajectories, with adolescents who experienced chronic food insecurity being most disadvantaged, and that the earlier the experience of food insecurity at home, the lower an adolescent's standardized test scores.

There were a few exceptions to this overall trend: adolescents living in food insecure households at 12 years performed worse on reading and maths compared to adolescents who became food insecure at age 8. Moreover, adolescents who became food insecure at age 8 scored roughly equivalently to those who were food insecure at age 5 in English. This may be linked both to critical learning periods for subject-specific skills, and to the timing of curriculum. For instance, at the time the survey was conducted, the teaching of

English generally started around Grade 4 (at around age 8/9 years) in Government schools, making mid-childhood episodes of food insecurity more salient for achievements in this domain.

Figure 2. Adolescent learning achievements at 12 years by household food insecurity trajectories



Notes: This figure presents mean standardized test scores at 12 years old in different skills by household food insecurity trajectories. Each test score was standardized to have mean equal to 0 and standard deviation 1.

4.2. Main results

Table 2 presents estimated coefficients from household food insecurity trajectories. Results of the full estimates are reported in Appendix 3. We focus on four key findings. First, transitioning from a situation of household food insecurity during early childhood (at age 5) to later food security consistently predicted lower vocabulary, reading, and maths test scores. Results for English scores were negative, but non-significant.

Second, starting from a situation of household food security at 5 years and becoming food insecure at home in mid- to late-childhood—that is, at age 8 or 12 years

—was not significantly associated with performance on vocabulary and reading tests compared to children who were always food secure. There was, however, a significant, strong, and negative association between becoming food insecure at age 8 and both maths and English scores. The pattern for children who became food insecure at age 12 was quite similar, with significant, negative associations between food insecurity and both maths and English scores. Similarly, transitory household food insecurity was significantly, negatively associated with maths and English scores. However, neither mid- to late-childhood nor transitory food insecurity were significantly associated with vocabulary nor reading scores.

A third pattern was observable for children who experienced household food insecurity at all ages: although these were only 2% of the sample, the negative association between chronic household food insecurity and both PPVT and English scores was strong and significant. Albeit negative, there was no significant association with reading and maths scores, perhaps due to limited statistical power arising from few households being food insecure at all rounds. These were the highest magnitude coefficients across categories of food insecurity for the respective academic performance tests. Nevertheless, comparing coefficients across categories of food insecurity, the direction and magnitude of the coefficients for reading and maths for children experiencing chronic food insecurity were roughly on par with those for children who were food insecure at age 5 and then transitioned to food security. This is logically consistent with expectations, as children in the chronically food insecure category experienced early life food insecurity as well, but also continued to do so through all observed time points.

Among the other predictors, as expected, cognitive outcomes at age 5 predicted between 0.1 and 0.2 of a standard deviation across all scores. Notably, however, many coefficients related to household food insecurity were often stronger predictors of adolescent learning than early cognition measures. Appendix 3 shows that boys had an advantage in receptive vocabulary, perhaps indicating some pro-boy biases in early education investments, while being a girl was predictive of higher reading scores. Children that were firstborn had consistently higher achievement domains, which may be driven by the higher parental investments in first-borns (Jayachandran & Pande, 2017). Consistent with previous evidence on the intergenerational transmission of poverty and inequalities in human capital (Behrman et al., 2017), maternal education

and household wealth were also positively related with better learning outcomes. The number of older adolescent boys (13-17 years) in the household and the number of younger girls was negatively predictive of English test scores, perhaps indicating competition for resources, particularly around enrolment in private schools or private English tuition.

Table 2. Household food insecurity trajectories and child learning, "value-added" OLS estimates with community-fixed effects

	(1)	(2)	(3)	(4)
	Vocabulary	**Reading**	**Maths**	**English**
Household food insecure when child was aged 5 years and then became food secure	-0.225**	-0.252**	-0.332**	-0.147
	(0.089)	(0.111)	(0.118)	(0.122)
Household became food insecure when child was aged 8 years	-0.126	0.006	-0.198**	-0.274**
	(0.100)	(0.075)	(0.076)	(0.102)
Household became food insecure when child was aged 12years	-0.075	-0.108	-0.319***	-0.160**
	(0.100)	(0.091)	(0.069)	(0.064)
Transitory household food insecurity	-0.038	-0.078	-0.133**	-0.157***
	(0.053)	(0.065)	(0.054)	(0.052)
Chronic food insecurity	-0.343*	-0.214	-0.289	-0.406**
	(0.170)	(0.209)	(0.176)	(0.150)
Lagged PPVT score	0.118***	0.131***	0.134***	0.119***
	(0.035)	(0.027)	(0.031)	(0.021)
Lagged CDA score	0.205***	0.199***	0.187***	0.122***
	(0.029)	(0.027)	(0.025)	(0.028)
Constant	-0.011	0.439	0.680	0.023
	(0.850)	(1.003)	(0.774)	(0.763)
Observations	1,773	1,730	1,733	1,739
R-squared	0.179	0.180	0.241	0.272

***** p<0.01, ** p<0.05, * p<0.1**

Notes: Errors clustered at the community level in parentheses. All the models control for: child age in months, gender, caste, child is first born; caregiver's age and education (in years of completed schooling); household size, number of boys aged 0-12 years (excluding the index child), number of girls aged 0-12 years (excluding the index child), number of boys aged 13-17 years (excluding the index child), number of girls aged 13-17 years (excluding the index child), wealth index, head of the household is female, household is urban; three dichotomous variables for whether the household has changed community between rounds 1 and 2; at round 3 and at round 4.

4.3. Extended models

This section presents extended models that include potential explanations for the food insecurity gap in adolescent learning achievements, where the value-added model was augmented by (alone and in combination): (i) educational inputs; (ii) health inputs; (iii) and psychosocial skills. As discussed in Section 2.1, these factors may vary between children based on the timing and duration of household food insecurity. Accordingly, once these potential explanations are included, the food insecurity gaps in learning may diminish substantially or disappear altogether.

Table 3 presents differences in means of these variables by household food insecurity trajectory. Consistent with the descriptive patterns on learning, adolescents who were never food insecure tended to fare better across all intermediate outcomes. Within adolescents that had ever experienced food insecurity, those who experienced later or transitory food insecurity tended to have better outcomes in all dimensions than adolescents who were in food insecure households at age 5 or in chronically food insecure households. Moreover, the later food insecurity occurred, the better the intermediate outcomes tended to be. There were two exceptions to this general trend: on the one hand, children who became food insecure at age 8 had the lowest enrolment in private school (13%) across categories of food insecurity, with even lower enrolment than children whose household was food insecure at age 5 or children living in chronically food insecure households. There was also a large, clear gap between children who became food insecure at age 8 versus age 12 for some outcomes, highlighting the vital role of the timing of food insecurity across these intermediate outcomes. Specifically, for children who became food insecure at age 8, the proportion enrolled in private school and their caregiver's aspirations for their educational attainment were closer to that of children who became food insecure at age 5 than for those children whose household became food insecure at age 12.

On the other hand, while children's self-efficacy scores were below the sample mean for this group, their self-esteem scores were actually well above the mean. In fact, children who were food insecure at age 5 had the highest self-esteem scores across all the remaining categories of food insecurity. A strikingly similar pattern can be observed for children experiencing chronic food insecurity, with both their self-efficacy and self-esteem scores being slightly above the mean. We hypothesize that this finding had to do with the relative impacts of food insecurity, both over time and within our

communities. It is possible that children who were food insecure from a very young age, and those who regularly experienced food insecurity, experienced food insecurity as a state of normalcy. So, to the extent that food insecurity is associated negatively with correlates of self-esteem such as formation of friendships, experiences of bullying, and so forth, it may be more detrimental to *lose* friends or begin experiencing bullying in mid-childhood and early adolescence than to experience this as the norm from the outset. This would explain why we observe lower self-esteem scores when children transition into food insecurity later in childhood, but we observe the inverse for early and chronic food insecurity.

Table 3. Difference in means of intermediate outcomes at 12 years old by household food insecurity trajectories

	% Enrolled	% Enrolled in private school	Height-for-age z-scores	% Parents would like adolescent to	% adolescents that would	Child self-efficacy z-scores	Child self-esteem z-scores
Household never food insecure	99	55	-1.29	92	93	0.07	0.07
Food insecure when child was aged 5 years	93	17	-1.88	71	76	-0.18	0.12
Became food insecure when child was aged 8 years	96	13	-1.52	72	78	-0.07	-0.19
Became food insecure when child was aged 12years	97	26	-1.61	80	83	-0.09	-0.12
Any other food insecurity	95	25	-1.55	84	87	-0.05	-0.06
Chronic food insecurity	92	18	-1.94	68	68	0.03	0.03
Overall	97	40	-1.44	86	88	0	0
Probability Pearson Chi Squared	0	0	0.998	0	0	0.001	0.055

Table 4 presents the results for the value-added models with the additional covariates. These were included gradually in order to investigate whether individually (columns 2-4) or jointly (column 5) they could explain household food insecurity gaps. Estimates reporting the coefficients for the additional covariates are included in Appendix 4. An F-test of joint significance in the full covariates specification rejected the hypothesis that the estimated coefficients were jointly equal to 0.

The inclusion of these potential explanations was able to explain about a third of the variation in the early childhood household food insecurity associations for vocabulary, reading and maths and between chronic food insecurity and vocabulary and English. However, the inclusion of potential sources of disparities in adolescent learning outcomes by household food insecurity dynamics did not affect the main results presented in Table 2.

Further, given the relatively low sample sizes in both the early childhood and chronic food insecurity groups, it is quite remarkable that after the introduction of these additional controls, disparities in adolescent learning by household food insecurity remained significant and strong in most specifications. In the full model specification for vocabulary and maths, the coefficients related to early childhood food insecurity were about three times the size of the coefficients related to HAZ, and about twice as large as the estimates for lagged vocabulary scores (see Appendix 4). In the case of chronic food insecurity, coefficients for vocabulary and English were about the same size as parental aspirations for child education, which has been previously documented as a key driver of learning achievements in India and elsewhere (Dercon & Singh, 2013a). For maths, contemporaneous household food insecurity shocks negatively explained about a quarter of a standard deviation in test scores in the most conservative specification with all the factors jointly included (col. 5). Educational investments appeared to account for a large variation in the relation between household food insecurity and English achievements[7].

[7] We tested further the robustness of the model related to the private schooling with interactions testing the relation between wealth terciles and private enrolment – as wealthier children are more likely to enroll in those schools. However, we did not find substantial differences in our findings and the interactions were never significant (results available upon request).

Table 4. Decomposition of the household food insecurity gaps in adolescent learning by educational investments, health investments, and caregiver and adolescent psychosocial outcomes, OLS estimates with community fixed effects

		(1) Basic model	(2) Educational investments [a]	(3) Health investment	(4) Psychos ocials	(5) All
Vocabulary	Household food insecure when child was aged 5 years and then became food secure	-0.225**	-0.185*	-0.213**	-0.187**	-0.164**
		(0.089)	(0.095)	(0.088)	(0.075)	(0.076)
	Household became food insecure when child was aged 8 years and then stayed food insecure	-0.126	-0.096	-0.136	-0.067	-0.073
		(0.100)	(0.101)	(0.101)	(0.079)	(0.080)
	Household became food insecure when child was aged 12years	-0.075	-0.060	-0.068	-0.050	-0.041
		(0.100)	(0.100)	(0.100)	(0.105)	(0.105)
	Transitory household food insecurity	-0.038	-0.012	-0.032	-0.028	-0.012
		(0.053)	(0.055)	(0.053)	(0.046)	(0.048)
	Chronic household food insecurity	-0.343*	-0.327*	-0.328*	-0.285*	-0.269*
		(0.170)	(0.158)	(0.170)	(0.149)	(0.147)
	Observations	1,773	1,773	1,767	1,736	1,731
	R-squared	0.179	0.195	0.184	0.229	0.234
Reading	Household food insecure when child was aged 5 years and then became food secure	-0.252**	-0.206*	-0.241**	-0.181*	-0.162
		(0.111)	(0.114)	(0.109)	(0.094)	(0.096)
	Household became food insecure when child was aged 8 years and then stayed food insecure	0.006	0.022	-0.007	0.073	0.060
		(0.075)	(0.079)	(0.078)	(0.078)	(0.082)
	Household became food insecure when child was aged 12years	-0.108	-0.105	-0.106	-0.093	-0.091
		(0.091)	(0.092)	(0.091)	(0.093)	(0.096)
	Transitory household food insecurity	-0.078	-0.066	-0.077	-0.068	-0.063
		(0.065)	(0.067)	(0.065)	(0.066)	(0.067)
	Chronic household food insecurity	-0.214	-0.210	-0.198	-0.174	-0.160
		(0.209)	(0.197)	(0.207)	(0.187)	(0.188)
	Observations	1,730	1,730	1,725	1,697	1,692
	R-squared	0.180	0.196	0.188	0.245	0.252
M	Household food insecure when child	-0.332**	-0.267*	-0.316**	-0.272**	-0.221*
		(0.118)	(0.131)	(0.118)	(0.104)	(0.116)

	was aged 5 years and then became food secure					
	Household became food insecure when child was aged 8 years and then stayed food insecure	-0.198**	-0.160*	-0.200**	-0.140*	-0.123
		(0.076)	(0.081)	(0.077)	(0.076)	(0.077)
	Household became food insecure when child was aged 12years	-0.319***	-0.287***	-0.305***	-0.297***	-0.273***
		(0.069)	(0.071)	(0.067)	(0.073)	(0.075)
	Transitory household food insecurity	-0.133**	-0.097*	-0.126**	-0.126**	-0.093*
		(0.054)	(0.051)	(0.052)	(0.050)	(0.046)
	Chronic household food insecurity	-0.289	-0.268	-0.268	-0.269*	-0.240
		(0.176)	(0.162)	(0.177)	(0.155)	(0.156)
	Observations	1,733	1,733	1,727	1,701	1,696
	R-squared	0.241	0.258	0.247	0.282	0.296
English	Household food insecure when child was aged 5 years and then became food secure	-0.147	-0.032	-0.123	-0.081	0.017
		(0.122)	(0.121)	(0.118)	(0.123)	(0.117)
	Household became food insecure when child was aged 8 years and then stayed food insecure	-0.274**	-0.189*	-0.274**	-0.202**	-0.152
		(0.102)	(0.100)	(0.106)	(0.095)	(0.097)
	Household became food insecure when child was aged 12years	-0.160**	-0.103	-0.140**	-0.116*	-0.067
		(0.064)	(0.070)	(0.063)	(0.066)	(0.071)
	Transitory household food insecurity	-0.157***	-0.099**	-0.144***	-0.147***	-0.085**
		(0.052)	(0.047)	(0.049)	(0.047)	(0.040)
	Chronic household food insecurity	-0.406**	-0.373**	-0.379**	-0.369**	-0.327*
		(0.150)	(0.163)	(0.148)	(0.163)	(0.172)
	Observations	1,739	1,739	1,733	1,706	1,701
	R-squared	0.272	0.325	0.281	0.322	0.364

***** p<0.01, ** p<0.05, * p<0.1**

Notes: Errors clustered at the community level in parentheses. All the models control for: child age in months, gender, caste, child is first born; caregiver's age and education (in years of completed schooling); household size, number of boys aged 0-12 years (excluding the index child), number of girls aged 0-12 years (excluding the index child), number of boys aged 13-17 years (excluding the index child), number of girls aged 13-17 years (excluding the index child), wealth index, head of the household is female, household is urban; age 5 PPVT score; age 5 CDA score; three dichotomous variables for whether the household has changed community between rounds 1 and 2; at round 3 and at round 4.

[a] Child currently enrolled; private school; [b] HAZ at 12 years; [c] *Caregiver aspires for adolescent to finish Grade 12; adolescent aspires to finish Grade 12; adolescent self-efficacy and self-esteem;* [d] *This model includes a+b+c.*

4.4. Robustness checks

We also ran a series of robustness checks. First, we investigated the extent to which our results were driven by the noted change in the household food insecurity measure between Rounds 2 (age 5) and 3 (age 8) (see Section 3.2). So far, following our conceptual framework, we have attributed the differential associations between learning outcomes and food insecurity at age 5 compared to ages 8 and 12 to the particularly sensitive period of early childhood in the formation of skills like vocabulary, reading and maths. However, it may be possible that our findings are in fact only an artefact of the change in food insecurity metrics between early- and mid-childhood.

We checked for this possibility by relying on a new measure of household food insecurity based only on items that are common across rounds (see Section 3.2). Appendix 5 presents results from the value-added models using the "standard measure", which we used so far in the analyses, and the "robustness measure". There were a few minor differences between the measures, to be expected, but in general the direction, strength, and significance of the coefficients were similar across specifications, and larger differences seemed primarily to result from smaller cell sizes in some categories. For example, for transitory (any other) food insecurity, the relationship between food insecurity and vocabulary scores was stronger for the robustness versus the standard measure, but the standard measure was statistically significant while the robustness measure was not. Also, early childhood food insecurity was significant for English using the robustness measure, whereas it had not been significant using the standard measure. On the whole, however, these results provide evidence that the timing effects we have identified above in terms of early versus later childhood food insecurity were not the result of changes in the food insecurity measure over time.

Another limitation related to the lack of assessment of household food insecurity in 2002, when the adolescent would have been aged about one year. Household food insecurity is a key driver of illness and malnutrition in infancy, which may lead to impaired cognition later in life. Although we believe the lifecourse effects of early health investments should already be captured by age-5 cognitive achievements, we ran an additional model including infancy HAZ (HAZ1) and weight-for-height z-scores (BAZ1). HAZ1 provides a synthetic measure of chronic food insecurity the adolescent

may have faced *in utero* and in the first year, while BAZ1 assesses concurrent nutritional status, which is likely to be directly influenced by sudden shocks in household food security. Results are presented in Appendix 6. Consistent with the literature (e.g. (Schott, Crookston, Lundeen, Stein, & Behrman, 2013)) HAZ1 scores were predictive of between 0.02-0.07 standard deviations across all domains, and BAZ1 scores were predictive of about 0.05 of a standard deviation in vocabulary scores, indicating the early-life origins of vocabulary development. However, the inclusion of indicators of early nutrition in the value-added model did not change our main results, suggesting that household food insecurity at later stages of the lifecourse acts as a strong and independent channel on adolescent learning, over and above early-life food insecurity.

5. Discussion and Conclusions

This paper examined adolescent learning disparities by household food insecurity trajectories during early childhood, mid-childhood and adolescence. Even in the most conservative "value-added" estimates, household food insecurity was a significant predictor of lower learning achievements. Consistent with our expectations, we found considerable heterogeneity based on the interaction between timing and persistency of food insecurity, and different learning domains. Early childhood and chronic household food insecurity were the most consistent predictor of impaired cognitive skills at 12 years, but with a larger effect on vocabulary development and reading. The magnitude of the coefficient related to transitions from household food insecurity at age 5 to later food security was much larger than the one related to concurrent food insecurity, suggesting that early-childhood experiences of food insecurity have mid-term associations with learning. Strikingly, the same pattern was documented in a previous study focusing on food insecurity transitions among US fifth-graders (Howard 2010). Food insecurity in mid-childhood and early adolescence were also predictive of impaired maths and English scores. The inclusion of additional variables related to education, health and psychosocial skills was able to explain part of the variation in achievement scores, but household food insecurity remained an important predictor.

Consistent with our initial hypotheses, children in households experiencing only a transitory episode of food insecurity exhibited a lower degree of disadvantage in terms of vocabulary and reading as compared to peers that experienced longer spells

of food insecurity. This, however, was not the case for maths and English. We interpret this result as arising from differences in sensitive periods of skills formation across the learning domains considered. Once a child has some foundational vocabulary and literacy skills, a certain amount of catching up may be possible in terms in these domains, and children may be resilient to temporary food insecurity shocks. However, resilience may be more difficult for skills such as maths. In this case, learning at one level is directly built on the previous level and it may be more difficult to fill basic gaps while the school curriculum moves forward, increasing the risk for the child to be left behind. By the same token, mid-childhood and early adolescence food insecurity at home may be comparatively more detrimental for English, as households may decrease the educational inputs invested in the adolescent, and with those enrolment in private schools or after-school tuition.

Compared to most previous literature, a considerable advantage of our identification strategy relates to the use of value-added models: across all the domains of learning, the lagged vocabulary and CDA scores were strong and significant predictors of adolescent achievements, which highlights the importance of early investments for learning trajectories. Lagged cognitive scores did not only capture underlying variation in ability, but also the cumulative lifetime effects of exposures to adverse conditions, particularly during critical periods such as maternal nutrition during pregnancy, adherence to best practices for infant and young child feeding, early life undernutrition and education investments, and a range of other household and community influences that affect children's early life cognition and development. As these factors are key drivers of later-life learning disparities (Cunha, Heckman, & Schennach, 2010; Heckman & Mosso, 2014), their inclusion in the econometric models strengthen the robustness of the findings related to household food security as a source of divergence in adolescent learning.

This study has some limitations: first, food security was measured at the household level rather than at the child level. This may result in failure to capture intra-household effects, based, for instance, on gender and age (Aurino, 2016). Secondly, in contrast to Howard (2010), we did not consider the intensity of the household food insecurity experience, as the change in the scales renders this particularly problematic. Also, issues related to quantity and quality of food access were not directly included. Future study may consider these nutritional aspects, and

also incorporate coping strategies (e.g. as substitution of more expensive/nutritious food with cheaper food to ensure the necessary caloric intakes), and their effect on educational attainments. Finally, we did not directly address the role of social protection programmes such as the public distribution system and the midday-meal scheme; this important question will require ad-hoc future studies that include evaluation methods.

Importantly, the fact that household food insecurity dynamics were a strong predictor of achievements, controlling for early-childhood cognition and key sources of learning inequalities (e.g. gender, caste, wealth, etc.), suggests an independent role for household food insecurity in the formation of adolescent learning disparities. Also, these results highlighted the importance of considering not only whether or not children have ever experienced food insecurity at home, but also when, for how long, and in relation to which specific skills. These considerations have important implications for the design, targeting, and delivery of interventions directed at children from food insecure households at critical life stages both at home and at school. From an educational perspective, these results may contribute to inform educational programmes targeting children at higher risk of food insecurity (e.g. tribal areas, urban slums, remote areas) and providing them with extra educational support. Also, the focus of those programmes may be tailored based on the period on which each specific skill may be more likely to be impaired from household food insecurity episodes. This could be achieved through programmes focusing on foundational skills such as vocabulary in the preschool and early primary school years (Jalongo & Sobolak, 2011) and/or through remedial education through primary in basic literacy and numeracy skills (Banerjee, Cole, Duflo, & Linden, 2007).

On the other hand, our findings can be used by policy-makers working in food programmes and other social protection to devise potential ways in which those schemes can enhance their "educational-sensitiveness". For instance, based on the robust and detrimental associations between household food insecurity at age 5 and adolescent outcomes, there may be scope for strengthening food-for-education preschool programmes (e.g. by including breakfast or take-home rations in areas where food insecurity is particularly widespread, such as in remote tribal communities); to improve the nutritional content of the food received through the public distribution systems for households with preschoolers; and to strengthen the overall quality of early

education. Also, if the potential educational spillovers of such programmes are taken into account, the potential benefits of social protection spending could be larger than previously estimated.

Taken together, our results demonstrated that household food insecurity poses a considerable risk for adolescent learning, and highlighted the importance of considering the timing and chronicity of food insecurity to understand this association from a lifecourse perspective. As articulated in the Sustainable Development Agenda, investment in children and adolescents' education is a vital component of achieving equitable, sustainable development. Our findings suggest that a tailored approach to mitigating the effects of household food insecurity, with particular attention to the timing and chronicity of the experience of food insecurity, may be critically important for improving adolescent learning outcomes in India.

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Appendix tables

Table 1. Differences in baseline characteristics between children lost to follow-up and those belonging to the panel

	Lost to follow up (N=100)	**Panel (N=1,911)**	**Difference**
Child's age - in months	12.29	12.32	-0.03
Child is male	0.55	0.54	0.01
Scheduled caste	0.19	0.18	0.01
Scheduled tribe	0.10	0.15	-0.05
Backwards caste	0.34	0.47	-0.13**
Other caste	0.37	0.20	0.17***
Height-for-age z-score	-1.33	-1.27	-0.07
Weight-for-length z-score	-1.18	-1.12	-0.05
Wealth index	0.46	0.41	0.06**
Antenatal visits	0.90	0.88	0.02
Head of the household is male	0.92	0.92	0.00
Household size	5.12	5.44	-0.32
Number of females aged 0-5	0.12	0.16	-0.04
Number of females aged 6-12	0.24	0.27	-0.03
Number of females aged 13-17	0.09	0.11	-0.02
Number of males aged 0-5	0.16	0.14	0.02
Number of males aged 6-12	0.28	0.22	0.06
Number of males aged 13-17	0.13	0.10	0.03
Mother's level of education	3.59	3.07	0.52
Father's level of education	4.55	4.59	-0.04

****** p<0.01, ** p<0.05, * p<0.1***

Table 2. Descriptive statistics of all controls

	Obs	Mean	Std. Dev.	Min	Max
Child age in months	1,906	143.8	3.8	134	154
Child is male	1,911	0.5	0.5	0	1
Scheduled caste	1,911	0.2	0.4	0	1
Scheduled tribe	1,911	0.1	0.4	0	1
Backward caste	1,911	0.5	0.5	0	1
Other caste	1,911	0.2	0.4	0	1
First child	1,911	0.4	0.5	0	1
Caregiver's age	1,911	35.3	6.2	8	81
Caregiver's education	1,907	3.5	4.4	0	14
Household size	1,911	4.9	1.8	1	25
Number of males aged 0-12 years in the household (excluding the index adolescent)	1,911	0.4	0.6	0	4
Number of females aged 0-12 years in the household (excluding the index adolescent)	1,911	0.4	0.7	0	7
Number of males aged 13-17 years in the household (excluding the index adolescent)	1,911	0.3	0.5	0	4
Number of females aged 13-17 years in the household (excluding the index adolescent)	1,911	0.4	0.6	0	4
Child changed community before age 5 years	1,911	0.0	0.2	0	1
Child changed community between 5 and 8 years	1,911	0.0	0.2	0	1
Child changed community between 8 and 12 years	1,911	0.1	0.3	0	1
Head of the household is female	1,911	0.0	0.1	0	1
Household is urban	1,878	0.3	0.4	0	1
Wealth index	1,911	0.6	0.2	0.1	0.9
PPVT in early childhood (age 5 years)	1,816	0.0	1.0	-1.2	4.3
Cognitive Development Assessment in early childhood (age 5 years)	1,890	0.0	1.0	-3.6	1.8
Adolescent is enrolled in school	1,908	1.0	0.2	0	1
Private school	1,911	0.4	0.5	0	1
Height for age z-scores at 12 years	1,900	-1.4	1.0	-4.96	2.61
Caregiver aspires adolescent to finish secondary school	1,877	0.9	0.3	0	1
Child aspires to finish secondary education	1,886	0.9	0.3	0	1
Self-efficacy z-scores	1,911	0.0	1.0	-6.1	3.0
Self-esteem z-scores	1,911	0.0	1.0	-5.0	2.3

Notes: if not indicated otherwise, variables are measured at Round 4(2013) when adolescent was aged about 12 years

Appendix 3. Basic model, full results

	Vocabulary	**Reading**	**Maths**	**English**
Household food insecure when child was aged 5 years	-0.225**	-0.252**	-0.332**	-0.147
	(0.089)	(0.111)	(0.118)	(0.122)
Household became food insecure when child was aged 8 years	-0.126	0.006	-0.198**	-0.274**
	(0.100)	(0.075)	(0.076)	(0.102)
Household became food insecure when child was aged 12years	-0.075	-0.108	-0.319***	-0.160**
	(0.100)	(0.091)	(0.069)	(0.064)
Transitory household food insecurity	-0.038	-0.078	-0.133**	-0.157***
	(0.053)	(0.065)	(0.054)	(0.052)
Chronic household food insecurity	-0.343*	-0.214	-0.289	-0.406**
	(0.170)	(0.209)	(0.176)	(0.150)
Age in months	-0.003	-0.005	-0.009	-0.007
	(0.005)	(0.006)	(0.005)	(0.005)
Male	0.090*	-0.086**	-0.004	0.019
	(0.048)	(0.035)	(0.044)	(0.052)
Scheduled caste	0.217	-0.020	-0.044	0.001
	(0.156)	(0.089)	(0.093)	(0.080)
Scheduled tribe	0.046	-0.019	-0.043	-0.022
	(0.184)	(0.086)	(0.122)	(0.084)
Backward caste	0.145	-0.020	0.018	-0.027
	(0.159)	(0.079)	(0.076)	(0.052)
First child	0.079	0.114	0.108*	0.146*
	(0.056)	(0.068)	(0.056)	(0.072)
Caregiver's age	-0.003	-0.004	0.000	0.001
	(0.004)	(0.003)	(0.003)	(0.004)
Mother's years of education	0.023***	0.037***	0.049***	0.044***
	(0.006)	(0.006)	(0.007)	(0.006)
Household size	-0.040*	-0.007	0.018	0.017
	(0.021)	(0.014)	(0.011)	(0.016)
Number of males aged 0-12 years	-0.030	-0.045	-0.054	-0.026
	(0.041)	(0.044)	(0.032)	(0.052)
Number of females aged 0-12 years	0.010	-0.002	-0.022	-0.072**
	(0.035)	(0.028)	(0.028)	(0.029)
Number of males aged 13-17 years	-0.019	-0.047	-0.070	-0.092**
	(0.053)	(0.070)	(0.043)	(0.040)
Number of females aged 13-17 years	0.032	0.017	0.049	-0.013
	(0.036)	(0.034)	(0.034)	(0.042)

Household head is female	0.178	-0.154	-0.052	-0.244
	(0.189)	(0.157)	(0.182)	(0.208)
Urban	-0.164	-0.075	-0.109	0.234***
	(0.099)	(0.083)	(0.090)	(0.070)
Wealth index	0.911***	0.631***	0.693***	1.270***
	(0.246)	(0.176)	(0.177)	(0.171)
Child changed sentinel site between R1 and R2	-0.008	0.037	0.054	0.152
	(0.159)	(0.131)	(0.126)	(0.101)
Child changed sentinel site between at R3	0.203	-0.063	0.090	0.168*
	(0.140)	(0.110)	(0.107)	(0.090)
Child changed sentinel site between at R4	0.092	0.076	0.115	0.014
	(0.093)	(0.081)	(0.081)	(0.056)
Lagged PPVT score	0.118***	0.131***	0.134***	0.119***
	(0.035)	(0.027)	(0.031)	(0.021)
Lagged CDA score	0.205***	0.199***	0.187***	0.122***
	(0.029)	(0.027)	(0.025)	(0.028)
Constant	-0.011	0.439	0.680	0.023
	(0.850)	(1.003)	(0.774)	(0.763)
Observations	1,773	1,730	1,733	1,739
R-squared	0.179	0.180	0.241	0.272

****** p<0.01, ** p<0.05, * p<0.1***

Notes: OLS estimates with community fixed effects. Errors clustered at the community level in parentheses.

Appendix 4. Extended model results (all explanations)

	Vocabulary	Reading	Maths	English
Food insecure when child was aged 5 years and then became food secure	-0.164**	-0.162	-0.221*	0.017
	(0.076)	(0.096)	(0.116)	(0.117)
Became food insecure when child was aged 8 years and then stayed food insecure	-0.073	0.060	-0.123	-0.152
	(0.080)	(0.082)	(0.077)	(0.097)
Became food insecure when child was aged 12years	-0.041	-0.091	-0.273***	-0.067
	(0.105)	(0.096)	(0.075)	(0.071)
Any other food insecurity	-0.012	-0.063	-0.093*	-0.085**
	(0.048)	(0.067)	(0.046)	(0.040)
Chronic food insecurity	-0.269*	-0.160	-0.240	-0.327*
	(0.147)	(0.188)	(0.156)	(0.172)
Lagged Vocabulary score	0.081**	0.101***	0.107***	0.084***
	(0.034)	(0.026)	(0.029)	(0.023)
Lagged CDA score	0.175***	0.167***	0.153***	0.078**
	(0.029)	(0.026)	(0.026)	(0.030)
Parent would like child to complete at least Grade 12	0.294***	0.195***	0.196***	0.250***
	(0.084)	(0.059)	(0.054)	(0.062)
Child would like to at least graduate from college	0.451***	0.571***	0.382***	0.409***
	(0.073)	(0.109)	(0.056)	(0.112)
Self-efficacy	0.042	0.138***	0.110***	0.093**
	(0.039)	(0.031)	(0.024)	(0.036)
Self-esteem	-0.025	-0.064**	-0.065**	-0.040
	(0.031)	(0.023)	(0.025)	(0.024)
Enrolled	0.175	0.207	0.296**	0.433**
	(0.139)	(0.212)	(0.123)	(0.180)

Private school	0.061	0.017	0.213***	0.432***
	(0.055)	(0.037)	(0.058)	(0.068)
Height-for-Age z-scores	0.066**	0.076***	0.080***	0.097***
	(0.026)	(0.024)	(0.022)	(0.023)
Constant	-1.106	-0.837	-0.521	-1.810**
	(0.749)	(1.026)	(0.837)	(0.826)
Observations	1,731	1,692	1,696	1,701
R-squared	0.234	0.252	0.296	0.364

****** p<0.01, ** p<0.05, * p<0.1***

Notes: OLS estimates with community fixed effects. Errors clustered at the community level in parentheses. All the models control for: child age in months, gender, caste, child is first born; caregiver's age and education (in years of completed schooling); household size, number of boys aged 0-12 years (excluding the index child), number of girls aged 0-12 years (excluding the index child), number of boys aged 13-17 years (excluding the index child), number of girls aged 13-17 years (excluding the index child), wealth index, head of the household is female, household is urban; three dichotomous variables for whether the household has changed community between rounds 1 and 2; at round 3 and at round 4.

Appendix 5. Robustness check: Comparison of results based on alternative food insecurity measure

	Vocabulary		Reading		Maths		English	
	Standard measure	**Robustness measure**	**Standard measure**	**Robustness measure**	**Standard measure**	**Robustness measure**	**Standard measure**	**Robustness measure**
	-0.225**	-0.216**	-0.252**	-0.273***	-0.332**	-0.216**	-0.147	-0.209*
	(0.089)	(0.086)	(0.111)	(0.091)	(0.118)	(0.094)	(0.122)	(0.111)
Household food insecure when child was aged 5 years	-0.126	0.066	0.006	-0.048	-0.198**	-0.218*	-0.274**	-0.312
	(0.100)	(0.097)	(0.075)	(0.157)	(0.076)	(0.124)	(0.102)	(0.181)
Household became food insecure when child was aged 8 years	-0.075	-0.164	-0.108	-0.156*	-0.319***	-0.255***	-0.160**	-0.228**
	(0.100)	(0.113)	(0.091)	(0.079)	(0.069)	(0.087)	(0.064)	(0.105)
Household became food insecure when child was aged 12years	-0.038	-0.071	-0.078	-0.088	-0.133**	-0.173**	-0.157***	-0.167**
	(0.053)	(0.059)	(0.065)	(0.051)	(0.054)	(0.063)	(0.052)	(0.059)
Transitory household food insecurity	-0.343*	-0.551	-0.214	-0.355	-0.289	-0.055	-0.406**	-0.167
	(0.170)	(0.358)	(0.209)	(0.392)	(0.176)	(0.244)	(0.150)	(0.322)
Chronic household food insecurity	-0.003	-0.002	-0.005	-0.004	-0.009	-0.007	-0.007	-0.006
	(0.005)	(0.005)	(0.006)	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)
Constant	-0.011	-0.140	0.439	0.310	0.680	0.362	0.023	-0.149
	(0.850)	(0.840)	(1.003)	(0.939)	(0.774)	(0.687)	(0.763)	(0.689)

Observations	1,773	1,764	1,730	1,721	1,733	1,725	1,739	1,730
R-squared	0.179	0.182	0.180	0.182	0.241	0.238	0.272	0.272

***** p<0.01, ** p<0.05, * p<0.1**

Notes: OLS estimates with community fixed effects. Errors clustered at the community level in parentheses. All the models control for: child age in months, gender, caste, child is first born; caregiver's age and education (in years of completed schooling); household size, number of boys aged 0-12 years (excluding the index child), number of girls aged 0-12 years (excluding the index child), number of boys aged 13-17 years (excluding the index child), number of girls aged 13-17 years (excluding the index child), wealth index, head of the household is female, household is urban; age 5 PPVT score; age 5 CDA score; three dichotomous variables for whether the household has changed community between rounds 1 and 2; at round 3 and at round 4. The "robustness" measure has been constructed on the basis of the common items between Round 2 and Round 3 and 4 scales.

Appendix 6. Estimates with early-life nutritional variables

	Vocabulary	Reading	Maths	English
Household food insecure when child was aged 5 years	-0.230**	-0.291**	-0.349***	-0.138
	(0.090)	(0.111)	(0.118)	(0.123)
Household became food insecure when child was aged 8 years	-0.123	0.006	-0.172**	-0.266**
	(0.103)	(0.073)	(0.071)	(0.105)
Household became food insecure when child was aged 12years	-0.074	-0.092	-0.321***	-0.162**
	(0.100)	(0.092)	(0.063)	(0.059)
Transitory household food insecurity	-0.022	-0.069	-0.107**	-0.153**
	(0.049)	(0.067)	(0.048)	(0.055)
Chronic household food insecurity	-0.387**	-0.282	-0.322*	-0.450***
	(0.176)	(0.194)	(0.158)	(0.154)
Lagged PPVT score	0.105***	0.118***	0.124***	0.112***
	(0.036)	(0.025)	(0.031)	(0.022)
Lagged CDA score	0.190***	0.190***	0.187***	0.115***
	(0.029)	(0.028)	(0.025)	(0.030)
Weight-for-height z-scores at age 1 year	0.044**	0.005	0.023	0.017
	(0.020)	(0.027)	(0.021)	(0.017)
Height-for-Age z-scores at age 1 year	0.069***	0.055***	0.029**	0.051***
	(0.013)	(0.014)	(0.012)	(0.016)
Constant	-1.039	-0.376	-0.068	-0.753
	(0.921)	(0.973)	(0.834)	(0.834)
Observations	1,728	1,686	1,689	1,696

R-squared	0.192	0.184	0.247	0.283

***** p<0.01, ** p<0.05, * p<0.1**

Notes: OLS estimates with community fixed effects. Errors clustered at the community level in parentheses. All the models control for: child age in months, gender, caste, child is first born; caregiver's age and education (in years of completed schooling); household size, number of boys aged 0-12 years (excluding the index child), number of girls aged 0-12 years (excluding the index child), number of boys aged 13-17 years (excluding the index child), number of girls aged 13-17 years (excluding the index child), wealth index, head of the household is female, household is urban; age 5 PPVT score; age 5 CDA score; three dichotomous variables for whether the household has changed community between rounds 1 and 2; at round 3 and at round 4.