Livestock Ownership and Child Nutrition in Uganda: Evidence from a Panel Survey

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This paper investigates the relationship between livestock ownership and child nutrition in Uganda by using a panel household survey. The analysis focuses on linear growth, as growth in height/length reveals the cumulative nutritional status of a child up to his current age. Three linear growth measures are assessed: besides the standard height-for-age z-scores, we analyse the height-for-age differences, more appropriate for a dynamic evaluation of the growth trend across ages, and growth velocity, that is usually used in clinical studies, but less frequently available in large socio-economic datasets in low-income countries. The results presented do point to a positive effect of livestock ownership on child nutrition, with different effects according to child age and animal species. Large ruminants seem to affect relatively more nutrition of older children, while small ruminants attenuate child growth faltering as they are more associated to the initial height trajectory, while poultry has a positive effect on growth, which is usually considered as a more responsive measure of child nutrition. Finally, the role of livestock ownership in sustaining linear growth seems to be crucial when households living in remote areas have a limited access to purchased foods and livestock becomes the only source of certain nutrients.

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The results presented do point to a positive effect of livestock ownership on child nutrition, with different effects according to child age and animal species. Large ruminants seem to affect relatively more nutrition of older children, while small ruminants attenuate child growth faltering as they are more associated to the initial height trajectory, while poultry has a positive effect on growth, which is usually considered as a more responsive measure of child nutrition. Finally, the role of livestock ownership in sustaining linear growth seems to be crucial when households living in remote areas have a limited access to purchased foods and livestock becomes the only source of certain nutrients.

1. Owning livestock: good or bad for child nutrition?

The relationship between livestock ownership and child nutritional well-being is quite complex, given the several factors and causal mechanisms at play.[1] Livestock increases availability and consumption of ASF which directly increase nutritional well-being of household members through a more varied and micronutrients-rich diet (Neumann et al., 2002; Murphy and Allen, 2003; Azzarri et al., 2015). Rearing livestock can also increase income, directly through sales and indirectly through draft power in agriculture. Higher income can be translated into enhanced access to more nutritious food or better healthcare (Smith et al., 2003; Fischer, 2003; Hoddinott et al., 2015).

On the other hand, livestock might also bear negative effects on child nutritional status. As noted by Randolph et al. (2007, p. 2791), “allocation of household resources such as land and labor to livestock can, under some circumstances, reduce production, consumption, and sales of other food”. In addition, especially when animals are not confined in proper sheds or paddocks, they can become vehicles for the dissemination of pathogens to the human population, thus increasing the risk of occurrence of diseases, particularly among children (Zambrano et al., 2014; Headey et al., 2017).

In the theoretical framework of the agricultural household model (Sing, Squire and Strauss, 1986) all markets function perfectly and households’ production and consumption decisions can be considered independent of each other, and this is hence referred to as a separable household model. When markets are missing or imperfect, on the other hand, production decisions are conditional on consumption decisions and are therefore considered ‘non-separable’ (Sing, Squire and Strauss, 1986; Key, Sadoulet, and de Janvry, 2000). Non-separability implies that livestock ownership and management decisions are simultaneously taken with consumption decisions. Under a non-separability framework, a different herd composition may be chosen by the household in order to fulfill different needs. Large ruminants usually take on the role of physical and financial asset, in addition to important ASF, manure and draft power. On the other hand, large ruminants require a larger amount of feed and fodder than small ruminants or poultry, with the latter being more affordable and representing a steadier source of cash (Robinson, Franceschini, and Wint, 2007).

[1] A more comprehensive discussion of the linkages between livestock ownership and nutrition is available in Azzarri et al, 2015 and in Headey and Hirvonen, 2016.

Higher ASF consumption, possibly due to livestock ownership, does not necessarily lead to a better nutritional status. Indeed, beyond direct food intake, there are several factors contributing to nutritional well-being. In particular, looking at child nutrition, intra-household allocation could have a significant impact on the distribution of (food) resources across household members, linked to the individual taking income and production decisions (Senauer, 1990; Villa, Barrett, and Just, 2010).[2]

Different animals may impact nutrition differently, depending on the nutritional value of their products as well as frequency and method of intake. Consumption of beef may occur less frequently than consumption of dairy or meat from poultry, since in small-scale, poor settings meat consumption from large ruminants usually occurs when animals are unproductive or sick (Randolph et al., 2007). The nutrient content of milk and meat also varies by species, as for instance goat milk has a lower vitamin A content than cow milk, but it is richer of fats (Pandya and Chodke, 2007).

Quantifying such complex relationships is an empirical issue, and this paper tries to go beyond the assumption that promoting livestock ownership would necessarily translate into better nutrition, to offer a more nuanced picture based on a dynamic analysis of causal mechanisms.

Whether and, if so, to what extent a link between livestock ownership and nutrition exists is therefore an empirical question. In this paper, we contribute to the existing literature by investigating the relationship between livestock ownership and child linear growth in Uganda. The country offers a promising environment for this type of analysis due to a combination of high prevalence of livestock ownership, recent growth in the livestock sector, and high level of undernutrition – 33 percent of stunting and 50 percent of anemia prevalence in children under 5 (DHS, 2011).

Moreover, the Uganda National Panel Survey (UNPS) has several features that make it particularly interesting to look at the research questions of interest in ways that have rarely been possible in this literature, particularly on the African continent. The UNPS panel structure allows us to track children over time, and hence to control for time-invariant unobservable characteristics, with the latter confounding the relationship of interest in analyses based on cross-sectional data. Multiple observations over time on the same subject also allow to compute a measure of child growth

[2] For example, among the Bahima of Uganda, all decisions about production and selling are made by the head of the household. In addition, milking is the domain of men, while females process all the milk (Wurzinger et al., 2009).

velocity, a powerful indicator of general health status (Hoddinott and Kinsey, 2001) and, in early months, a strong predictor of physiological and cognitive achievement in adulthood (Victora et al., 2008). As noted by Schmidt et al. (1995) socio-economic factors influence height and growth through biological mediators (mainly, nutrition and infection) and individual genetic endowments. Measures of growth velocity are not available in cross-sectional data where height is only measured at one point in time.

Additional advantages offered by the UNPS data are that the survey is nationally representative, thus allowing for inference at the national level given the reference population, and that it includes a very rich questionnaire which allows controlling for a full suite of socio-economic indicators. All household and communities in the UNPS are geo-referenced, which also allows controlling for agro-ecological and climatic conditions.

The paper is organized as follows. Section 2 describes the data used in the empirical analysis and reports some descriptive sample statistics. In Section 3 the empirical strategy is described; Sections 4 and 5 discuss results and Section 6 concludes.

2. The Data

a. Sample characteristics and descriptives

This study uses panel household survey data from the UNPS implemented by the Uganda Bureau of Statistics, with support from the Living Standard Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) program at the World Bank, in 2009/10, 2010/11 and 2011/12.

In order to estimate the impact of livestock ownership on child nutrition, we focus our analysis on linear growth, as growth in height/length reveals the cumulative nutritional status of a child up to his current age.

To characterize growth, we estimate the z-scores of height-for-age (HAZ), the height-for-age difference (HAD) and the growth velocity (defined as the difference in height between two measurements).

The HA-z scores are computed based on the 2006 World Health Organization's Child Growth Standards (WHO, 2006), drawing on data on children age, weight and height collected in the UNPS. Children are classified as stunted if their HA are below -2 z-scores, calculated as the difference between the observed value and the median value of the reference population over the standard deviation value of reference population.

Recently, the use of HAD, which unlike the HAZ does not embed the standard deviation value of reference population, has been presented as an alternative indicator of linear growth retardation. The rationale of this measure is that, as standard deviation for height increases with child's age, "changes in HAZ with age can be due […] to changes in the denominator (the increasing SD with age), which means that a change in HAZ does not directly correspond to the absolute change in height across ages" (Leroy et al. 2014, p. 1461). As HAZ is cross-sectional in its definition and evaluates the nutritional status of a children at a particular age, HAD is more appropriate for a dynamic evaluation of the growth trend across ages. As noted in Leroy et al. (2014), results obtained by using HAD for a number of countries contrast with the theory of catch-up growth even after 2 years of age. According to this theory, after 1,000 days of age there is no additional deterioration in child growth and, under certain circumstances, a reversal of linear growth can occur. Leroy et al. (2014), comparing HAZ and HAD trend across ages, find a continued deterioration even after 2 years of age.

Although HAZ and HAD are perfectly correlated and have the same predictive value at any time point, as noted by Lundeen et al. (2014, p. 824) "changes in HAZs and height deficits over time are not necessarily perfectly correlated, and therefore these two measurements may differ in their ability to predict long-term outcomes."

Moreover, we also use the difference in height between two surveys in order to analyze growth velocity. This is an indicator more often used in clinical studies, but less frequently available in large socio-economic datasets in low-income settings such as the UNPS, mostly for the difficulty of re-contacting survey subjects over time. Indeed, most studies about child growth are cross-sectional. While it is maintained that examining velocity should lead to earlier identification of growth problems, surveys allowing the construction of such indicators are 'highly unusual' (WHO, 2009, p. 1). Hence, the combined availability of height/growth measures and a rich set of socio-economic and environmental variables give us important research tools.

Our sample consists of all children from 6 to 59 months of age with valid anthropometric information, surveyed at least in two subsequent survey years. The final (unbalanced) panel contains 2,062 observations. Table 1 reports some descriptive statistics on HAZ, HAD and growth velocity and livestock ownership over the three years (2009/10, 2010/11 and 2011/12), not revealing huge differences between children in livestock and non-livestock keeper households. The observed difference appears to be driven particularly by differences in the 2009, and to some extent 2010, rounds of data.

Both Figure 1 and Figure 2 show that younger children (6-23 months) among livestock-keeping households show higher HAZ z-scores, on average, than their counterparts among non-keepers, while for older children (24-59 months) this result is reversed. The difference of z-scores in children among livestock keeping and non-keeping households is higher (and significant) in a crucial interval of the z-score distribution: in particular, for younger children HA z-scores mainly differ around the interval [-2.5, -1.5] (see Figure 2). For older children the picture is less sharp, with higher z-scores for children in livestock-keeping households in the interval [-5.5, -2.0] and the opposite trend in the interval [-2.0, 1.0].

As regards the trend across ages, our data confirm the finding by Leroy et al. (2014): unlike HAZ, HAD does not show any catch-up trend but a continued deterioration even after 1,000 days. Children in livestock keeping households are better of nourished up to about 30 months of age, while there are no differences from 30 to 52 months of age.

b. *Attrition and Potential Selectivity Bias*

In order to test if our estimates are biased by attrition, following Alderman, Hoddinot and Kinsey (2006) and Alderman et al. (2001), we estimate a probit model where the dependent variable is equal to 1 if the child if observed more than once, and 0 otherwise, to assess whether our sample is biased by attrition, based on observables variables. We carry out two specifications for both HAZ and HAD[3]: one with the initial (i.e. the measure in year 2009) measure as the only regressor, and the other with all the regressors included in the equation model described in Section 3. As shown in Table 2, both the lagged value of HAZ and HAD are significant in the first specification, although the relationship becomes not statistically significant when we control for number of children, household, dwelling, agro-ecological, and climatic characteristics. This finding suggests that height measures do not differ with the number of repeated observations on the same children over time, conditional on other observable characteristics, leading us to conclude that the panel sample is not systematically selected.

[3] Growth measure is excluded from this analysis as, by definition, it needs at least two measurement to be calculated.

3. Estimation Strategy

a. *Height and growth estimates*

In order to assess the impact on height of the ownership of different animals, we use a standard individual production-type anthropometric regression, estimating the following individual-specific effects model for both HAZ and HAD measures:

$$HA_{it} = \beta_1 LR_{it} + \beta_2 LR_{it}^2 + \beta_3 SR_{it} + \beta_4 SR_{it}^2 + \beta_5 P_{it} + \beta_6 P_{it}^2 + \beta_7 M_{it} + \beta_8 H_{it} + \beta_9 C_{it} + \beta_{10} D_{it} + \beta_{11} S_{it} + \beta_{12} F_{it} + \varepsilon_{it} \quad (1)$$

where, *i* and *t* express individual and time indices. Since our aim is to test if each type of livestock bears a different impact on child nutrition, we define the main variables of interest as the following three livestock categories: *LR,* the number of large ruminants (bulls, cows, calves); *SR,* the number of small ruminants (goats and sheep); and *P,* the number of poultry birds (chickens, turkeys, and ducks). The associated squared terms (LR^2, SR^2, P^2) are included to capture possible non-linearities in the relationship between child nutrition and number of livestock, since anthropometric measures could be significantly affected by a marginal increase of herd size for low number of livestock, with a decreasing impact for households with large herds.

Our data also allows to test if the relationship between livestock ownership and nutrition outcomes is mediated by market access. In order to capture market integration, and differentiate the role of livestock in case of complete or incomplete markets, we include a dummy (M_{it}) equal to 1 if the household is less than about 30 minutes far from the nearest town with no less than 20,000 people, which captures the dimension of market access[4], and we interact this dummy with the livestock variables *LR*, *SR* and *P*.

Additional controls are included in the regressions to capture variability in household, child, and dwelling characteristics, in cropping patterns, as well as in geographic location and key survey features.

H_{it} is a vector of household and parental characteristics: per capita total consumption expenditure (expressed in 2011 Purchasing Power Parity international dollars), dependency ratio, age of the

[4] The travel time threshold is chosen as the distance from the nearest town with at least 20,000 people within the share of own produced food remains below the 50% of total food expenditure.

mother (and its squared term), education of the mother, and dummies for whether household experienced natural, economic or other shocks.

C_{it} is a vector of child characteristics: gender, age in months (and its squared term), whether child is 24 months younger than older sibling, whether child suffered from diarrhea during the 7 days prior to the survey, whether child experienced any illness during the previous 30 days, and whether the child was exclusively breast-fed for the first 6 months.

D_{it} is a vector of dwelling characteristics: whether drinking water is filtered or boiled and whether household has flush toilet.

S_{it} expresses the Simpson diversity crop index, as under imperfect markets crop diversity has been shown to correlate with dietary diversity (Dillon, McGee, Oseni, 2015).

F_{it} is a vector of fixed effects for interview quarter, stratum of residence, survey year, agro-ecological zone (AEZ)[5], as well as biophysical control variables such as the Normalized Difference Vegetation Index (NDVI)[6], the average temperature, and the Palmer Drought Severity Index (PDSI)[7]. The unobservable time-varying factors affecting the z-scores are represented by ε_{it}.

Standard errors are calculated by clustering child-individual observations at the household level, to control for potential intra-household correlation.

In order to control for the possible correlation between observed explanatory variables and unobserved time-invariant factors affecting anthropometric outcomes, we estimate Correlated Random Effect (CRE) models[8]. Therefore, the error term in Eq. (1) can be split into two components:

$$\varepsilon_{it} = \gamma_i + \vartheta_{it} \tag{2}$$

where γ_i and ϑ_{it} represent the unobserved time-invariant heterogeneity and the unobserved time-varying shocks, respectively. In the CRE specification, γ_i term includes household time average

[5] AEZs are geographical areas with similar climate characteristics with respect to their potential to support agricultural production (Fisher et al., 2001).

[6] It measures the degree of live green vegetation in the observed area. Negative values of NDVI (approaching -1) correspond to water. Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, sand, or snow. Lastly, low, positive values represent shrub and grassland (approximately 0.2 to 0.4), while high values indicate temperate and tropical rainforests (values approaching 1).

[7] PDSI is a measurement of dryness based on precipitation and temperature (Kayantash and Dracup, 2002).

[8] See Ricker-Gilbert, Jumbe and Chamberlin (2014) for an application of CRE model in a similar context.

of all time-varying covariates ($\bar{X}_i$). Thus, for a correct CRE estimation $\bar{X}_i$ need to be included as covariates in Eq. (1).

In addition, our interest in time-invariant covariates (e.g. gender and mother's education) precludes the use of a fixed effects estimator. Unlike fixed effects, the CRE estimator allows for time-invariant covariates. Moreover, since fixed effects estimation reduces total variation, it also maximizes error-in-variables bias due to measurement errors in the explanatory variables, leading to downward biased parameter estimates (Greene, 2003). In addition, in case of little over-time variability for the same individual fixed effects estimates may not be appropriate (Wooldridge, 2010).

As regards the estimation of the role of livestock in growth velocity, we use a different model, largely drawn on Hoddinott and Kinsey (2001):

$$height_{t+1} - height_t = \beta_1 height_t + \beta_2 LR_{it} + \beta_3 LR_{it}^2 + \beta_4 SR_{it} + \beta_5 SR_{it}^2 + \beta_6 P_{it} + \beta_7 P_{it}^2 + \beta_8 M_{it} + \beta_9 H_{it} + \beta_{10} C_{it} + \beta_{11} D_{it} + \beta_{12} S_{it} + \beta_{13} F_{it} + +\varepsilon_{it} \quad (3)$$

where the dependent variable is the difference between height at time *t*+1 and height at time *t*. The same control variables as in Eq. (1) appear as independent regressors with the addition of their lagged values (at time *t*), and the inclusion of height at time *t*. In vector C_{it} we include also the time lag between successive height measurements, and the interaction of child age with time lag[9]. Since growth velocity decreases with age, the latter is expected to negatively affect growth, while duration of observation to positively impact growth, given the dependent variable measured as difference over a discrete time interval.

Since the dependent variable is the difference between the measurements in two rounds, we are not able to run estimates for children aged 6-23 months. Hence, we run estimates for the whole sample, using both panel and cross-sectional data.

Following Yamano, Alderman and Christiaensen (2005), we treat height at time *t* as endogenous and we instrument for it using weight and its squared term at time *t*[10].

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[9] As noted by Hoddinott and Kinsey (2001, p.422), "the interaction term is included because the effects of age and duration of observation are not independent of each other."

[10] Alderman and Kinsey (2001) instrument initial height with a dummy variable equal to 1 if child's birthweight in case of known child's birthweight and child birthweight interacted with this dummy variable. In our case, we do not know the child birthweight, hence we opt for other instruments.

b. Testing for omitted variable bias

Even if we control for unobserved heterogeneity by using CRE models, correlation between our independent variables of interest (LR_{it}, SR_{it} and P_{it}) and ϑ_{it} could arise because of omitted variable bias, which can arise since both child nutrition and livestock ownership are potentially affected by unobserved local and institutional factors.

In order to test the robustness of our results to omitted variable bias we follow the approach developed by Oster (2013), who demonstrate that the range provided by the *controlled estimate* (the coefficient of the variable of interest from the model controlling for the full set of observable variables) and the *bias-adjusted estimate* (the coefficient of the variable of interest from an hypothetic model controlling for both observables and unobservable variables) can be used to assess the robustness of the *controlled estimate* to omitted variable bias. Our results are robust if such range is within the *controlled estimate* confidence interval and does not include zero (Nghiem et al., 2015). The *bias-adjusted estimate* is calculated as follows:

$$\beta^{*} = \beta^{c} - (\beta^{*uc} - \beta^{*c}) * \frac{R^{max} - R^{c}}{R^{c} - R^{uc}} \quad (4)$$

where β^{c} and β^{uc} are respectively the *controlled estimate* and the coefficient of the uncontrolled regression where the variable of interest is the only independent variable. R^c and R^{uc} are the R^2 of the regression from which the *controlled estimate* is obtained, and the R^2 of the uncontrolled regression, respectively. R^{max} is the R^2 of an unknown hypothetical regression controlling for both observables and unobservables. According to Oster (2013), $R^{max} = min\{2.2R^2, 1\}$, while Gonzalez and Miguel (2015) note that R^{max} =1 is too high for analyses in developing countries where the measurement error in variables is likely to be substantial.[11] Thus, we choose R^{max} =0.80 in our analysis. Since the approach developed by Oster (2013) is available only for linear estimators, we run the test just for fixed effects estimates[12] (see the bottom section of Tables 5 and 6). For the same reason, for growth velocity we run Oster's robustness test after OLS estimates instead of IV estimates (bottom section of Table 7). Since the range of estimates based on the method proposed by Oster (2013) to assess the robustness omitted variable bias is within the

[11] According to Angrist and Krueger (1999), the reliability ratios typically range between 0.70 and 0.90 in U.S. survey data.

[12] Fixed effects estimates are available upon request.

confidence interval of the *controlled estimate* and does not include zero for most of specifications, our estimates are robust to omitted variable bias (Oster, 2013; Freier et al., 2015).

4. Empirical Results

Tables 3, 4 and 5 report the results for HAZ, HAD and growth velocity, respectively. Livestock differently affects height and growth according to the type of animals and the age of children.
Small ruminants have by far the highest (positive) impact on both height measures, in particular for younger children, while they do not affect growth velocity. Instead, large ruminants positively affect height of older children in HAD and in growth velocity estimates, while their coefficient is not significant in HAZ estimates. One possible interpretation is that large ruminants positively impact growth because they provide the body with more protein stimulating growth, while HAZ is more related to WASH dimensions (correlated to illnesses and diarrhea) and parent's biological characteristics. Though, the impact of large ruminants on height is consistent with the findings reported by Rawlins et al. (2014) in Rwanda and Hoddinott et al. (2015) in Ethiopia. Moreover, our results show that rearing poultry seems to be positively correlated with growth velocity. Finally, all estimates show that the impact of livestock diminishes as the herd size increases[13].
As regards growth velocity, the coefficient on initial height needs to be interpreted as in Hoddinott and Kinsey, 2001 (p.421): "a coefficient not significantly different from zero would have indicated that height growth is independent of initial height. A coefficient equal to -1 would have indicated complete catch-up in the sense that with this value, height in period *t*+1 is independent of height in period *t*". In our case the coefficient of initial height differs in pooled and panel estimates, thus being difficult to be interpreted. However, as both coefficients are between 0 and -1, we can exclude the hypothesis of complete catch-up.[14]
It is interesting to note that the presence of a local food market not far from the household mitigate the role of livestock on nutrition. In other words, livestock rearing may be crucial when the access to commercialized sources of food is limited because of missing markets. Indeed, both in height and growth velocity estimates, coefficients of the interaction terms between the number of

[13] In order to control for multicollinearity among animal species, we have also run HAZ, HAD and growth velocity models including animal species one by one. Results are basically equal to those obtained with large ruminants, small ruminants and poultry in the same equation.
[14] Both F-test on excluded test and Sargan-Hansen tests for over-identification instruments confirm the validity of our instruments for initial height.

livestock animals having a significant impact on nutrition and the presence of a market are negative and significant, as these animals are more difficult to rear and, as a consequence, their products more difficult to obtain without a market where commercialize them. The interaction term is significant, but positive, for small ruminants in growth velocity estimates.

Per-capita expenditure has a significant role in the initial height trajectory while it is not significant for older children (and growth velocity specifications), while child's age is significantly negatively related to both height and growth. Mother's characteristics (age and education) appear to be positively related to height and growth in some specifications. Exclusive breastfeeding for 6 months has a significant role on height, in particular for older children, but not on growth velocity. Contrary to expectations (Headey and Hirvonen, 2016), illness and diarrhea do not significantly impact height and growth outcomes[15], not revealing another channel through which livestock rearing may worsen child undernutrition by increasing children's exposure to pathogens (Headey and Hirvonen, 2016). In addition, as in Headey et al. (2014), piped water supply has no effect on child growth measures. However, this channel, as well as other WASH dimensions (toilet) may be captured by expenditure levels.

Being a girl is associated to a statistically significantly higher height and growth outcomes, corroborating results from other studies in Sub-Saharan Africa (see Slavchevska, 2015).

In general, livestock bear a differential effect on height according to child age and animal type: large ruminants seem to affect relatively more nutrition of older children; while small ruminants might attenuate child growth faltering as they are more associated to the initial height trajectory.

Moreover, livestock ownership appears to affect child nutrition when height growth velocity is used as a *proxy* of nutritional outcomes, although the magnitude of the parameters seems to be relatively low (even though higher than other studies on growth velocity, e.g. Yamano, Alderman and Christiansen, 2005). Poultry seem to affect only growth but not height measure. One possible explanation might be due to the relatively high measurement error in z-scores, as they require a precise measurement of height, and age in months. Conversely, growth velocity only requires the measurement of height, albeit at two points in time, and it is generally considered a more responsive measure of child nutrition.

[15] This result is also found in Nguyen et al. (2017).

However, when the households have a limited access to purchased foods livestock may be the sole source of certain foods and nutrients, and its role can be crucial in limiting height and growth deficits.

5. Focusing on age dynamics: average marginal effects estiamtions

As preliminary results show a diversified impact of different animal species according to the age of the child, we further investigate the role of age dynamics in the relationship between livestock ownership and linear growth by estimating the average marginal effects (AMEs) of livestock ownership on HAZ, HAD and growth velocity at different ages of children.
In order to estimate AMEs, we interact the variable referring to the age of the child with the number of animals. Specifically, since we want to get AMEs from the models specified in equations (1) and (3), we interact age and animal variables with their squared terms, too. Hence, for both HA and growth models we put the following interaction terms:

$$LR_{it} * age + LR_{it}^2 * age + SR_{it} * age + SR_{it}^2 * age + P_{it} * age + P_{it}^2 * age + LR_{it} * age_{it}^2 + SR_{it} * age_{it}^2 + P_{it} * age_{it}^2 + LR_{it}^2 * age_{it}^2 + SR_{it}^2 * age_{it}^2 + P_{it}^2 * age_{it}^2$$

The same control variables used in equations (1) and (3) are used for AME estimations for HA and growth estimates, respectively[16][17].
As shown in Table 6, AMEs basically confirm the results previously discussed, but also give some interesting insights of the role of different livestock species along childhood (for a graphical representation see Figures 4)[18].
Large ruminants have a negative role in the early stages of child development, confirming the hypothesis that, as large ruminants represent a major asset for rural households, keeping them reduces the time devoted to child care-giving (Iannotti, 2013). This impact is reversed as child grows, with large ruminants positively (and significantly) affecting height outcomes of older children. As already noted in Section 4, the impact of small ruminants decreases as child grows,

[16] The only exception refers to the market distance variable. Since in the AME equations there are several interaction terms, we include the travel distance (in minutes) to the market instead of the dummy of market access and the interaction terms with livestock animals as in equations (1) and (3).
[17] Growth AMEs estimates refer to children 20-59 years old as the very few observations for children aged less than 20 months lead to unstable estimates for early stage of growth.
[18] Coefficients of models run in order to estimate AMEs are available upon request.

though it is significant (just for HAZ) only for children around 26 and 46 months of age. Poultry has a reversed U-shaped (significant) impact: the negative impact at early stages of development can be the result of the transmission of animal-borne diseases (Headey and Hirvonen, 2016). Poultry has a positive (and significant) effective for children aged between 26 and 42 months, while it negatively affects height older children, when the positive effect of egg consumption does not compensate for the negative effect of the transmission of animal-borne diseases. As regards growth, the interpretation of AMEs is not straightforward: however, comparing them with the AMEs for HAD and HAZ for the 22-58 months of age interval give a similar picture of the impact of livestock ownership on child linear growth.

6. Conclusions

The paper sets out to empirically estimate whether livestock ownership/rearing in rural settings in Sub-Saharan Africa, such as in Uganda, may play a role in affecting child nutritional status. This is an important empirical question as poor nutritional status is a strong predictor of morbidity and mortality. Moreover, undernutrition, especially during the first 1000 days since conception, has been demonstrated to bear long lasting effects on cognitive ability, earning potential and overall welfare.

Livestock is generally expected to play a positive effect on child nutrition via direct access to nutrient-dense animal source foods, as well as higher and steadier household income. However, livestock has also been shown to negatively affect nutrition, particularly by exposing young children to pathogens insofar rearing livestock is associated with lower levels of hygiene in the dwelling. Where markets work well, and hygiene conditions are acceptable, no direct correlation between livestock ownership and child nutrition should be found, other things equal.

The analysis presented in this paper focuses on linear growth, as growth in height/length reveals the cumulative nutritional status of a child up to his current age. Three linear growth measures are assessed: besides the standard height-for-age z-scores, we analyse the height-for-age differences, which is more appropriate for a dynamic evaluation of the growth trend across ages, and growth velocity, a measure that is usually used in clinical studies, but less frequently available in large socio-economic datasets, especially in low-income countries. Indeed, our study takes advantage of the rather unique features of the UNPS data, which allow to control for both time-invariant child and household characteristics by exploiting the panel structure of the data.

The results presented in the paper do point to a positive effect of livestock ownership on child nutrition, with different effects according to child age and animal type. In particular, the estimation of average marginal effects allows to capture age dynamics in the relationship between livestock ownership and linear growth.

Large ruminants seem to affect relatively more nutrition of older children, while they have a negative effect in the early stages of child development as keeping they reduces the time devoted to child care-giving. Small ruminants might attenuate child growth faltering as they are more associated to the initial height trajectory, while poultry has a positive effect on growth, which is usually considered as a more responsive measure of child nutrition, though also a negative impact likely due to the transmission of animal-borne diseases is detected. Finally, the role of livestock ownership in sustaining height and growth outcomes seems to be crucial when households living in remote areas have a limited access to purchased foods and, as a consequence, livestock becomes the sole only source of certain nutrients.

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Table 1 – Child anthropometric measures by year and livestock ownership

		Livestock ownership	HA z-score	Difference in means (t-test)	Difference in distribution (Kolgomorov -Smirnov)	HAD (cm)	Difference in means (t-test)	Difference in distribution (Kolgomorov -Smirnov)	Growth (cm)	Difference in means (t-test)	Difference in distribution (Kolgomorov -Smirnov)	n
Whole sample		No	-1.61	-	-	-6.03	-	-	9.78	-	-	458
		Yes	-1.60			-6.10			9.36			1604
Age group	**6-23**	No	-1.60	-	*	-4.90	-	-	10.59	-	-	142
		Yes	-1.41			-4.46			11.34			440
	24-59	No	-1.62	-	-	-6.53	-	-	9.67	-	-	316
		Yes	-1.66			-6.72			9.15			1164
Year	**2009**	No	-1.76	-	**	-6.16	*	*	NA	NA	NA	122
		Yes	-1.51			-5.43			NA			474
	2010	No	-1.51	-	-	-5.53	*	*	9.23	-	-	187
		Yes	-1.60			-6.08			8.71			652
	2011	No	-1.61	-	-	-6.53	-	-	10.13	-	-	149
		Yes	-1.67			-6.79			9.94			478
Tercile	**I**		-1.76			-6.60			9.68			
	II		-1.60			-6.09			9.13			
	III		-1.40			-5.22			9.28			

* p<.1, ** p<.05, *** p<.01

Table 2 – Testing selection bias due to attrition

	HAZ and HAD measured more than once			
	(1)		(2)	
	coef	std dev	coef	std dev
Initial HA z-scores	-0.050***	0.018	-0.040	0.028
Intitial HAD (cm)	-0.012*	0.006	-0.003	0.005
Controls	*No*		*Yes*	

* p<.1, ** p<.05, *** p<.01

Table 3 - Correlated Random Effect Estimates on Height-for-age z-scores

	6-59		6-23		24-59	
	coef	se	coef	se	coef	se
Number of LR	0.007	(0.005)	-0.022	(0.032)	0.008	(0.005)
Number of LR^2	-0.000*	(0.000)	0.000	(0.000)	-0.000**	(0.000)
Number of SR	0.031***	(0.010)	0.099***	(0.035)	0.020**	(0.009)
Number of SR^2	-0.000*	(0.000)	-0.002**	(0.001)	-0.000***	(0.000)
Number of P	0.001	(0.002)	-0.001	(0.014)	-0.003	(0.002)
Number of P^2	0.000	(0.000)	0.000	(0.000)	0.000	(0.000)
Mkt	-0.041	(0.113)	-0.041	(0.194)	0.042	(0.111)
Mkt*LR	-0.003	(0.018)	-0.018	(0.057)	-0.009	(0.020)
Mkt*SR	-0.034***	(0.012)	-0.140*	(0.073)	-0.035***	(0.013)
Mkt*P	0.007	(0.005)	0.001	(0.021)	0.005	(0.005)
Per-capita expenditure	0.038	(0.026)	0.151**	(0.062)	0.017	(0.029)
Female	0.210***	(0.078)	0.269**	(0.130)	0.214***	(0.083)
Age in months	-0.109***	(0.010)	-0.324***	(0.085)	-0.036**	(0.018)
Age in months ^2	0.001***	(0.000)	0.008***	(0.003)	0.000*	(0.000)
24mns younger	-0.110	(0.108)	-0.146	(0.177)	-0.107	(0.114)
Age of Mother	0.039*	(0.022)	-0.002	(0.040)	0.039	(0.024)
Age of mother^2	0.000	(0.000)	0.000	(0.001)	0.000	(0.000)
Mother's education	0.010	(0.011)	0.018	(0.021)	0.020*	(0.011)
Dependency ratio	0.005	(0.026)	0.045	(0.079)	-0.010	(0.028)
Diarrhea	-0.098	(0.111)	-0.100	(0.221)	-0.258	(0.353)
Illness	-0.086*	(0.050)	-0.053	(0.158)	-0.103**	(0.047)
Breastfeeding	0.258**	(0.104)	-0.055	(0.173)	0.218*	(0.112)
Toilet	0.011	(0.058)	-0.119	(0.152)	0.037	(0.058)
Water	-0.001	(0.062)	-0.026	(0.146)	0.044	(0.069)
Simpson index	0.037	(0.028)	0.041	(0.082)	0.023	(0.023)
N	2060		581		1479	
R-squared within	0.185		0.423		0.128	
R-squared between	0.111		0.197		0.132	
R-squared overall	0.123		0.219		0.132	
Std dev time-level	0.692***		0.857***		0.510***	
Std dev panel-level	1.048***		1.032***		1.079***	
Chi-squared	1046.304		266.049		2326.649	
Probability	0.000		0.000		0.000	
Rho	0.697		0.592		0.817	
Range of estimates for omitted variables bias [based on Oster (2013)]						
Number of LR	[0.002 0.013]		[-0.043 0.008]		[0.002 0.013]	
Number of SR	[0.011 0.024]		[0.036 0.111]		[0.013 0.020]	
Number of P	[-0.000 0.003]		[0.008 0.032]		[0.003 0.004]	

Controls for shocks in the past 12 months included, fixed effects for NDVI, AEZ, PSDI, interview quarter and stratum included. All regressions include time averages of time-varying covariates and year dummies.
p < .1, ** p < .05, *** p < .01. Cluster-robust standard errors in parentheses.

Table 4 - Correlated Random Effect Estimates on Height-for-age difference

	6-59		6-23		24-59	
	coef	se	coef	se	coef	se
Number of LR	0.031	(0.020)	-0.071	(0.083)	0.048**	(0.019)
Number of LR^2	-0.000*	(0.000)	0.001	(0.001)	-0.000***	(0.000)
Number of SR	0.107***	(0.032)	0.296***	(0.101)	0.076**	(0.037)
Number of SR^2	-0.001*	(0.001)	-0.005**	(0.002)	-0.001**	(0.001)
Number of P	0.004	(0.008)	-0.021	(0.037)	-0.008	(0.008)
Number of P^2	0.000	(0.000)	0.000	(0.000)	0.000	(0.000)
Mkt	0.006	(0.376)	-0.115	(0.509)	0.213	(0.415)
Mkt*LR	0.002	(0.064)	-0.031	(0.158)	-0.043	(0.077)
Mkt*SR	-0.135***	(0.040)	-0.349*	(0.197)	-0.143***	(0.052)
Mkt*P	0.023	(0.016)	0.003	(0.053)	0.020	(0.018)
Per-capita expenditure	0.080	(0.082)	0.378**	(0.161)	0.067	(0.110)
Female	0.462*	(0.277)	0.433	(0.347)	0.563*	(0.315)
Age in months	-0.406***	(0.029)	-0.625***	(0.189)	-0.275***	(0.072)
Age in months ^2	0.004***	(0.000)	0.011*	(0.006)	0.002***	(0.001)
24mns younger	-0.353	(0.384)	-0.351	(0.482)	-0.391	(0.435)
Age of Mother	0.081	(0.071)	-0.039	(0.107)	0.122	(0.088)
Age of mother^2	-0.001	(0.001)	0.001	(0.002)	-0.001	(0.001)
Mother’s education	0.031	(0.036)	0.029	(0.054)	0.081*	(0.043)
Dependency ratio	-0.064	(0.089)	-0.029	(0.206)	-0.070	(0.111)
Diarrhea	0.012	(0.330)	-0.106	(0.561)	-0.457	(1.503)
Illness	-0.252	(0.156)	-0.123	(0.426)	-0.340*	(0.189)
Breastfeeding	0.996***	(0.356)	-0.062	(0.468)	0.843**	(0.421)
Toilet	0.079	(0.191)	-0.379	(0.411)	0.186	(0.226)
Water	0.025	(0.205)	0.014	(0.384)	0.159	(0.270)
Simpson index	0.109	(0.088)	0.086	(0.210)	0.091	(0.093)
N	2060		581		1479	
R-squared within	0.289		0.540		0.082	
R-squared between	0.135		0.191		0.136	
R-squared overall	0.158		0.238		0.132	
Std dev time-level	2.219***		2.097***		2.041***	
Std dev time-level	3.774***		2.890***		4.066***	
Chi-squared	2558.295		365.847		3550.168	
Probability	0.000		0.000		0.000	
Rho	0.743		0.655		0.799	
Range of estimates for omitted variables bias [based on Oster (2013)]						
Number of LR	[0.005 0.030]		[-0.157 0.029]		[-0.005 -0.028]	
Number of SR	[0.001 0.003]		[0.107 0.423]		[0.016 0.078]	
Number of P	[-0.000 0.001]		[-0.108 0.032]		[0.006 0.016]	

Controls for shocks in the past 12 months included, fixed effects for NDVI, AEZ, PSDI, interview quarter and stratum included. All regressions include time averages of time-varying covariates and year dummies.
* p < .1, ** p < .05, *** p < .01. Cluster-robust standard errors in parentheses.

Table 5 - Panel IV estimates on growth velocity

	coef	se
Height[a]	-0.085**	(0.033)
Number of LR	0.146***	(0.036)
Number of LR^2	-0.002***	(0.001)
Number of SR	-0.023	(0.050)
Number of SR^2	-0.002	(0.001)
Number of P	0.023*	(0.012)
Number of P^2	0.000	(0.000)
Mkt	0.140	(0.274)
Mkt*LR	-0.124*	(0.074)
Mkt*SR	0.120	(0.082)
Mkt*P	-0.030	(0.028)
Per-capita expenditure	-0.085	(0.073)
Female	0.330*	(0.198)
Age in months	-0.248***	(0.073)
Age in months ^2	0.002**	(0.001)
Interview interval*age`	0.011***	(0.004)
Interview interval`	-0.128	(0.112)
24mns younger	-0.165	(0.252)
Age of Mother	0.141	(0.088)
Age of mother^2	-0.002	(0.001)
Mother's education	0.055*	(0.033)
Dependency ratio	-0.030	(0.094)
Diarrhea`	-0.299	(0.554)
Illness`	-0.084	(0.176)
Breastfeeding	0.296	(0.246)
Toilet	0.219	(0.230)
Water	0.199	(0.229)
Simpson index	0.037	(0.068)
N	1074	
R-squared within panel	0.216	
R-squared between panel	0.181	
Rho	0.507	
Range of estimates for omitted variables bias[b]		
Number of LR	[0.004 0.155]	
Number of SR	[0.002 0.003]	
Number of P	[0.001 0.025]	
F-test of IVs on initial height	F(2, 201)= 15.02***	
Over-identification test (Sargan-Hansen)	χ^2(1.254)	

Controls for shocks in the past 12 months included, Fixed effects for NDVI, AEZ, PSDI, interview quarter and stratum included. * $p < .1$, ** $p < .05$, *** $p < .01$. Cluster-robust standard errors in parentheses.

[a] Endogenous variable (instrumented): initial height. Excluded instrument for height: initial weight and its squared term.

[b] Based on Oster (2013). The test is performed on linear (not-IV) specification since the Oster's approach is valid for linear models only.

` Non-lagged variables

Table 6 – Average Marginal Effects

		HAZ		HAD		Growth Velocity	
	Months	dy/dx	Std. Err.	dy/dx	Std. Err.	dy/dx	Std. Err.
Large ruminants	6	-0.019	(0.025)	-0.147**	(0.061)		
	10	-0.013	(0.021)	-0.113**	(0.051)		
	14	-0.008	(0.017)	-0.082*	(0.045)		
	18	-0.003	(0.015)	-0.054	(0.041)		
	22	0.001	(0.013)	-0.029	(0.039)	-0.100	(0.146)
	26	0.005	(0.012)	-0.006	(0.037)	-0.025	(0.074)
	30	0.008	(0.011)	0.013	(0.035)	0.031	(0.048)
	34	0.010	(0.009)	0.030	(0.031)	0.067	(0.052)
	38	0.011	(0.008)	0.044**	(0.025)	0.083	(0.052)
	42	0.012**	(0.006)	0.055***	(0.019)	0.079	(0.058)
	46	0.012***	(0.005)	0.063***	(0.016)	0.056	(0.103)
	50	0.012***	(0.006)	0.068***	(0.022)	0.012	(0.189)
	54	0.011	(0.010)	0.071**	(0.035)	-0.051	(0.307)
	58	0.009	(0.015)	0.070	(0.054)	-0.133	(0.456)
		HAZ		HAD		Growth Velocity	
	Months	dy/dx	Std. Err.	dy/dx	Std. Err.	dy/dx	Std. Err.
Small ruminants	6	0.036	(0.045)	0.143	(0.118)		
	10	0.032	(0.035)	0.118	(0.092)		
	14	0.028	(0.027)	0.097	(0.071)		
	18	0.025	(0.020)	0.079	(0.055)		
	22	0.022	(0.016)	0.065	(0.045)	-0.040	(0.170)
	26	0.020	(0.013)	0.055	(0.040)	-0.054	(0.093)
	30	0.018	(0.012)	0.048	(0.037)	-0.055	(0.071)
	34	0.017	(0.011)	0.044	(0.036)	-0.043	(0.073)
	38	0.016	(0.011)	0.044	(0.034)	-0.018	(0.068)
	42	0.016	(0.010)	0.047	(0.033)	0.020	(0.081)
	46	0.016*	(0.010)	0.054	(0.034)	0.072	(0.153)
	50	0.017*	(0.010)	0.065	(0.041)	0.136	(0.274)
	54	0.019	(0.013)	0.079	(0.054)	0.214	(0.436)
	58	0.020	(0.018)	0.096	(0.073)	0.305	(0.637)
		HAZ		HAD		Growth Velocity	
	Months	dy/dx	Std. Err.	dy/dx	Std. Err.	dy/dx	Std. Err.
Poultry	6	-0.035**	(0.017)	-0.118**	(0.048)		
	10	-0.023*	(0.012)	-0.080**	(0.035)		
	14	-0.013	(0.009)	-0.048*	(0.025)		
	18	-0.004	(0.006)	-0.021	(0.017)		
	22	0.002	(0.004)	0.001	(0.012)	-0.004	(0.041)
	26	0.007**	(0.003)	0.017	(0.011)	0.019	(0.024)
	30	0.010***	(0.003)	0.027**	(0.011)	0.035	(0.027)
	34	0.011***	(0.004)	0.033***	(0.013)	0.043	(0.032)
	38	0.010**	(0.004)	0.032**	(0.013)	0.045	(0.032)
	42	0.007	(0.004)	0.026**	(0.013)	0.039	(0.031)
	46	0.003	(0.004)	0.015	(0.014)	0.027	(0.041)
	50	-0.004	(0.004)	-0.002	(0.016)	0.007	(0.068)
	54	-0.012**	(0.005)	-0.024	(0.021)	-0.020	(0.109)
	58	-0.022***	(0.008)	-0.052*	(0.029)	-0.053	(0.162)

* p < .1, ** p < .05, *** p < .01

Figure 1 – Distribution of Z-Scores by Livestock Ownership

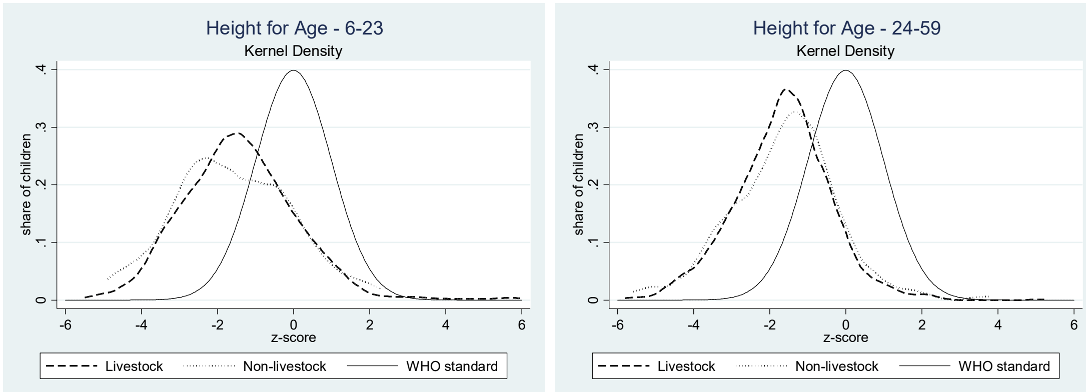


Figure 2 – Differences of Z-Scores by Livestock Ownership

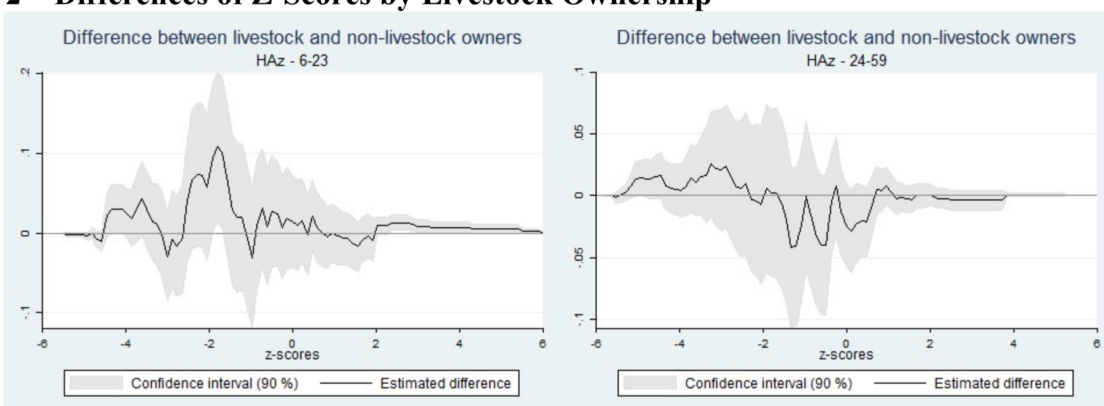


Figure 3 – HAZ and HAD measures across ages, by livestock keeping

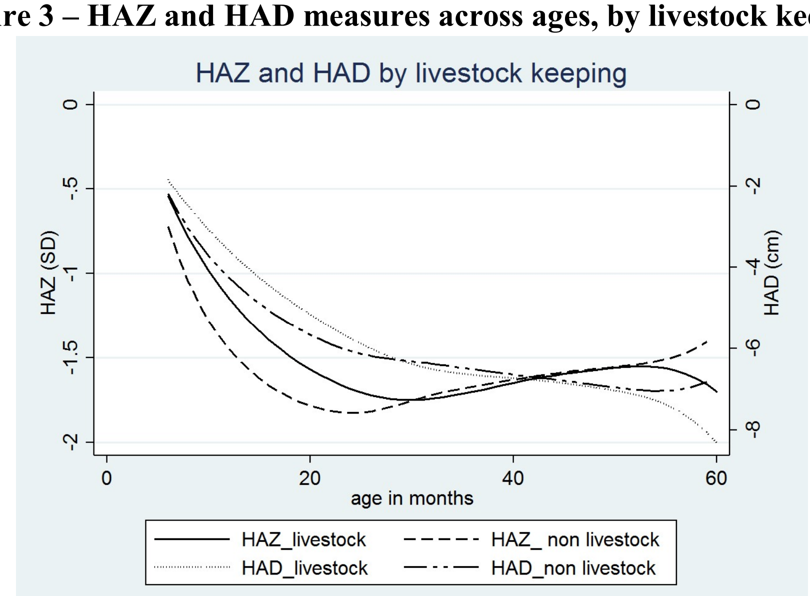
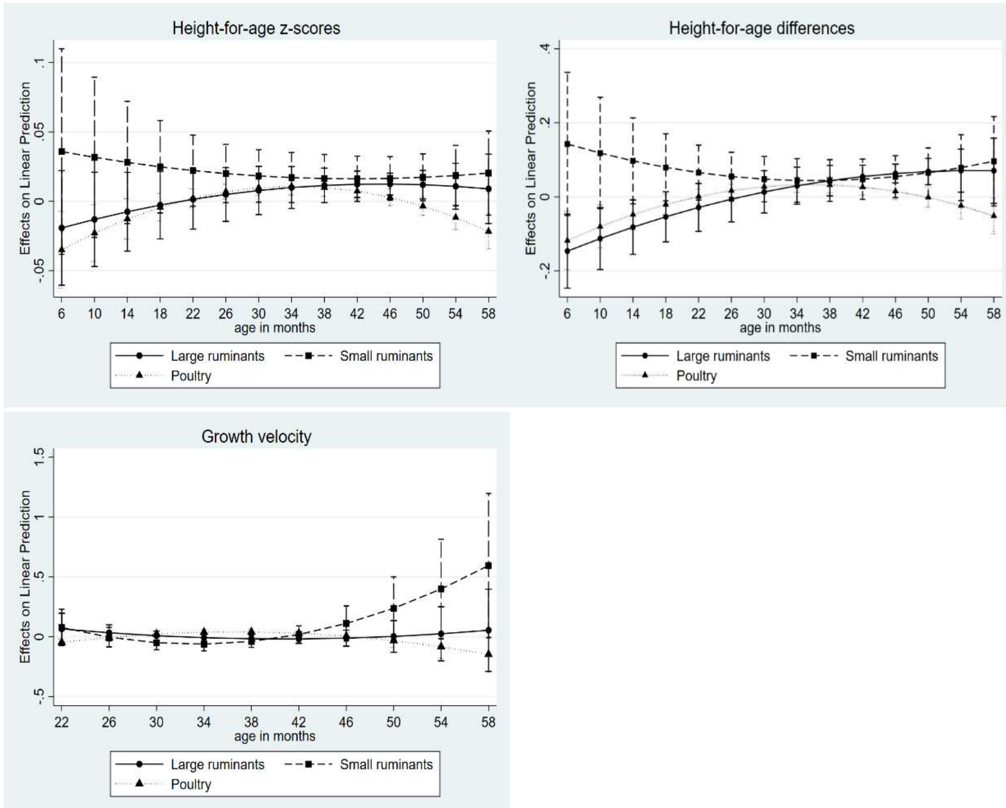


Figure 4 – Average marginal effects



Appendix

A1 – Pooled and panel estimates on growth velocity – first stage

	Pooled	
	coef	Std. Err.
Number of LR	-0.017	(0.037)
Number of LR^2	0.001**	(0.001)
Number of SR	0.112**	(0.050)
Number of SR^2	-0.002	(0.001)
Number of P	0.002	(0.012)
Number of P^2	0.000	(0.000)
Mkt	0.290	(0.274)
Mkt*LR	-0.013	(0.075)
Mkt*SR	-0.118	(0.082)
Mkt*P	-0.003	(0.028)
Per-capita expenditure	0.310***	(0.073)
Female	0.072	(0.199)
Age in months	0.578***	(0.074)
Age in months ^2	-0.004***	(0.001)
Interview interval*age`	-0.001	(0.004)
Interview interval`	0.105	(0.113)
24mns younger	-0.182	(0.253)
Age of Mother	0.062	(0.089)
Age of mother^2	-0.001	(0.001)
Mother's education	0.040	(0.034)
Dependency ratio	0.042	(0.094)
Diarrhea`	0.329	(0.555)
Illness`	0.151	(0.177)
Breastfeeding	-0.093	(0.247)
Toilet	0.279	(0.230)
Water	-0.298	(0.230)
Simpson index	0.226***	(0.068)
Weight	1.644***	(0.295)
Weight^2	0.013	(0.012)
N	1074	
F	489.091	
Root mean squared error	2.954	

Controls for shocks in the past 12 months included, Fixed effects for NDVI, AEZ, PSDI, interview quarter and stratum included.
* p < .1, ** p < .05, *** p < .01. Cluster-robust standard errors in parentheses.
` Non-lagged variables