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Young Lives
An International Study of Childhood Poverty

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Contents

Abstract

The aim of this paper is to examine the link between early stunting and later cognitive achievement. It differs from nutrition–learning studies in other developing countries in that it focuses on pre-school children, and therefore time spent in school plays no role. Data comes from a cohort of children in Peru (Young Lives survey), for which information is available from two points of time: 2002, when they were six to 20 months old; and 2006-7, when they were 4 to 6 years old. For the empirical estimation, I use Ordinary Least Squares (OLS), controlling for lagged child and household characteristics and taking into account community characteristics. To try to identify early nutrition, I use maternal height and exposure to low temperatures during the first months of life as instrumental variables (IVs) for early nutrition. OLS results show a positive and statistically significant impact of early nutrition on cognitive achievement four years later for the full sample. Using maternal height as an instrument, IV estimations produce a higher coefficient for the parameter of interest, implying that OLS might be downward biased. Using average minimum temperature as an IV for a sub-sample of communities located in the Highlands produces results in the same direction. Preliminary results are reported and discussed.

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About Young Lives

Young Lives is an innovative longitudinal study investigating the changing nature of childhood poverty. Young Lives is tracking 12,000 children in Ethiopia, India (Andhra Pradesh), Peru and Vietnam over 15 years through a quantitative survey and participatory qualitative research, linked to policy analysis. Young Lives seeks to:

- improve understanding of the causes and consequences of childhood poverty and to examine how policies affect children's well-being
- inform the development and implementation of future policies and practices that will reduce childhood poverty.

Young Lives is a collaborative partnership between research and government institutions in the 4 study countries, the University of Oxford, the Open University, other UK universities, and Save the Children UK.

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1. Introduction

This paper aims to contribute to the understanding of the nutrition–learning nexus. While the link between early nutrition and schooling outcomes is relatively well established in the economic literature (Glewwe et al. 2001; Glewwe and King 2001; Alderman et al. 2006; and Alderman et al. 2001) and in a handful of experimental studies (Pollit et al. 1993; Walker et al. 2005), here we test whether this link is already present during the pre-school period (i.e., pre-school cognitive achievement). If cognitive differences between well-nourished and undernourished children are already present before school attendance, this would suggest that nutrition affects educational outcomes not only because malnourished children are more likely to spend less time in school (due to delayed enrolment as shown by Glewwe and Jacoby (1995) and absenteeism due to health problems), but because they are ill-prepared for school life from a cognitive point of view.

Empirically, the main obstacle in tackling the relation between nutrition and learning is the endogenous nature of child health. Parental investment in nutrition, health and education can be seen as part of the same investment decision – investment in child ‘quality’. Inasmuch as this decision is partially based on factors that are unobserved, OLS is likely to be biased, initially in an unknown direction. In an attempt to identify causality, this paper uses maternal height and exposure to low temperatures as instrumental variables to identify early nutrition (the latter for a subsample of districts located in the Highlands). Exposure to low temperature events is a plausible instrument in the Peruvian context: frosts represent the main type of economic shock reported by households in the sample, particularly those households located in the Highlands. Maternal height, meanwhile, is predetermined.

Results reported in this version include OLS and IV estimations, using standardised Peabody test scores at 4 to 6 years old as the cognitive outcome measure and height-for-age z-scores at 6 to 20 months as the nutritional measure. All estimations control for child characteristics, as well as lagged parental and household characteristics that can be taken as exogenous within the model. Cluster fixed effects are also included to address community heterogeneity. OLS results show that the link between early stunting and cognitive achievement is negative and statistically significant. Specifically, if the average child in the sample was one standard deviation taller, she would score approximately 1.1 points more in the Peabody Picture Vocabulary Test (PPVT), representing approximately 6 per cent of the PPVT standard deviation.[1] This result is robust to the inclusion of additional controls (e.g., pre-school attendance, household consumption per capita) and to censoring problems in the lower tail of the Peabody Test distribution.

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[1] The following Young Lives disclaimer applies ’Verbal and mathematic skills and achievement were measured using tests developed or adapted from standardised international tests, such as the Peabody Picture Vocabulary Test (PPVT). Young Lives acknowledge that bias may arise when testing children with different languages and cultures using the same instruments, although measures were taken to adapt them to local contexts and languages and in no case were original standard scores used. Bias is an especially important consideration in testing children who speak minority languages. Reliability and validity results for test administrations and concerns are presented and discussed in Young Lives Technical Note 15. In particular, it is recommended that results should not be compared across countries, or across groups with different maternal languages within countries.’

Using maternal height as an IV produces a higher coefficient, suggesting that OLS is downward biased, possibly due to measurement error. When focusing on the subsample for which weather data is available (approximately 470 households), a positive link is found between average minimum temperature (expressed as deviations of the ten year average) during the first nine months of life and early nutritional status. Similarly, the reduced form shows that average minimum temperature during this critical period is correlated to cognitive achievement four years later. Results obtained using this variable as an IV reinforces the evidence that OLS is likely to be downward biased. Since the IV is weak, methods partially robust to the presence of weak instruments are used for inference and point estimates.

This paper is organised as follows. Section 2 briefly describes what is known about the links between early stunting and later cognitive outcomes. Section 3 formalises the relationship between nutrition and education as two outcomes that arise as optimal solutions from a unitary household decision-making process. It also provides a formal discussion of the identification problem involved in the use of non-experimental data. Section 4 presents the data used in the estimations. Section 5 presents OLS and IV results, providing a justification of the choice of instruments; and Section 6 provides guidelines for further research in the light of the results.

2. Early chronic malnutrition and later cognitive outcomes: The empirical literature

The empirical literature relating early nutrition to later cognition and school progress in developing countries from a causal point of view is not abundant. On the one hand, there is evidence from food-supplementation trials carried out in Guatemala, Jamaica, Colombia, Indonesia and Mexico between 1960 and 1980, most of which led to follow-up studies in later years. On the other hand, and more recently, a handful of econometric studies that use instrumental variables techniques sometimes in combination with household fixed effects have been able to show a causal nexus between early nutrition and school achievement using non-experimental data.

2.1 Food supplementation trials

At least five randomised food supplementation trials can be identified in developing countries: Guatemala (Pollit et al. 1993; Maluccio et al. 2005), Jamaica (Walker et al. 2005), Bogota-Colombia (Waber et al. 1981), Mexico (Grantham-McGregor et al. 1999) and Indonesia (Husaini et al. 1991).[2] Except for Indonesia, children were followed up years later. The most influential of these studies (with a sample size of about 2,000 children and follow-up to adulthood) is the Guatemala study, a food supplementation trial randomised at village level

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[2] These studies are identified in reviews by Grantham-McGregor et al. (2007), Grantham-McGregor et al. (1999) and Gorman (1995).

(two treated villages, two control villages).[3] Overall, results from these studies provide evidence in support of the existence of a link between early height-for-age, motor development and mental development during childhood, as measured by a wide array of cognitive tests (intelligence scales, verbal and non-verbal ability, spatial memory, information processing, literacy, numeracy and schooling outcome). However, whether these cognitive benefits persist during adolescence and adulthood is less clear.

Results across studies are hard to compare due to differences in design. For instance, studies differ in the type of food supplementation provided (different combinations of calories, nutrients and micronutrients), the timing of the intervention and the duration of the trial. The fact that timing differs is of particular importance because carrying out interventions on nutritionally-at-risk children who are still at gestation (which was the case in Mexico and for some of the children in Guatemala and Bogota-Colombia) might be substantially different from carrying out interventions on already stunted children (Jamaica and Indonesia), as the effects of early stunting on mental development could be irreversible (Walker et al. 2007: 7).

An additional feature of these studies is that their design tends to be imperfect, for obvious ethical reasons. In Guatemala, treatment was randomised at village level, with mothers living in the treated or placebo villages able to choose whether or not to attend feeding centres and, if they did so, the amount of intake. Thus, only the intention-to-treat can be measured. In Jamaica, although the treatment was randomly allocated among stunted children, the non-stunted control group was matched with the stunted control group for age, sex and neighbourhood. However, it is likely that other observable and, importantly, unobservable characteristics could explain differences between these two groups. Studies in Indonesia and Mexico also have design problems. The only seemingly ‘ideal’ study in terms of design is the Bogota-Colombia study.

2.2 Econometric evidence

Econometric studies (Glewwe et al. 2001; Glewwe and King 2001; Alderman et al. 2001; and Alderman et al. 2006) rely on two methodologies to infer causality from non-experimental data: household fixed effects (HFE or *within-siblings* estimation) and instrumental variables (quasi-experiments). Glewwe et al. (2001) applied HFE using data from the Cebu Longitudinal Health and Nutrition Survey (Philippines), finding a positive link between pre-school height-for-age and academic achievement by age 11 in terms of number of grades completed and performance on a school curricula related score test.[4] This result controls for the age of enrolment and time spent in school. Glewwe and King (2001) used data from the same cohort to study differences in the timing of a child’s growth failure on subsequent educational achievement. Instead of HFE, they instrumented nutrition, using information on price shocks, rainfall, maternal height and mother’s health during pregnancy.

Alderman et al. (2006) used HFE to estimate the effects of stunting on school attainment in Zimbabwe. They further instrumented the *within-sibling* nutrition with exposure to two specific events: the Zimbabwe civil war during late the 1970s and the 1982-1984 drought. Using this strategy, they found substantial returns for early nutrition in terms of number of grades

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[3] In the two treated villages, all children less than 7 years old and all pregnant women were eligible to receive a high-calorie, high-nutrient supplement at a feeding centre. In the two control villages an analogous group was eligible to receive a high-calorie *placebo* supplement.

[4] The test was based on the primary school curriculum in Philippines.

completed and age of enrolment. Similarly, Alderman et al. (2001) use price shocks (but not HFE) to instrument early nutrition, finding that it impacts upon school enrolment (Pakistan).

In addition to this evidence, Maluccio et al. (2005) go one step further by using data from the Guatemala food-supplementation trial, using standard OLS techniques to measure the nutrition-cognition link. Since the trial was randomised at the village level, they use age of exposure to the intervention to measure its impact. Their results are similar to those discussed previously in terms of school outcomes. In addition, they find substantial returns from the intervention in terms of IQ during adulthood.[5]

As this evidence shows, strong returns from early nutrition in terms of age of enrolment, number of grades completed and IQ levels during adulthood are found. However, it is still hard to separate the effect of malnutrition on time spent in school (age of enrolment, absenteeism) from its hypothetical direct effect on cognition (note that grade repetition could be the consequence of absenteeism due to health problems). In an extreme case, the greatest impact of malnutrition on schooling achievement could be due to delayed enrolment. A second, related, problem, is that econometric results are forced to use truncated data, i.e., some of the sampled children were still attending school, so that final grade attainment was not yet observed. On the one hand, this means that the cost of malnutrition in terms of time taken to earn a school degree (or foregone earnings due to delayed labour force enrolment) could be even higher than the currently estimate. On the other hand, the impact of malnutrition in terms of number of grades completed and, ultimately, on cognitive achievement, could be overstated.

3. A household model of investment in nutrition and education

In this section, the relationship between nutrition and cognitive outcomes is formally framed as the result of a household decision-making process. I use this framework to provide a formal discussion of the identification problem that arises when non-experimental data is used. I rely heavily on Glewwe and Miguel (2008) for specification issues and on Glewwe et al. (2001) for the discussion of the identification problem.

Consider a framework in which the first two years of life is considered as Period 1, and the remainder of infancy (in this case, from 3 to 5 years of age) as Period 2. Nutritional status accumulated at the end of Period 1, described as H_{1i}, is assumed to be an input for the formation of cognitive skills during Period 2, described as A_{2i} (measured at the end of the period). Both H_{1i} and A_{2i} are scalars. Denote parental investments in A_{2i} and H_{1i} as I_{2i} and I_{1i}, respectively. For instance, parental time devoted to educating the child is an example of I_{2i}, whereas the quantity and quality of food given to the child is an example of I_{1i}. Also, suppose that initial conditions matter, in the sense that the genetic endowment of the child plays a

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[5] Note that due to the design of the intervention, they only estimate the intention-to-treat effect (mothers within each treated village were able to choose whether or not to receive the food supplementation).

direct role in the production of both A_{2i} and H_{1i}.The production functions of H_{1i} and A_{2i} can then be defined in the following way:

$$A_{2i} = g_2[\varphi_{2i}, \upsilon_{2i}, H_{1i}, I_{2i}] \qquad (1)$$

$$H_{1i} = g_1[\varphi_{1i}, \upsilon_{1i}, I_{1i}] \qquad (2)$$

where (ϕ_{2i}, υ_{2i}) are time-invariant child and household predetermined characteristics that affect the outcomes of investment in cognitive skills, while (ϕ_{1i}, υ_{i1}) are the analogous terms for child and household characteristics that affect the outcomes of investment in nutrition. Specifically, ϕ_{2i} aims to reflect the child's innate ability to learn, whereas ϕ_{1i} aims to reflect the child's health endowment. Similarly, υ_{2i} and υ_{1i} might reflect aspects such as household intellectual environment and parental health knowledge, respectively. In this framework, A_{2i} and H_{1i} are determined according to (I_{1i}, I_{2i}), which in turn are chosen by parents. In that sense, not only are A_{2i} and H_{1i} part of the same decision-making process but A_{2i} is technologically constrained to previous investment in H_{1i}. Depending on the elasticity of substitution between H_{1i} and I_2, scenarios might arise in which early nutrition could effectively become a bottle-neck for later investment in cognition.

Consider a two-period framework where parents of child 'i' derive utility from their own consumption and from investing in child nutrition and cognition in a two-period framework,

$$V_i = U(C_{1i}) + \gamma U(C_{2i}) + \sigma_i f(H_{1i}, A_{2i}) \qquad (3)$$

where (C_{1i}, C_{2i}) is the consumption vector, γ is the parameter of time preference, $f(H_{1i}, A_{2i})$ is a function that represents the utility gains that parents derive from having a well-nourished, well-educated child ('child quality', as it is referred to in the literature) and σ_i is the parameter that measures parental preference for child quality. Each sub-element of V_i is assumed to be twice continuously differentiable and concave in its arguments.

$$\frac{\partial^2 U(C_i)}{\partial^2 C_i} < 0, i = 1,2 \qquad (A1)$$

$$\frac{\partial^2 f(H_{1i}, A_{2i})}{\partial^2 H_{1i}} < 0, \frac{\partial^2 f(H_{1i}, A_{2i})}{\partial^2 A_{2i}} < 0 \qquad (A2)$$

Furthermore, it is assumed that (1) and (2) are twice continuously differentiable in their arguments and increasing in (H_{1i}, I_{2i}) and I_{1i}, respectively. Consumption in each period can be defined in the following way:

$$C_{1i} = Y_{1i} - p_1 I_{1i} - s_{1i} \qquad (4)$$

$$C_{2i} = Y_{2i} - p_2 I_{2i} + R s_{1i} \qquad (5)$$

where (Y_{1i}, Y_{2i}) is exogenous income, s_{1i} represents savings (either positive or negative) which deliver a fixed interest rate r in the next period (R = 1+r). In this framework, the pay-off of human capital is expressed purely as an element of parent's utility (altruism). In this setup, parents optimally choose s_{1i}, I_{1i} and I_{2i} maximising (3) subject to (1)-(2) and (4)-(5). These solutions are denoted as s^*_{1i}, I^*_{1i} and I^*_{2i}. As the optimum solution, the marginal productivity of parental investment in cognitive skills, I^*_{2i}, equates to the marginal utility ratio of own consumption and child quality in the form of cognitive achievement.

$$\frac{\partial A_2}{\partial I_2^*} = \frac{p_2 \dfrac{\partial U(C_2)}{\partial C_2}}{\sigma \dfrac{\partial f}{\partial A_2}} \qquad \text{FOC (i)}$$

In turn, at the optimum, the marginal productivity of investment in child development in Period 1 equates to the marginal utility ratio of own consumption and child quality in the form of both nutritional status and cognitive skills.

$$\frac{\partial H_1}{\partial I_1^*} = \frac{p_1 \dfrac{\partial U(C_1)}{\partial C_1}}{\sigma(\dfrac{\partial f}{\partial H_1} + \dfrac{\partial f}{\partial A_2}\dfrac{\partial A_2}{\partial H_1})} \qquad \text{FOC (ii)}$$

Note that if assumptions A1-A2 hold, an increase in parental preference for child quality (that is, an increase in σ) leads to an increase in (I^*_{1i}, I^*_{2i}) and hence to higher levels of H_{1i} and A_{2i}. This result is useful because it shows that a positive correlation between H_{1i} and A_{2i} might arise simply due to heterogeneity in parental preferences for child quality. Finally, including the third First Order Condition (FOC) and rearranging using the previous results, the following relation arises between the relative prices, relative marginal utilities and relative marginal productivities of I^*_{1i} and $I^*_{2i:}$

$$\frac{\partial f \big/ \partial I^*_1}{\partial f \big/ \partial I^*_2} = \frac{\dfrac{\partial H_1}{\partial I_1}(\dfrac{\partial f}{\partial H_1} + \dfrac{\partial f}{\partial A_2}\dfrac{\partial A_2}{\partial H_1})}{\dfrac{\partial f}{\partial A_2}\dfrac{\partial A_2}{\partial I_2}} = R\frac{p_1}{p_2}$$

It is not strictly necessary to obtain a closed form solution for (I^*_{1i}, I^*_{2i}) to show that both types of parental investment are to be functions of the parameters of the model (ϕ_{1i}, ϕ_{2i}, υ_{1i}, υ_{2i}, p1, p2, σ, Y_{1i}, Y_{2i} R and γ). Demand functions for cognitive achievement and nutrition can be obtained by plugging I^*_{1i} and I^*_{2i} into (1) and (2).

$$A_{2i}^* = g_2[\phi_{2i}, \upsilon_{2i}, H_{1i}^*(\psi), I_{2i}^*(\psi)] \qquad (1a)$$

$$H_{1i}^* = g_1[\phi_{1i}, \upsilon_{1i}, I_{1i}^*(\psi)] \qquad (2a)$$

where $\psi = \phi_{1i}, \phi_{2i}, \upsilon_{1i}, \upsilon_{2i}, p_1, p_2, \sigma, Y_{1i}, Y_{2i}, R, \gamma$. Note that the demand for child nutrition is affected by child innate health endowment, ϕ_{1i}, in two ways. First, directly, as an element of the production function. Second, indirectly, through its effect on parental investment in Period 1. That is, in this framework, parents observe child health endowment and allocate health investments in Period 1 accordingly. Similarly, the child's innate cognitive ability has two effects on the accumulation of cognitive skills: a direct effect, as an input of cognition, and an indirect effect, as parents take it into account when allocating both health investments (Period 1) and cognitive investment (Period 2). The picture is similar for household predetermined characteristics that act as inputs in the production function, as they affect child skills both directly and indirectly, since they are also determinants of parental investment decisions.

Another definition that is of interest is the demand function of A_{2i} conditional on H_{1i},

$$A_{2i}^* \mid H_{1i} = g_2[H_{1i}; I_{2i}^* \mid H_{1i}(\phi_{2i}, \upsilon_{2i}, p_2, \sigma, Y_{1i}, Y_{2i}, R, \gamma)] \qquad (1a')$$

$$A_{2i}^* \mid H_{1i} = g_2[H_{1i}; \phi_{2i}, \upsilon_{2i}, p_2, \sigma, Y_{1i}, Y_{2i}, R, \gamma]$$

which explains the demand for cognitive achievement conditional on a fixed level of early child nutrition. In this case, I^*_{1i} is no longer on the right-hand side because its effect is already incorporated in H_{1i}. Similarly, cognitive investments take child nutrition as given, showing how additional parental investments in education would affect cognitive achievement for a fixed level of early nutrition.

Although not explicitly incorporated in this framework, there are other household characteristics that are likely to play a role in the determination of the outcomes of interest. Consider, for instance, the role of parental education. Parents that are better educated are likely to dedicate more time to educating their child. As Glewwe and Miguel (2008) suggest, the effective price of investing in the education of the child (p2, the price of I_{2i}) is lower (in terms of opportunity cost) for these parents. A similar case can be made for other household characteristics, such as mother's age, mother's native tongue, etc. (for very young mothers with little command of the predominant language, the effective price of educating the child is higher). Note that while some forms of parental investment are typically unobserved, many of their determinants are still observed. This matters empirically, as one can replace parental investments with their determinants. In particular, the following relationship is of interest,

$$A^*_{2i} \mid H_{1i} = g_2[H_{1i}; I^*_{2i} \mid H_{1i}(X_i, \phi_{2i}, \upsilon_{2i}, \sigma, \gamma, R)] \qquad \text{(1a'')}$$

$$A^*_{2i} \mid H_{1i} = g_2[H_{1i}; X_i, \phi_{2i}, \upsilon_{2i}, \sigma, \gamma, R]$$

where X_i incorporates all the observable determinants of parental investments (including household income and input prices). $\phi_{2i}, \upsilon_{2i}, \sigma$ are assumed to be unobservable (although observed by the parents). In this paper, specification (1a'') is the estimation target. As Glewwe and Miguel (2008) stress, an equation of this form provides different information to the production function. While the latter explains the biological process linking nutrition to cognitive skills, the conditional demand function incorporates both biological mechanisms and behavioural adjustments. Given an (exogenous) increase in child nutrition, the resulting change in cognitive achievement would be due to both the biological process linking the two variables and to changes in educational investments, I_{2i} (e.g., once parents observe that early nutrition has improved, they might adjust the allocation of educational investments to that child).

3.1 The identification problem

For the purpose of the empirical estimation, consider a log linear version of equation (1a''),

$$lA_{2i} = \varpi_{21} + \varpi_{22} lH_{1i} + \varpi_{23} X_i + z_i \qquad \text{(1a''')}$$

where z_i are the residuals of the equation. The linearity of the equation is obtained by making further assumptions about the technology and about the form of the utility function.[6] Specification (1a''') is the empirical target. If (1a''') is estimated using OLS, the estimation of the parameter of interest, ϖ_{22}, the impact of early nutrition, will be unbiased only if $E[H_{1i}, z_i] = 0$. But a key aspect that follows from the model is that child innate cognitive ability, the intellectual environment of the household and parental preference for child quality (embodied in υ_{2i}, ϕ_{2i}, and σ_i, respectively) must be part of the residuals, as they are unobserved.

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[6] Specifically, assuming a Cobb-Douglas technology for (1a) and (2a), a logarithmic form for $[U(C_{1i}), U(C_{2i})]$. and that time preferences, γ, equal the (inverse of the) rate of interest, 1/R, so that they cancel out.

$$z_i = \eta_H + \eta_i + \varepsilon_i \qquad (3)$$

where η_H and η_i represent the net effects of household and child unobserved factors, respectively, and ε_i is noise. In terms of the model previously presented, η_i captures the effect of the child's innate ability to learn as one of the determinant of parental investments. Likewise, η_H represents the net effect of household unobserved characteristics on parental investments. Thus, OLS will be biased if:

$$E[H_{1i}, \eta_H] \neq 0 \qquad \text{(i)}$$

$$E[H_{1i}, \eta_i] \neq 0 \qquad \text{(ii)}$$

which in turn creates the following possibilities:

P1. $E[H_{1i}, \eta_H] \neq 0$; if parental preferences for child quality are correlated with both child health and cognitive outcomes; or if household predetermined characteristics for the raising of a healthy child in Period 1 are correlated with household predetermined characteristics for the raising of a well-educated child in Period 2.

P2. $E[H_{1i}, \eta_i] \neq 0$; if the child's ability to learn is known by the parents in Period 1, they might allocate nutrition in Period 1 accordingly.

P3. $E[H_{1i}, \eta_i] \neq 0$; if the child's ability to learn is correlated with the child's health endowment due to genetics.

Related studies have used a combination of HFE and IV methods to eliminate bias due to P1-P3. HFE can be applied if there is comparable information available for two siblings 'i' and 'j', so that equation (1a''') can be defined for both siblings:

$$lA_{2i} = \varpi_{21} + \varpi_{22} lH_{1i} + \varpi_{23} X \ + (\eta_H + \eta_i + \varepsilon_i)$$

$$lA_{2j} = \varpi_{21} + \varpi_{22} lH_{1j} + \varpi_{23} X \ + (\eta_H + \eta_j + \varepsilon_j)$$

Taking the difference between the two siblings leads to the HFE estimation or the within-siblings estimation:

$$(\mathrm{l}A_{2j} - \mathrm{l}A_{2i}) = \varpi_{21}(lH_{1j} - lH_{1i}) + (\varepsilon_j - \varepsilon_i) \qquad (4)$$

In specification (4), potential bias due to P1 is ruled out. However, bias is still possible due to P2 and P3, which is why instrumental variables are still needed. Two published studies have used HFE-IV estimators: Glewwe et al. (2001) and Alderman et al. (2006). In Glewwe et al. (2001), the authors test the link between nutrition at age 2 and educational achievement during adolescence. They instrumentalise within-siblings nutrition at age 5 with nutrition at age 2 (H_0) for the older sibling. If we assume that, at age 2, the child's innate ability has not yet been revealed to the parents, this rules out bias due to P2. However, bias due to P3 is still possible.

In Alderman et al. (2006) (Zimbabwe), in addition to HFE, two events were used to instrument sibling difference in nutrition at age 3: the Zimbabwe civil war during the late 70's and the 1982-1984 drought, both of which took place when sampled children were still of pre-school age. While these shocks affected all households in the sample and, importantly, all children within each household, variation across children and within households was induced by interacting the shock with the age of the child at the time of the shock. These instruments rule out bias due to P2 and P3.

If there is bias due to P1-P3, the sign of the bias will depend on the sign of the correlation between H_{1i} and the correspondent omitted variable, as well as on the sign of the impact of the omitted factor on cognitive achievement (Behrman and Lavy (1994) discuss this extensively). Assuming the latter relation is positive, and focusing only on $E[H_{1i}, \eta_H]$ for simplicity, ϖ_{22OLS} can be biased upwards if parental preference for education and nutrition are positively related; or if parents who invest more time in educating their children are also more likely to devote more time to taking care of their nutrition. In turn, ϖ_{22OLS} can be biased downwards if any of the previous relationships were negative. For instance, if ability to raise healthy children is negatively correlated with ability to raise educated children, or if parental preference for nutrition and education are negatively correlated across households.

In practice, ϖ_{22OLS} can also be biased due to measurement error in the variable used to proxy chronic malnutrition (attenuation bias). Importantly, the attenuation bias and the omitted variable bias might go in opposite directions. While attenuation bias pushes OLS estimation towards zero, the omitted variable bias is likely to cause an upward bias in OLS. Interestingly, all econometric studies find that OLS is downward biased compared to IV results.

4. Empirical strategy and data

4.1 Empirical strategy

The objective is to estimate a conditional demand equation for cognitive achievement (i.e., conditional on early nutrition) akin to that defined in equation (1a'''). For this I use longitudinal data from the Young Lives survey in Peru, which collects information on early nutrition and cognitive achievement for the same cohort of children at age 6-20 months and 4.5-6 years, respectively (see data description in section 4.2).

The implementation of a strategy to avoid endogeneity due to P1-P3 is crucial for the reliability of the estimation of the coefficient of interest. For this, I rely on two instruments: (a) maternal height and (b) exposure to low temperatures, as measured by temperature variation at the community level. Other potentially valid instruments available in the dataset were considered (e.g., adverse events that affected the household during the first two years of the child's life) but dismissed due to their low correlation with early stunting after controlling for other factors.

The justification of using maternal height as an instrumental variable is based on the assumption that it does not have a direct effect on child cognitive achievement but that it can have an effect on child height-for-age. One possible channel of transmission between maternal height and child growth is due to the effect that maternal height has on the placental weight, which medical research suggests imposes a restriction on child size.[7] In turn, evidence from twin studies suggests a causal link between birth weight and child growth.[8] Thus, maternal height is likely to have a causal effect on child's height-for-age. However, one

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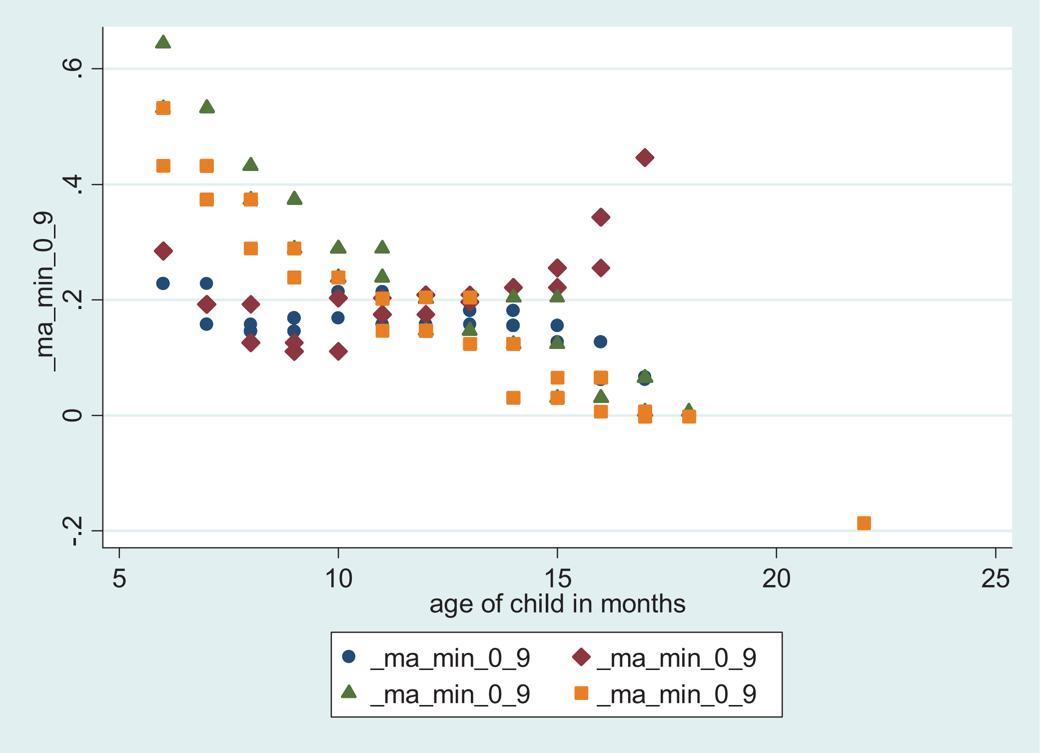
[7] There is considerable evidence that, beginning at 34-36 weeks, foetal growth slows down, owing to space constraints within the uterus. For instance,'[t]wins slow down demonstrably earlier when their combined weight is approaching that of a 36-week singleton foetus' (Falkner, Holzgreve and Schloo 1993).

[8] 'The Louisville Longitudinal Study of Twins (Falkner and Matheny 1993) provides evidence of a strong positive correlation between placental weight and birth weight. In monozygous twins, who are phenotypically similar, differences in birth weight and in postnatal growth may be determined by placental weight (…) Could it be that there is a critical placental mass, below which postnatal growth deficit occurs?' (Falkner, Holzgreve and Schloo1993.)

can still think of ways in which this variable can be endogenous, particularly in a developing country. It could be the case that taller mothers, who are likely to have been better nourished when children, might be better at educating their children because they accumulated more human capital compared to shorter mothers. This would imply that mother's height should be a direct determinant of cognitive achievement rather than an IV for early nutrition. In using this instrument, one is forced to assume that this is not the case.

For a subsample of districts located in the Highlands for which weather data is available, exposure to low temperatures is considered as an instrumental variable for early nutrition. The motivation for using such an instrument is country-specific: in Peru, an important segment of the population in the Highlands is frequently affected by frosts of variable duration and intensity. These events are also reported in the sample (22 per cent of households in the Highlands report having been affected by frosts between rounds). Subject to the characteristics of the event, exposure to temperature levels below the historical average in the Highlands can affect nutrition by disrupting household income-earning activities, by increasing children's nutritional requirements, or both. While households might differ in their strategies for coping with climate variation and children can be more or less vulnerable to these events according to differences in health endowment, the event itself (which is the instrument) is unlikely to be correlated with either child or household unobserved characteristics, so that bias due to P1-P3 is expected to be avoided (although it is acknowledged that this could be the case if the area of residence is exogenous). At the same time, since these events took place four years before cognitive achievement was measured, the assumption that any effect of these shocks on cognitive achievement took place only through their impact on early nutrition seems plausible.

Figure 1 *(horizontal axis, child's age in months; vertical axis, average temperature deviation) 0-9 month average*



To create the exposure to low temperatures variable, I used data from weather stations provided by *SENAMHI* (Peru National Meteorology and Hydrology Service) for a subsample of around 470 children (from six districts in the Highlands: Lucanas, Vinchos, Huaraz, Juliaca, Chuquis and Cajamarca) to calculate the average temperature to which they were exposed during the first months of life according to the district and year/month they were born. Specifically, I use as an instrument the average temperature for the nine months following birth, expressed as a deviation from the 1999-2007 average. Because of the way it is defined, the 'treatment' variable varies between communities and across children with different dates of birth within a given community. For comparability purposes, I restrict the use of this instrument to districts located in the Highlands so that variation arises mainly due to the date of birth of the children rather than place of birth.

4.2 Data

Data comes from the Young Lives survey in Peru, a sample of approximately 2,000 households who had at least one child below 2 years old at the time of the first data collection. From the initial survey in 2002, 1,963 children (96 per cent of the original sample) and their caregivers were traced and re-interviewed in 2006-7, when they were 4.5 to 6 years old. Most of the attrition is due to migration, but the attrition rate is very small by international standards. From the 2,052 households, 1,357 and 690 are located in urban and rural areas, respectively. Approximately 21 per cent of the sampled children were stunted in 2002. Key characteristics of the sample are described in Table 4.1.

Table 1 *Young Lives sample characteristics*

	Total	Urban	Rural
Sample size	2047	1357	690
PPVT score (range 50-140) in 2007 (median)	88	96	72
Height-for-Age Z-score in 2002 (average)	-1.02	-0.73	-1.57
% of stunted children	21%	14%	34%
Mother's years of schooling in 2002 (average)	7.8	9.6	4.4
% of mothers with Spanish as native tongue	92%	100%	77%
Child's birth weight (average)	3.2	3.3	3.0
Child's % of male	50%	51%	48%
Child's age in 2002 (in months)	12.2	12.2	12.4
Wealth Index in 2002 (average)	0.46	0.58	0.26

The sample is cluster stratified, with twenty districts randomly selected across the country. Thus, the sample provides information on households living in a variety of conditions in terms of geography, climate conditions, economic activities, access to public services, linkage with other cities, etc. Seven districts are located on the Pacific Coast, ten in the Highlands (*Sierra*) and three in the Amazonian Jungle. The objective was to sample 100 children in each district. Within districts, an initial community/town was randomly selected to start the search of eligible households (those with at least one child aged 6-20 months); in most cases, many communities within a district were surveyed to find 100 eligible households (especially in rural areas). In total, the sample is formed of 82 communities (31 in urban districts, 51 in rural areas). On average, districts located at a higher altitude (Highlands) are less developed in terms of access to private and public assets, show lower levels of maternal education and higher levels of linear growth retardation.

The two main variables extracted from this survey are height-for-age to proxy early stunting and Peabody Picture Vocabulary Test (PPVT) standardised scores to proxy cognitive achievement. The former, expressed as a z-score (WHO 2006 standards), was measured in

2002, when children were six to 20 months old. The latter, PPVT, is a test of receptive vocabulary that can be used to measure preparedness for school. In this test, the child hears a word ('boat', 'lamp', 'cow', etc) and is then asked to identify which of four figures corresponds with the spoken word. Questions vary according to the child's age and results are made age-comparable by using a standardised score that ranges from 55 to 150. The distributions of both variables are presented in the graphs below (4.1 and 4.2).

Figure 2

PPVT Histogram (Round 2)

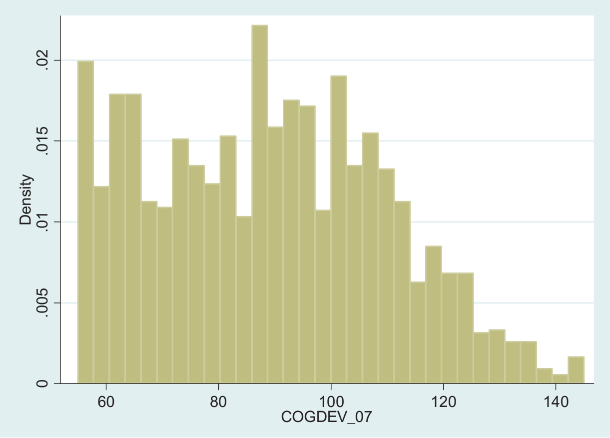


Figure 3

Height-for-age distribution (Round 1)

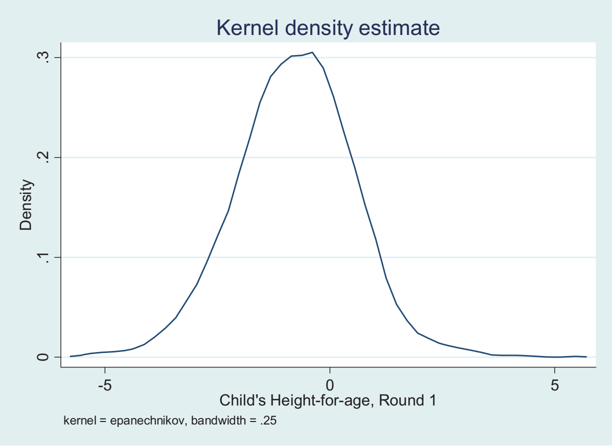


Table 2 *Percentage of undernourished children (stunting) across age groups: YL vs DHS*

Age	**DHS (%)**	**YL**	
		(%)	**n**
Less than 6 months	3.9	14.3	665
6-9 months	10.1		
10-11 months	12.7	15.8	329
12-15 months	22.1	24.2	487
16-23 months	31.3	28.2	631

At least three characteristics of these variables require further attention. First, height-for-age in the sample differs across age groups. In particular, children aged less than ten months report lower levels of growth failures (see Table 4.2 for a comparison between average height-for-age in Young Lives and the Peru Demographic and Health Survey across age groups). It is thought that during the first months of life the child is relatively well protected from malnutrition due to breastfeeding, which could explain this pattern. This, in turn, makes height-for-age as measured in 2002 an imprecise measure of linear growth retardation, as some of the youngest children who are not classified as stunted in 2002 might become stunted in later months. A second characteristic of the data that requires attention is that some of the children in the sample were attending pre-school, which has an effect on their performance on the PPVT in which success depends upon vocabulary. Finally, it is noteworthy that PPVT scores might be censored in the lower bound, due to the high frequency of children scoring 55, even though it is likely that these children have different abilities. The way I deal with these and other data characteristics is explained in the next section.

5. Empirical strategy and results

5.1 OLS results

This section presents OLS results obtained from regressing PPVT scores measured at 4 to 6 years old (Round 2) on height-for-age at six to 20 months (Round 1). This equation can be interpreted as a conditional demand function for cognition (i.e., conditional on early nutrition and replacing parental investments in education with their determinants). Child characteristics included in the estimation are sex, age, native tongue and birth order. Household characteristics are area of residence, mother's education, mother's native tongue (as a proxy of ethnicity), mother's age, household size, sex of the head of the household and access to private and public assets, all as reported by the household in 2002.[9] These are household characteristics that have been shown to matter in the context of health and nutrition-related estimations in Peru.[10] In addition, cluster fixed effects are included to control for community unobserved heterogeneity. See descriptive statistics in Table 5.1.

OLS results are presented in Table 5.2 for the whole sample, with standard errors (clustered, robust to heteroskedasticity – or differing variance – of unknown form) reported in brackets. According to these results, the association between early height-for-age and PPVT scores four years later is found to be positive and statistically significant. Had the average child been one standard deviation taller, she would score approximately 1.1 points more in the PPVT. This effect represents about 6.7 per cent of the PPVT standard deviation (see standardised coefficient). Its effect is relatively small in comparison to the effect of a one standard deviation increase in average mother's years of schooling (equivalent to an increase that represents about 27 per cent of the PPVT standard deviation), but important compared to the marginal effect of other cognitive determinants (e.g. housing quality index, access to services index; see standardised coefficients). Results are also reported for the subsample of Native Spanish speakers to take into account the possibility that PPVT results might be culturally biased towards those children who grew up in a Spanish-speaking household.

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[9] Private and public assets correspond to the definitions of the Housing Quality Index (building material of roof, floor and walls), the Consumer Durables Index (possession of radio, telephone, electric cooker, etc) and the Services Index (access to drinking water and electricity, type of toilet facility). These are all components of the Wealth Index estimated by the Young Lives project.

[10] See, for instance, Valdivia (2004).

Table 3 *Descriptive statistics of the full sample OLS regression*

Variable	Obs.	Mean	S.D.	Min.	Max.
PPVT standardised score, Round 2	1867	89.05999	20.76443	55.0	145.0
Child's height-for-age, Round 1	1867	-0.75961	1.263442	-5.0	3.8
Maternal height (in cm)	1863	150.0072	5.387509	122.8	174.7
Child's age in months, Round 2	1867	5.335614	0.387332	4.4	6.2
Child is female	1867	0.498661	0.500132	0.0	1.0
Child's birth order, Round 1	1867	2.619711	2.042684	1.0	14.0
Child's native tongue is Aymara or other than Spanish or Quechua	1867	0.018747	0.135665	0.0	1.0
Child's native tongue is Quechua	1867	0.123192	0.328746	0.0	1.0
Caregiver's age	1867	26.96733	6.958575	14.0	68.0
Mother's years of education	1867	7.805035	4.360315	0.0	17.0
Mother's native tongue is Quechua	1867	0.250134	0.433206	0.0	1.0
Mother's native tongue is Aymara	1867	0.02196	0.146593	0.0	1.0
Mother's native tongue is other than Spanish, Quechua or Aymara	1867	0.028923	0.167636	0.0	1.0
Head of the household is male, Round 1	1867	0.875737	0.32997	0.0	1.0
Household size, Round 1	1867	5.711837	2.336275	2.0	18.0
Housing quality index, Round 1	1867	0.461946	0.261893	0.0	1.0
Consumer durables index, Round 1	1867	0.276469	0.216585	0.0	0.9
Access to services index, Round 1	1867	0.668318	0.332093	0.0	1.0
Area of residence is rural, Round 1	1867	0.330477	0.470511	0.0	1.0
Child didn't speak in Spanish during PPVT administration	1867	0.111944	0.315382	0.0	1.0

Table 4 *OLS results / Dependent variable: PPVT score*

	Full sample			Native Spanish speakers only	
	Coefficient	Standard error	Standardised coefficient	Coefficient	Standard Error
Child's height-for-age, Round 1	1.102**	0.388	0.067	1.173**	0.422
Child's age in months, Round 2	3.720**	1.534	0.069	3.693*	1.809
Child is female	-0.566	0.673	-0.014	-0.439	0.760
Child's birth order, Round 1	-0.197	0.306	-0.019	-0.522*	0.279
Child's native tongue is Aymara or other than Spanish or Quechua	-0.907	2.147	-0.006	(dropped)	
Child's native tongue is Quechua	-1.867**	0.877	-0.030	(dropped)	
Caregiver's age	0.130	0.083	0.044	0.155*	0.085
Mother's years of education	1.304***	0.124	0.274	1.304***	0.132
Mother's native tongue is Quechua	-0.091	2.381	-0.002	0.343	2.491
Mother's native tongue is Aymara	3.625	3.773	0.026	3.685	3.768
Mother's native tongue is other than Spanish, Quechua or Aymara	-0.117	2.951	-0.001	0.154	3.184
Head of the household is male, Round 1	-0.207	1.329	-0.003	-0.343	1.417
Household size, Round 1	-0.142	0.155	-0.016	-0.071	0.160
Housing quality index, Round 1	5.223**	2.304	0.066	5.911**	2.541
Consumer durables index, Round 1	11.602***	2.188	0.121	10.442***	2.167
Access to services index, Round 1	6.880***	1.494	0.110	6.985***	1.873
Area of residence is rural, Round 1	-2.020	1.603	-0.046	-2.863*	1.610
Child didn't speak in Spanish during PPVT administration	2.982	1.832	0.045	2.264	7.542
Constant	44.911***	9.158		44.791***	10.315
Number of observations	1,867			1,602	
Adjusted R2	0.468			0.461	

NOTE: .01 - ***; .05 - **; .1 - *.
**Includes cluster fixed effects. Standard errors are clustered and robust to heteroskedasticity.

One characteristic of the PPVT score distribution that requires attention is that this variable seems to be censored in the lower bound (see histogram, Graph 4.1). The minimum score is 55 and there is a relatively high percentage of children reporting this score. This leads to the suspicion that the test might be failing to discriminate among low-achievers, i.e., there might be differences in the word knowledge of children who score 55, but this cannot be observed because of the test design, which can lead to a biased estimation. To account for this, Annex B reports results using a censored regression model. Results remain unchanged.

Compared to the information available in the survey, the previous estimation is parsimonious. While there are other informative variables such as place of birth, type of assistance at birth, number of antenatal visits, vaccines and the like, these variables are not included in the regression because they can all be regarded as endogenous within the model (chosen by the parents). However, even though care has been taken in choosing household controls that can be considered exogenous, criticism could be made regarding this assumption of exogeneity in relation to mother’s education and access to private assets. If one were to extend the original model to account for inter-generational mechanisms, it could be argued that more able parents are more likely to accumulate physical and human capital assets over the life-cycle and that, in turn, these parents are also more likely to provide a better education for their children. Thus, the impact of the mother’s education on cognitive achievement would be biased upwards, affecting the properties of all the estimated parameters. The same logic follows for the holding of private assets. However, it is important to include these variables in order to control for household heterogeneity. Hence, we are forced to assume that unobserved parental ability plays no role in the determination of PPVT scores once parental education and access to private assets are controlled for.

5.1.1 Robustness checks

Two other features require further discussion: (a) average height-for-age varies significantly across age groups for children less than 2 years old, which complicates its interpretation as a measure of early nutrition; and, (b) some of the sampled children were attending pre-school in 2007, which affects their performance on the PPVT (see Graph 5.1). The former is partially taken care of by including an age control in the estimation. Two other robustness checks (reducing the sample to those who were at least ten months old by 2002 and using height-for-age as measured in 2007) are presented in Table 5.3 (from here onwards, control variables are omitted from the tables).

Pre-school attendance can be interpreted as a community characteristic. This is justified on the grounds that, firstly, parents who do not send their children to pre-school in the sample report failure to do so because there are no available pre-school institutions in their communities; and, second and related to the first point, because it is directly observable that differences in PPVT score between children who attend pre-school and those who do not reduce greatly after controlling for community heterogeneity (compare Graphs 5.1 and 5.2). Note that attendance of pre-school should not be included as a regressor as it is clearly endogenous in the context of the theoretical model presented, but it is included in the robustness check estimation for the sake of information (Table 5.3).

Besides pre-school attendance, birth weight and current household consumption per capita were included as additional controls for the robustness check. The latter variable was added to disentangle the effect that monetary poverty has on cognitive achievement from the effect that early nutrition has on the same outcome. In comparison to the results reported in Table 5.2, the effect of early nutrition reduces slightly when adding these controls, but the coefficient remains statistically significant.

Figure 4

PPVT score according to attendance to preschool(density)

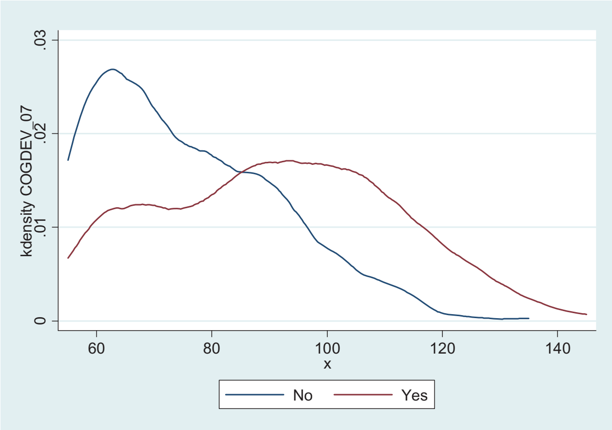

Figure 5

PPVT score according to attendance to preschool

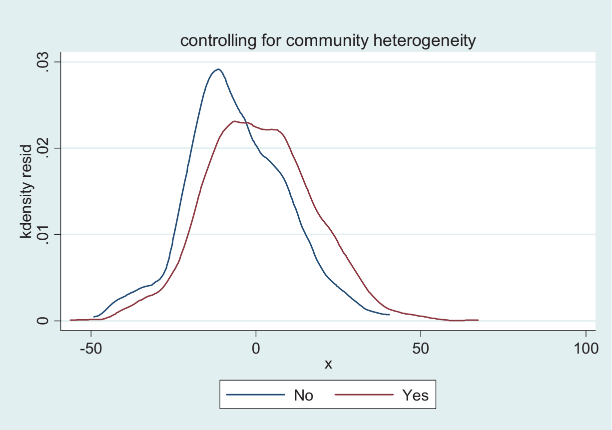

Table 5 *Robustness Checks*

Robustness check / Dependent variable: Standardised PPVT scores

	Additional controls			**Age > 10 months**	**Using contemporaneous Height-for-age**
Child's Height-for-age, Round 1	0.910**	1.079***	0.927**	1.150**	
	(0.394)	(0.374)	(0.392)	(0.507)	
Child's Height-for-age, Round 2					2.126***
					(0.439)
Log household consumption per capita	2.732***		2.739***		
	(0.419)		(0.540)		
Child attended pre-school	3.690***		3.626***		
	(1.123)		(0.978)		
Child's birth weight		1.003	0.609		
		(0.708)	(0.718)		
Child controls	Yes	Yes	Yes	Yes	Yes
Maternal controls	Yes	Yes	Yes	Yes	Yes
Household controls	Yes	Yes	Yes	Yes	Yes
Cluster fixed effects	Yes	Yes	Yes	Yes	Yes
Number of observations	1,865	1,636	1,634	1,099	1,867
Adjusted R2	0.482	0.440	0.454	0.488	0.473

Note: .01 - ***; .05 - **; .1 - *.

** Standard errors reported in brackets (clustered, robust to heteroskedasticity).

5.2 IV estimations

Table 5.4 presents two stage least square (TSL2) results using maternal height as an instrument for child nutrition. For comparability purposes, OLS is re-estimated as the sample is marginally different.[11] It is important to establish whether the (partial) correlation between maternal height and child nutrition is high, as a low correlation has consequences for the reliability of the TSLS estimation of the coefficient of interest. The standard approach for testing whether the correlation between the instrumental variable and the endogenous variable is sufficiently high (i.e., whether the instrument is strong) is to use the Stock-Yogo test proposed in Stock and Yogo (2004). This test uses the F-statistic of the first-stage and compares it with critical values calculated by these authors to test the null hypothesis that the instrument is weak.[12] As reported in Table 5.4, the first-stage F-statistic for this instrumental variable largely surpasses the Stock-Yogo critical value, so the null hypothesis that the instrument is weak is rejected.

TSLS estimates obtained using maternal height as an instrumental variable result again in a positive, statistically significant coefficient, which suggests that the relationship between early nutrition and cognitive achievement found with OLS is not spurious. Interestingly, the TSLS estimation of the coefficient doubles that obtained by OLS, suggesting that OLS might be downward biased.

Table 6 *IV estimation (TSLS) / Dependent Variable: PPVT score, Round 2*

	OLS (dependent variable: PPVT)		**Second stage (dependent variable: PPVT)**		**First stage (dependent variable: early height-for-age)**	
	Coefficient	**S.E.**	**Coefficient**	**S.E.**	**Coefficient**	**S.E.**
Child's Height-for-age, Round 1	1.098***	(0.367)	2.154**	(1.043)	-	
Maternal height (in cm)	-		-		0.056***	(0.005)
Child controls	Yes		Yes		Yes	
Maternal controls	Yes		Yes		Yes	
Household controls	Yes		Yes		Yes	
Cluster fixed effects	Yes		Yes		Yes	
First-stage statistics						
F-statistic	-		-		124.89	
Stock-Yogo Critical Value						
10% maximal IV size	-		-		16.38	
15% maximal IV size	-		-		8.96	
Weak instrument robust inference						
Anderson-Rubin test (chi2 p-value)	-		-		0.04	
Number of observations	1,863		1,863		1,863	
Adjusted R2	0.468		-		-	

Note: .01 - ***; .05 - **; .1 - *.
** Standard errors reported in brackets (clustered, robust to heteroskedasticity).

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[11] I have used both ivregress and ivreg2 STATA commands, using TSLS as the default method unless otherwise expressed. For the standard errors, I used vce(cluster clustvar) to allow for within-community correlation between observations.

[12] See Stock and Yogo 2004 for a full description of this test.

I now turn to the second proposed instrumental variable. For the subsample of districts located in the Highlands for which temperature data is available, minimum average temperature during the first 'n' months of life expressed in deviations from the average minimum over ten years is used as an instrument for early nutrition. Since there is no reason to focus on a specific interval of time *a priori*, several are considered here: 0 to 3 months, 0 to 6 months and 0 to 9 months after birth (further intervals, e.g., from 12 to 18 months, were not considered as this would entail a drastic reduction in sample size, since a large proportion of the sampled children were aged less than 12 months when anthropometric measures were measured). Anticipating possible weak instrument problems, reduced-form results are reported first to test the link between the excluded instrument and later cognitive achievement. See Table 5.5, Part A.

Only for the 0-9 month period is a positive, statistically significant coefficient found. The fact that the relationship is only significant for this period is not surprising, as it is likely that during the first six months children are relatively well protected from nutritional shocks due to breastfeeding. The coefficient obtained for the 0-9 month period (equal to 15.120) implies that a 1 S.D. increase in average temperature during this period is associated with an increase in PPVT score that represents around 10 per cent of the PPVT S.D. (see mean and standard deviation of variables involved in the estimation in Appendix A). This shows that there is a link between temperature variation during the first nine months after birth and cognitive achievement four years later. Since the average temperature for the 0-3 and 0-6 months period is not statistically significant, I focus only on the 0-9 month period for the remaining analysis.

To carry out a TSLS estimation, it is essential to establish whether the correlation between the instrumental variable and the endogenous variable is high. While average temperature in the first 9 months is positively correlated with height-for-age (Table 5.5., Part B), the F-statistic of the first-stage (F=6.41) is below the Stock-Yogo critical value, implying that the correlation between the instrument and the problematic regressor is low and, therefore, the instrument is weak. In the presence of a weak instrument, both the estimation of the coefficient of interest and standard errors based on TSLS are unreliable and alternatives methods need to be used (see, for instance, Hahn and Hausman 2003; and Murray 2006). For the purpose of inference (that is, to test the null hypothesis that the coefficient linking early nutrition and cognitive achievement is zero), one can use the Anderson-Rubin test,[13] whereas for the purpose of obtaining an estimate of the coefficient of interest, we use a Fuller estimator as an alternative to the TSLS estimator (see Murray 2006; Andrews and Stock 2005). This estimator has been shown to be partially-robust to the presence of weak instruments. Both results are reported in Table 5.5 (for comparability purposes OLS is re-estimated for this sub-sample).

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[13] This test is equivalent to the conditional likelihood ratio test proposed by Moreyra (2009) in the presence of one endogenous variable and one instrumental variable (just-identified model).

Table 7 *Sub-sample: Highlands. IV estimation: Reduced form, First and Second Stage using average temperature as instrument*

	Part A			**Part B**			**Part C**	
	Reduced-form equation (dependent variable: PPVT)			**First-stage (dependent variable: early height-for-age)**			**OLS**	**Second stage, Fuller estimation**
	(0-3m)	**(0-6m)**	**(0-9m)**	**(0-3m)**	**(0-6m)**	**(0-9m)**		**(0-9m)**
Child's height-for-age, Round 1	-	-	-	-	-	-	2.485***	6.980***
							(0.209)	(2.525)
Min. average temp. 0-3 months	3.255	-	-	0.112	-	-	-	-
	(4.962)			(0.352)				
Min. average temp. 0-6 months	-	9.394	-	-	0.556	-	-	-
		(6.706)			(0.329)			
Min. average temp. 0-9 months	-		15.120**	-	-	0.924*	-	-
			(5.807)			(0.365)		
Child controls	Yes			Yes			Yes	
Maternal controls	Yes			Yes			Yes	
Household controls	Yes			Yes			Yes	
Cluster fixed effects	Yes			Yes			Yes	
First stage F-statistic	-	-	-	0.10	2.86	6.41	-	-
Stock-Yogo critical value								
10% maximal IV size	-	-	-	16.38	16.38	16.38	-	-
15% maximal IV size	-	-	-	8.96	8.96	8.96	-	-
Weak instrument robust inference								
Anderson-Rubin Test (chi2 p-value)	-	-	-	0.46	0.12	0.00	-	-
Number of observations	461	473	473	461	473	473	473	473
Adjusted R2	0.474	0.477	0.477	0.154	0.154	0.155	0.490	-

Note: .01 - ***; .05 - **; .1 - *.

** Standard errors reported in brackets (clustered, robust to heteroskedasticity). Fuller estimator uses a parameter equal to 4.

Focusing on the 0 to 9 months average temperature instrument, the p-value of the Anderson-Rubin test shows that the null hypothesis that the nutrition effect is zero is rejected in this case, reinforcing the idea that a nutrition-learning nexus exists. Using a Fuller estimator (with parameter equal to 4), the point estimate obtained more than doubles that obtained by OLS (a coefficient of 6.980 versus 2.485, respectively), suggesting again a downward bias in OLS.

Overall, the IV estimations reported reinforce the idea that early nutrition is causally linked to cognitive achievement. Although the theoretical model suggests that OLS should be upward biased, measurement error in the explanatory variable could explain a downward bias in the OLS estimation similar to the one I found and to that which has been found in other studies (Glewwe et al. 2001; Alderman et al. 2006).[14]

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[14] An alternative explanation for the downward bias in OLS is related to the omitted variable interpretation of the endogeneity problem. In particular, the impact of nutrition on cognition could be understated if there is a negative correlation between an omitted (unobserved) factor in the cognitive achievement demand function and height-for-age in 2002. As suggested by Behrman (1996), this could occur, for instance, if some parents are good at raising healthier children but not at educating them (or vice versa). But this possibility is rather counterintuitive.

6. Preliminary conclusions and further research

The results show that the link between early malnutrition and later cognitive outcomes is already present at pre-school age in a sample of Peruvian children. This result is robust to the inclusion of a wide array of controls. I tried to establish the case for causality by using maternal height and average minimum temperature during the first months after birth as a source of variation in early nutrition that can be assumed to be orthogonal to household and child unobservable characteristics. Using maternal height as an instrument, a higher coefficient was obtained compared to OLS. In turn, when using average temperature deviation during the first nine months of life as an IV for the subsample, a significant relationship between early nutrition on later cognitive achievement was also found.

Besides confirming that the nutrition-learning nexus is already present at an early age, this paper has produced evidence linking exposure to cold weather in the Andean highlands at an early age to later child development. This is important from a policy perspective, as those families living in the Peruvian Highlands are frequently affected by these climate events.

Further research will be focused on analysing whether the timing of malnutrition matters. This can be done more thoroughly by looking at how height-for-age at 4-6 years of age of children in the Highlands was affected by temperature variation in different sub-periods during the first three years of life (0-12, 12-24, 24-36 months). I will also test for the possible existence of complementarities between early nutrition and household cognitive investments between rounds. The hypothesis is that cognitive investments might be less productive when directed towards children who were malnourished at an early age.

Finally, given the strong predictive value of maternal height and birth weight on early nutrition, subsequent efforts will be directed towards the formulation of a model linking these variables in a recursive way.

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Appendix A: Descriptive statistics

A.1: Descriptive statistics of Highlands sub-sample regression

Variable	**Obs.**	**Mean**	**S.D.**	**Min.**	**Max.**
Average minimum temperature 0-9 months after birth (expressed as deviations from 10 year average)	473	0.121223	0.146076	-0.2	0.5
Average minimum temperature 0-6 months after birth (expressed as deviations from 10 year average)	473	0.121169	0.162497	-0.3	0.5
Average minimum temperature 0-3 months after birth (expressed as deviations from 10 year average)	461	0.096692	0.203233	-0.3	0.6
PPVT standardised score, Round 2	473	88.39112	20.60168	55.0	145.0
Child's height-for-age, Round 1	473	-1.13841	1.099833	-3.8	2.9
Child's age in months, Round 2	473	5.344221	0.346906	4.6	6.2
Child is female	473	0.509514	0.500439	0.0	1.0
Child's birth order, Round 1	473	2.767442	2.055593	1.0	13.0
Child's native tongue is Aymara or other than Spanish or Quechua	473	0.029598	0.169656	0.0	1.0
Child's native tongue is Quechua	473	0.221987	0.416023	0.0	1.0
Caregiver's age	473	27.2389	6.619822	16.0	51.0
Mother's years of education	473	7.44186	4.687852	0.0	17.0
Mother's native tongue is Quechua	473	0.479915	0.500125	0.0	1.0
Mother's native tongue is Aymara	473	0.057083	0.232246	0.0	1.0
Mother's native tongue is other than Spanish, Quechua or Aymara	473	0.02537	0.157413	0.0	1.0
Head of the household is male, Round 1	473	0.849894	0.357553	0.0	1.0
Household size, Round 1	473	5.723044	2.388496	2.0	18.0
Housing quality index, Round 1	473	0.42895	0.252837	0.0	1.0
Consumer durables index, Round 1	473	0.258457	0.20724	0.0	0.9
Access to services index, Round 1	473	0.624207	0.364297	0.0	1.0
Area of residence is rural, Round 1	473	0.315011	0.465012	0.0	1.0
Child didn't speak in Spanish during PPVT administration	473	0.181818	0.386103	0.0	1.0

Appendix B: Tobit marginal effects

Marginal effects after tobit

y = E(COGDEV_07|COGDEV_07>55) (predict, e(55,.))

= 89.500992

Variable	dy/dx	Std. Err,	z	P>|z|
Child's height-for-age, Round 1	1.415815	0.40898	3.46	0.001
Child's age in months, Round 2	5.252029	1.26007	4.17	0
Child is female	-0.5831128	0.67031	-0.87	0.384
Child's native tongue is Aymara or other	0.275635	2.17451	0.13	0.899
Child's native tongue is Quechua	0.1405757	2.46273	0.06	0.954
Caregiver's age	0.0663169	0.0586	1.13	0.258
Head of the household is male, Round 1	-0.6274715	1.25109	-0.5	0.616
Mother's years of education	1.199541	0.12969	9.25	0
Mother's native tongue is Quechua	2.089021	2.10049	0.99	0.32
Mother's native tongue is Aymara	-0.1272105	1.21469	-0.1	0.917
Mother's native tongue is other (diff. from Spanish)	1.973466	2.78282	0.71	0.478
Household size, Round 1	-0.2262487	0.14155	-1.6	0.11
Housing quality index, Round 1	4.802156	2.31116	2.08	0.038
Consumer durables index, Round 1	14.41301	2.76365	5.22	0
Access to services index, Round 1	10.57238	2.08638	5.07	0
Area of residence is rural, Round 1	-3.59238	1.18002	-3.04	0.002
Child didn't speak in Spanish during PPVT administration	5.617239	2.22578	2.52	0.012

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The Institute of Education, University of London, UK

Child and Youth Studies Group (CREET), The Open University, UK

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