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Working Paper

Young Lives

The Sooner The Better But It's Never Too Late:

The Impact of Nutrition at Different Periods of Childhood on Cognitive Development

Andreas Georgiadis

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JANUARY 2017

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ISBN 978-1-909403-78-6

A catalogue record for this publication is available from the British Library.

Core funded by

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Acknowledgements

I am grateful to Liza Benny for invaluable research assistance. I would also like to thank Jere Behrman, Flavio Cunha, Paul Glewwe, and an anonymous reviewer, for constructive feedback. Comments and suggestions by participants in seminars at the University of Pennsylvania, the University of Minnesota, UCLA, Emory University, the World Bank, IFPRI, IADB, CESS-Hyderabad, and the NBER cohort studies meeting in California are gratefully acknowledged.

This research was supported by the Bill and Melinda Gates Foundation (Global Health Grant OPP10327313), Eunice Shriver Kennedy National Institute of Child Health and Development (Grant R01 HD070993) and Grand Challenges Canada (Grant 0072-03 to the Grantee, The Trustees of the University of Pennsylvania). The data used in this study come from Young Lives, an international study of childhood poverty, following the lives of 12,000 children in four countries (Ethiopia, India, Peru and Vietnam) over 15 years.

Summary

Although it has been argued that undernutrition and its consequences for child development are irreversible after the age of 2, the evidence in support of these hypotheses is inconclusive. This working paper investigates the impact of nutrition at different periods from conception to middle childhood on cognitive achievement in early adolescence using data from Ethiopia, India, Peru, and Vietnam. In order to address estimation problems the paper develops a conceptual framework that delineates the channels through which child health impacts cognitive development and uses exogenous variation in nutritional status arising from weather shocks.

Results suggest that child growth both before and after the first 1,000 days is responsive to weather shocks and impacts cognitive achievement in early adolescence. The paper also finds that part of the effect of early growth on later cognitive achievement manifests through growth in interim periods. Another novel result is that parental investment responses to a change in child health depend on the timing of this change.

These findings have important policy implications. On the one hand, results indicate that nutrition early in life is important for physical growth and cognitive development in subsequent stages of childhood, but on the other hand they suggest that nutrition-promoting investments after infancy and early childhood can act as a remedy for early nutrition and cognitive deficits and protect from nutritional insults in later stages that may also lead to developmental setbacks. Overall, the evidence suggests that nutrition-promoting interventions that start early in life and continue to subsequent stages of childhood, combined with support in other areas such as cognitive stimulation and parental involvement, may hold the most promise for the promotion of child development.

1. Introduction

The literature on human development in economics, psychology, and other disciplines (Cunha and Heckman 2007; Heckman 2007; Grantham-McGregor et al. 2007) highlights the existence of critical and sensitive periods, when investments and environments are particularly effective in fostering the acquisition of capabilities. The identification of these periods for the development of different types of capabilities is therefore crucial for the design of effective interventions that mitigate harm and promote human development. Nevertheless, relatively little is still known on how resilient individuals are to adversity and the extent to which compensation at a later stage of life can remedy earlier deficits (Rutter 2004; Cunha et al. 2006; Almond and Currie 2011).

In low- and middle-income countries, where child undernutrition is endemic and has deleterious implications for child survival, health, and development (Black et al. 2008, 2013), interventions focus on the first 1,000 days of life, the period from conception to the age of 24 months, because this is highlighted as a critical period during which physical growth and cognitive development are particularly susceptible to nutritional insults (Pollitt et al. 1996; Glewwe et al. 2001; Black et al. 2008, 2013). In particular, it has been suggested that growth retardation and cognitive deficits resulting from undernutrition during this period can hardly be reversed in later periods (Martorell et al. 1994; Glewwe et al.,2001; Victora et al. 2010). The evidence, however, does not seem to provide unequivocal support to these hypotheses, as several studies find evidence consistent with reversal of undernutrition and associated developmental setbacks through changes in the environment and interventions occurring after the age of 2 (Golden 1994; Alderman et al. 2006; Grantham-McGregor and Baker-Henningham 2010; Prentice et al. 2013). Although this evidence may refute the "irreversibility" claim, it has been suggested that a primary focus of nutrition- and growth-promoting interventions on the first 1,000 days is still justified on the basis that the effect of undernutrition during this period on child health and development is larger compared to that of undernutrition in later periods (Black et al. 2013). Nevertheless, this is viewed by many as an assertion, as the evidence on the relative impact of nutrition at different periods of early life on cognitive development remains scarce (Glewwe and King 2001; Maluccio et al. 2009). The few existing studies investigating how the timing of undernutrition affects subsequent cognitive achievement are mainly experimental studies based on interventions (McKay et al. 1978; Maluccio et al. 2009; Barham et al. 2013) in children of different ages and studies from the biomedical literature investigating the association between nutrition trajectories, as measured by growth at different periods, with cognitive achievement using observational data (Gandhi et al. 2011; Crookston et al. 2013; Georgiadis et al. 2016). These studies have advantages but also several limitations. Experimental studies provide estimates of the impact of interventions on cognitive achievement that may not only manifest through nutrition improvements and produce mixed evidence that may partly reflect that results are context- and period-specific, and thus have limited external validity. Furthermore, the few studies from the biomedical literature examining the relationship between growth trajectories and cognition produce evidence of correlations that is difficult to interpret.

To our knowledge, the only study to date that directly investigates the impact of the timing of undernutrition on cognitive achievement is by Glewwe and King (2001). Glewwe and King (2001) examine the effect of growth at different periods from conception to age 8 on cognitive development at age 8, using data from the Cebu longitudinal health and nutrition survey and instrumental variables (IV) estimation that enables them to address the endogeneity of child growth. Their key finding is that only growth during the second year of life has a positive and significant effect on cognitive achievement at age 8. Nevertheless, one reason why the authors do not find a significant effect of growth after the ages of 2 on cognitive achievement may be that they consider growth over a long period, between age 2 and 8, and this may dilute the significant effect of growth in any sub-period during these years. Furthermore, one limitation of this study, that also plagues other studies examining the relationship between nutrition trajectories and human capital outcomes (Martorell et al. 2010), stems from the inclusion in the same specification of nutrition measures at different periods that are strongly correlated. Despite the use of IV estimation, estimates of the effect of growth at a given period on cognitive achievement at a later period are expected to be biased and inconsistent when one conditions for growth in interim periods, as this approach does not take into account the effect of early growth on later cognition manifesting through growth in interim periods.

Another limitation of existing studies purporting to identify critical periods for the impact of nutrition on cognitive development is that their results may reflect, at least in part, behavioural responses by parents, who may increase or decrease investments in the face of changes in child nutritional status (Glewwe and Jacoby 1995; Alderman et al. 2001). Therefore, because these studies do not produce evidence of the direction of these responses, it is very difficult to infer from their results the magnitude of direct biological effects running from nutrition in each period to cognitive development that is needed for the identification of critical periods (Almond and Currie 2011). The question of how parents respond to changes in child health, however, is little investigated and the existing evidence is rather mixed (Pitt et al. 1990; Behrman et al. 1994). Moreover, we know very little on whether and how parental investment responses depend on the timing of changes in child health.

This paper investigates the impact of child nutrition, as measured by growth, at different periods from conception through middle childhood on cognitive achievement in early adolescence, using data from the Young Lives cohort study in Ethiopia, India, Peru, and Vietnam. Several features of my analysis allow me to address some of the key estimation problems plaguing previous studies. As discussed above, one estimation problem arises from serial correlation of growth that makes it difficult to isolate the total effect of growth in each period on cognition. In order to address this problem, I develop a conceptual framework of the determination of child health and cognitive skills over different periods of childhood that delineates the channels through which health in each period impacts cognitive skills, and allows health at a given period to impact cognitive skills at a later period also through health in interim periods. The framework is used to distinguish between two demand relationships for cognitive skills conditional on child health; one that accounts for all channels through which child health impacts cognitive skills, and one that does not account for the effect of child health manifesting through health in subsequent periods. Estimation of both relationships allows one to identify the total effect of health on cognitive skills in each period and to assess the importance of the causal pathway linking early health with later cognition manifesting through health in interim periods. One key implication of the framework is that early health insults lead to cognitive deficits that are expected to accumulate over the life course, and this process could be counteracted through compensatory investments in child health and cognitive skills in later periods.

Another problem in estimation emanates from endogeneity of child nutrition in different periods due to the simultaneous determination of child health and cognitive skills through parental investments and to various sources of measurement error in nutrition measures. I overcome this problem employing IV estimation using as instruments for child growth in each period community weather shocks realised before each growth measurement that are expected to impact child growth and nutritional status through affecting the prevalence of infectious diseases (Skoufias and Vinha 2012). Finally, by using data from a unique international cohort study in low- and middle-income countries, I produce international evidence of higher external validity than those of studies focusing on a single context.

My key finding is that undernutrition in utero and through infancy and its impact on cognitive achievement in childhood can be reversed through investments in nutrition and cognitive skills in later periods of childhood. This is supported by evidence that child growth is responsive to weather shocks occurring after the age of 2 and has a large effect on cognitive achievement in early adolescence across countries, but also that a significant share of the impact of nutritional status from conception through infancy on later cognitive achievement manifests through nutrition in childhood. I also find evidence suggestive of a direct effect of nutrition both before and after infancy on cognitive achievement at age 8, and that the effect of nutrition in each period on cognitive achievement can be partly explained by changes in parental nutrition and cognitive skills investments in middle childhood.

Another novel finding is that parental investment responses to a change in child health are heterogeneous across multiple dimensions. In particular, I find that: (a) parents may compensate in cognitive skills investments and reinforce health investments after a change in child health at a given period; (b) different inputs to the production of a dimension of human capital, e.g. cognitive skills, may respond in opposite directions after a change in child health; (c) investments may respond differently to changes in child health at different periods; and (d) there are unobserved parental investment responses to a change in child health at a given period. These results may explain the mixed evidence and the current lack of consensus in the literature on whether parents compensate or reinforce the impact of child health insults in early life and highlight that, under heterogeneous and partially observed parental investment responses to child health, it is very difficult to infer whether reduced form estimates provide lower or upper bounds of biological effects of health on cognitive skills.

The remainder of the paper is organised as follows. Section 2 presents a conceptual framework of the relationship between child health and cognitive skills over different periods of childhood, and Section 3 sets out the specification of the econometric model and the identification strategy adopted. Section 4 discusses the data, presents descriptive statistics, and explains the instrumental variables strategy adopted, Section 5 presents the estimation results, and Section 6 concludes.

2. Conceptual framework

This section presents a framework of the determination of child health and cognitive skills over different stages of childhood and adolescence. The relationship of interest is the conditional demand for cognitive skills or the demand for cognitive skills conditional on child health that allows one to express the utility maximising level of child cognitive skills as a function of the utility maximising level of child health and a subset of exogenous variables that excludes variables that impact cognitive skills through child health (Pollak 1969; Glewwe and Miguel 2008). Conditional demands can be used to assess the total effect of a change in child health on the demand for cognitive skills that includes both direct (biological) effects manifesting through the cognitive skills production function, and indirect (behavioural) effects manifesting through responses of parental demands for cognitive skills inputs to changes in child health.

The framework here deviates from other frameworks, such as that by Glewwe and Miguel (2008) in one important respect. It considers an additional channel through which a change in child health in one period may impact child cognitive skills in a later period to those accounted by Glewwe and Miguel (2008) that manifests through child health in interim periods. This takes into account that a change in child health in one period may impact child health in subsequent periods both directly, through the health production function, and indirectly through changes in the demands for child health inputs in subsequent periods. Accounting for this channel highlights the potential for mitigating cognitive deficits arising from early health insults through health investments later in life.

I consider an optimisation programme, similar to that of Glewwe and Miguel (2008), based on which parents make choices to maximise utility over the first T periods of the child's life during which the child is a dependent, subject to technological constraints, such as the child health and cognitive skills production functions in each period, time constraints in each period, and an intertemporal budget constraint. Under this setting reduced form demand functions of health inputs at period t, with $t = 1, \dots T$, are as follows:

$$N_t^* = N_{t,D}(\{p_{C,\tau}, p_{N,\tau}, p_{I,\tau}, w_\tau, D_\tau, S_\tau, \xi_\tau, \lambda_\tau, \mu_\tau,\}_{\tau=1}^{t}, \delta, H_0, A_0, \alpha, r, \xi, \mu, \lambda, \{u_\tau\}_{\tau=1}^{t-1}, \{v_\tau\}_{\tau=1}^{t-1})$$

$$t = 1, \dots T \quad (1)$$

where health inputs, N, in each period are assumed to include also parental time spent in the production of child health, p_C, p_N, p_I are prices of consumption goods, health inputs, and cognitive skills inputs respectively, w is the wage, D is the disease environment, that is assumed to be outside parents' control, S stands for the school environment, including preschool in early stages of life, that is also assumed not to be subject to parental choice. Moreover, δ captures parental time preferences, H_0 is child's health endowment at conception, A_0 denotes household's assets at conception, α is child's innate ability, r is the interest rate, ξ and ξ_t denote fixed and time-variant taste shifters respectively, μ_t and μ are time-variant and fixed cognitive skills productivity shifters respectively, λ_t and λ are time-variant and fixed child health productivity shifters respectively, u and v denote health and cognitive skills productivity shocks respectively.[1] Furthermore, $\{K_\tau\}_{\tau=1}^{t}$ for $K = p_C$, p_N, p_I, w, D, S, ξ, μ, u, v denotes a sequence including the values of K from period 1 to period t, with $\{K_\tau\}_{\tau=t_1}^{t_2} = K_{t_1} = K_{t_2}$ if $t_1 = t_2$ and $\{K_\tau\}_{\tau=t_1}^{t_2} = \emptyset$ if $t_1 > t_2$. I assume that optimal choices are made under uncertainty about the level of exogenous variables in future periods and that in each period optimal choices in the same and all future periods are updated in the face of realisation of the levels of exogenous variables in that period. I also assume that child health inputs at any given period are updated and implemented prior to the realisation of shocks in the same period and cannot be adjusted after the shocks are realised. This is why equation (1) does not include shocks in the same period among the determinants of health inputs. This assumption is needed for the derivation of conditional demands that condition on child health that require that child health cannot be adjusted instantaneously to the long-run equilibrium in

1 The key distinction between shifters and shocks that is implied throughout this section is that the former are systematic factors determining the functional form of preferences and technology, whereas the latter are idiosyncratic. Another assumption imposed throughout is that shifters are determined either exogenously or prior to the first period. Parental total time endowment is normalised to 1 and this is why it is not included among the exogenous variables in the reduced form demands.

the face of an exogenous change in child health (Pollak 1969). Moreover, the reduced form demand for child health in period t is expressed by the following equation:

$$H_t^* = H_{t,D}(\{p_{C,\tau}, p_{N,\tau}, p_{I,\tau}, w_\tau, D_\tau, S_\tau, \xi_\tau, \lambda_\tau, \mu_\tau, u_\tau\}_{\tau=1}^{t}, \delta, H_0, A_0, \alpha, r, \xi, \mu, \lambda, \{v_\tau\}_{\tau=1}^{t-1}) \;\; t = 1, \ldots T \;\; (2)$$

Equation (2) is derived by substituting optimal health input demands from (1) into the child health production function that is as follows:

$$H_t = H_P[H_{t-1}, N_t; D_t, \lambda_t, u_t] = H_{t,P}[H_{t-1}, N_t] \;\; t = 1, \ldots T \;\; (3)$$

where H_{t-1} is child health one period before period t. As in Glewwe and Miguel (2008), equation (3) assumes that child health at a given point in time is a sufficient statistic for the history of investments in child health up to that point. Equation (3) is also based on the assumption that the productivity of investments at any given period is determined by the level of D, λ, and u in that period. Based on equations (1), (2), and (3), contemporaneous child health productivity shocks at a given period are assumed to affect optimal child health in this period directly through the child health production function but not indirectly through health inputs demands.

Under the assumption that demands for all endogenous variables other than child health inputs are determined after the realisation of health and cognitive skills productivity shocks and thus after the determination of child health input demands, the reduced form demand for child cognitive skills inputs and child cognitive skills in period t can be expressed by the following equations:

$$M_t^* = M_{t,D}(\{p_{C,\tau}, p_{N,\tau}, p_{I,\tau}, w_\tau, D_\tau, S_\tau, \xi_\tau, \lambda_\tau, \mu_\tau, u_\tau, v_\tau\}_{\tau=1}^{t}, \delta, H_0, A_0, \alpha, r, \xi, \mu, \lambda)$$
$$t = 1, \ldots T \text{ and } M = I, CS \;\; (4)$$

where I stands for cognitive skills inputs, including parental time devoted to child cognitive skills production, and CS denotes child cognitive skills. The reduced form demand for child cognitive skills in period t is derived by substituting the reduced form demands of all direct determinants of cognitive skills in the cognitive skills production function that is as follows:

$$CS_t = CS_P[\{H_\tau, I_\tau\}_{\tau=1}^{t}; \alpha, \mu, \{S_\tau, \mu_\tau, v_\tau\}_{\tau=1}^{t}] = CS_{t,P}[\{H_\tau, I_\tau\}_{\tau=1}^{t}] \;\; t = 1, \ldots T \;\; (5)$$

where also allows for direct effects of child health on cognitive skills at a given period by including child health in the same and all prior periods among the determinants of cognitive skills.[2] I also assume that the productivity of cognitive skills inputs at any given period is determined by the fixed level of α and μ, the level of S, and the levels of time-variant shifters and shocks μ and v respectively in the same and all prior periods.

Following Pollak (1969) and Glewwe and Miguel (2008), under the assumption that in each period t, parents update optimal choices taking child health prior to that point as fixed at the utility maximising level, the reduced form demand for child health inputs in (1) can be expressed as follows:

$$N_t^* = N_{t,CD}(\{H_\tau^*\}_{\tau=1}^{t-1}, p_{N,t}, D_t, \lambda_t, \{\omega_\tau\}_{\tau=1}^{t}, A_{t-1}^*, \kappa, \{v_\tau\}_{\tau=1}^{t-1}) \;\; t = 1, \ldots T \;\; (6)$$

where $\omega_\tau = \{p_{C,\tau}, p_{I,\tau}, w_\tau, \xi_\tau, \mu_\tau, S_\tau\}$, $\kappa = \{\delta, \alpha, r, \xi, \mu\}$, and A_{t-1}^*=$A_0 - \sum_{\tau=1}^{t-1} p_{N\tau,} N_\tau^*$ are assets at conception excluding expenditure on child health (I refer to this as household non-child health

2 Equation (3) assumes that H_t summarises child health over period t and this is why it excludes H_0, that is child health at the beginning of period 1 from the determinants of child cognitive skills in each period, as this is captured by H_1.

expenditure henceforth) in prior periods. Equation (6) is the conditional demand for child health inputs in period t that expresses the optimal level of child health inputs in that period as a function of the utility maximising level of child health in all periods prior to period t, household non-child health expenditure in prior periods, and exogenous variables excluding $\{p_{N,\tau}, D_\tau, \lambda_\tau, u_t\}_{\tau=1}^{t-1}$, λ, and H_0 that impact the utility maximising level of health inputs through optimal child health in periods 1 to $t-1$.[3] Substituting (6) in the child health production function one can derive the demand for child health in period t, conditional on child health in prior periods as follows:

$$H_t^* = H_{t,P}[H_{t-1}^*, N_t^*] = H_{t,CD}(\{H_\tau^*\}_{\tau=1}^{t-1}, p_{N,t}, D_t, \lambda_t, u_t, \{\omega_\tau\}_{\tau=1}^{t}, A_{t-1}^*, \kappa, \{v_\tau\}_{\tau=1}^{t-1})$$

$$t = 1, \dots T \quad (7)$$

The conditional demand for cognitive skills inputs in period t can be derived from (4) in a similar fashion and can be expressed as follows:

$$I_t^* = I_{t,CD}(\{H_\tau^*, \omega_\tau, v_\tau\}_{\tau=1}^{t}, A_t^*, \kappa) \quad t = 1, \dots T \quad (8)$$

where $A_t^* = A_0 - \sum_{\tau=1}^{t} p_{N,\tau} N_\tau^*$ and equation (8) takes into account that at the time child cognitive skills investments in that period are determined, optimal child health in the same period has been set and thus it is considered as fixed at the utility maximising level. Using (7) and (8) to substitute for the conditional demand for child health and cognitive skills inputs in in the cognitive skills production function in (5), one can derive the conditional demand for cognitive skills in period t as follows:

$$CS_t^* = CS_{t,P}[\{H_\tau^*, I_\tau^*\}_{\tau=1}^{t}] = CS_{t,CD}(\{H_\tau^*, \omega_\tau, v_\tau,\}_{\tau=1}^{t}, A_t^*, \kappa) \quad t = 1, \dots T \quad (9)$$

Using (9) and the fact that cognitive skills inputs demands, I^*, in each period, are expected to respond to an exogenous change in child health in the same or previous periods, by (8), and that child health in each period responds to a change in child health in prior periods, by (7), one can express the total effect of an exogenous change in the contemporaneous and one period prior utility maximising level of child health on the demand for cognitive skills at any given period t as follows:

$$\frac{dCS_t^*}{dH_{t-1}^*} = \frac{\partial CS_{t,P}}{\partial H_{t-1}^*} + \frac{\partial CS_{t,P}}{\partial H_t^*}\left(\frac{\partial H_{t,P}}{\partial H_{t-1}^*} + \frac{\partial H_{t,P}}{\partial N_t^*}\frac{\partial N_{t,CD}}{\partial H_{t-1}^*}\right) + \frac{\partial CS_{t,P}}{\partial I_{t-1}^*}\frac{\partial I_{t-1,CD}}{\partial H_{t-1}^*} +$$

$$\frac{\partial CS_{t,P}}{\partial I_t^*}\left[\frac{\partial I_{t,CD}}{\partial H_{t-1}^*} + \frac{\partial I_{t,CD}}{\partial H_t^*}\left(\frac{\partial H_{t,P}}{\partial H_{t-1}^*} + \frac{\partial H_{t,P}}{\partial N_t^*}\frac{\partial N_{t,CD}}{\partial H_{t-1}^*}\right) + \frac{\partial I_{t,CD}}{\partial A_t^*}\frac{\partial A_{t,CD}}{\partial H_{t-1}^*}\right] \quad (10a)$$

$$\frac{dCS_t^*}{dH_t^*} = \frac{\partial CS_{t,P}}{\partial H_t^*} + \frac{\partial CS_{t,P}}{\partial I_t^*}\frac{\partial I_{t,CD}}{\partial H_t^*} \quad (10b)$$

Equations (10a) and (10b) delineate all the channels through which an exogenous change in child health in period $t-1$ and t respectively impacts child cognitive skills in period t. In particular, equation (10b) suggests that the total effect of a contemporaneous change in child health on cognitive skills includes a direct effect, $\frac{\partial CS_{t,P}}{\partial H_t^*}$, operating through the cognitive skills production function in (5) and indirect effects expressed by the second term in (10b) that manifest through responses of cognitive skills inputs demands in period t to a change in

3 This uses the result of Pollak (1969) that when the quantity of some of the goods are fixed in the short run due to constraints that prevent instantaneous adjustment to the long-run equilibrium, standard demand functions are equivalent to conditional demand functions that express the utility maximising level of non-fixed goods as functions of the prices of non-fixed goods, the utility maximising quantity of fixed goods, and expenditure on the non-fixed goods (see also Glewwe and Miguel (2008) for details of this derivation in the case of demand functions conditional on child health).

optimal child health in the same period. The direction of the total effect is ambiguous, as, although the direct effect is positive, by assumption, the indirect effects may be positive, negative, or zero, depending on whether parents reinforce, compensate, or neither respectively for the impact of a change in child health by increasing or decreasing respectively cognitive skills investments. The situation is more complicated in the case of the total effect of a change in child health in period $t-1$ on cognitive skills in period t, as this includes a larger set of indirect effects, as suggested by equation (10a).[4] In particular, the total effect of H_{t-1}^* on CS_t^* includes the following effects:

(i) the direct effect of H_{t-1}on CS_t, $\frac{\partial CS_{t,P}}{\partial H_{t-1}^*}$, operating through the child cognitive skills production function in (5),

(ii) an indirect and purely biological effect, $\frac{\partial CS_{t,P}}{\partial H_t^*}\frac{\partial H_{t,P}}{\partial H_{t-1}^*}$, operating through H_t that is directly affected by a change in H_{t-1}, through the health production function in (3), and in turns has a direct effect on CS_t through the cognitive skills production function in (5),

(iii) an indirect effect, given by the term $\frac{\partial CS_{t,P}}{\partial H_t^*}\frac{\partial H_{t,P}}{\partial N_t^*}\frac{\partial N_{t,CD}}{\partial H_{t-1}^*}$, manifesting through responses of child health inputs demands in period t, N_t^*, holding A_t^* constant, that affect the level of H_t^*, that in turns impacts CS_t directly through (5),

(iv) an indirect effect, expressed by $\frac{\partial CS_{t,P}}{\partial I_{t-1}^*}\frac{\partial I_{t-1,CD}}{\partial H_{t-1}^*}$, that operates through cognitive skills inputs demands in period $t-1$ responses to a change in H_{t-1}^*,

(v) an indirect effect, as expressed by $\frac{\partial CS_{t,P}}{\partial I_t^*}\frac{\partial I_{t,CD}}{\partial H_{t-1}^*}$, that operates through responses of cognitive skills inputs demands in period t to a change in H_{t-1}^*, holding H_t^* and A_t^* constant,

(vi) an indirect effect, as expressed by the terms $\frac{\partial CS_{t,P}}{\partial I_t^*}\frac{\partial I_{t,CD}}{\partial H_t^*}\frac{\partial H_{t,P}}{\partial H_{t-1}^*}$, that operates through responses of cognitive skills inputs demands in period t to a change in H_t^* arising as a direct result of the change in H_{t-1}^* by (3),

(vii) an indirect effect, as expressed by the term $\frac{\partial CS_{t,P}}{\partial I_t^*}\frac{\partial I_{t,CD}}{\partial H_t^*}\frac{\partial H_{t,P}}{\partial N_t^*}\frac{\partial N_{t,CD}}{\partial H_{t-1}^*}$, that operates through cognitive skills inputs demands responses in period t to a change in H_t^* resulting from a change in child health inputs in period t, N_t^*, that in turns respond to the change in H_{t-1}^*, holding A_t^* constant, and

(viii) an indirect effect, as expressed by the term $\frac{\partial CS_{t,P}}{\partial I_t^*}\frac{\partial I_{t,CD}}{\partial A_t^*}\frac{\partial A_{t,CD}}{\partial H_{t-1}^*}$, that operates through cognitive skills inputs demands responses to a change in A_t^* resulting from change in H_{t-1}^*, holding H_t^* constant.[5]

The direction of effects (i) and (ii) is positive, by assumption, and the same holds for (viii) under certain assumptions,[6] and provided that at least one of the child health inputs in period t

4 The key reason why I consider the impact of a change in child health in period $t-1$ on cognitive skills in period t is that is allows for the identification of the type of different channels via which the impact of child health at a given period on cognitive skills at a future period manifests with minimum complexity, as the channels via which this impact manifests increase the further apart are the two periods.

5 Effects in (viii) can be viewed as an income effect of a change in child health in period $t-1$ on cognitive skills in period t (Pollak 1969), holding child health in period t constant. Intuitively, a change in H_{t-1}^* will impact H_t^* directly through the health production function in (3) and thus for H_t^* to decrease to the same level as before the increase in H_{t-1}^*, some health inputs should decrease. The change in the demand for health inputs will lead to a change in child health expenditure in period t and thus in resources available for all other goods, A_t^*, that in turns is going to lead to a change in the demand for cognitive skills inputs in period t and through that to child cognitive skills.

responds to a change in child health in period $t-1$, at least one of the effects in (iii) is expected to be positive.[7] The rest of the indirect effects of H_{t-1}^* on CS_t^* are expected to have an ambiguous sign, that depends on the direction of health and cognitive skills input demands responses to a change in child health in period $t-1$ that, as discussed above is ambiguous that further implies that the total effect of a change in H_{t-1}^* on CS_t^* is also ambiguous.

The key implication of equation (10a) is that, under certain conditions, cognitive deficits resulting from health insults in early life will tend to accumulate over the life course[8] and this process can be attenuated by compensatory (remedial) investments in child health and cognitive skills in later periods.

The rate of accumulation of cognitive deficits over the life course and the extent to which remedial investments can counteract this process depend partly on the nature of health and cognitive skills production technology.[9] One key aspect of these production technologies is related to the existence of critical and sensitive periods for investments (Cunha and Heckman 2007). For example, in the case of child nutrition, it has been suggested that the period from conception to 2 years old is a critical period for investments in nutrition (Hoddinott and Kinsey 2001; Glewwe et al. 2001). Based on Cunha and Heckman (2007), assuming that H stands for child nutritional status, under the framework here, the hypothesis that period $t-1$ is a critical period for investments in child nutrition implies that $\frac{\partial H_{t,P}}{\partial H_{t-1}^*}=1$, $\frac{\partial H_{t,P}}{\partial N_t^*}=\frac{\partial A_{2,CD}}{\partial H_{t-1}^*}=0$, and $\frac{\partial CS_{t,P}}{\partial H_t^*}=0$.[10] If this hypothesis holds, then equations (10a) and (10b) become as follows:

$$\frac{dCS_t^*}{dH_{t-1}^*}=\frac{\partial CS_{t,P}}{\partial H_{t-1}^*}+\frac{\partial CS_{t,P}}{\partial I_{t-1}^*}\frac{\partial I_{t-1,CD}}{\partial H_{t-1}^*}+\frac{\partial CS_{t,P}}{\partial I_t^*}\left(\frac{\partial I_{t,CD}}{\partial H_{t-1}^*}+\frac{\partial I_{t,CD}}{\partial H_t^*}\right)\ (11a)$$

$$\frac{dCS_t^*}{dH_t^*}=0\quad(11b)$$[11]

6 The assumptions required for this effect to be positive are that the health production function is homothetic and cognitive skills inputs are normal goods. The homotheticity assumption implies that after an increase in H_{t-1}^* that increases H_t^* directly, for H_t^* to decrease at the initial level, all child health inputs in period t will decrease (i.e. it is not possible to achieve a reduction in H_t^* by increasing some inputs and decrease others), and this will lead to an unambiguous decrease in child health expenditure and thus an increase in income available to be spent on goods other than child health inputs. The assumption that child cognitive skills inputs are normal goods implies that the increase in income available for other goods will lead to an increase in the demand for cognitive skills inputs and thus in child cognitive skills.

7 Although N_t^* is treated as a scalar for simplicity, it is used to denote a set in health inputs such as the quantity and quality of diet, parental time and effort devoted to child care, etc. Effects in (iii) and (vii) that manifest through adjustments of child health inputs in period t, N_t^*, to a change in H_{t-1}^*, holding A_t^* constant, involve a change in child health inputs resulting from a reallocation of a given level of child health expenditure across health inputs (Pollak 1969). This implies that not all inputs are expected to respond in the same direction, as for the demand of a given input to increase as a result of an increase in child health in period $t-1$ and for expenditure in child health to remain unchanged, the demand for another child health input should necessarily decrease.

8 This means that the total effect of a change in H_{t-1}^* on cognitive skills in period $t-1$ is smaller than the effect of a change in H_{t-1}^* on cognitive skills in period t manifesting through channels (i), (ii), (iv), and (viii). Based on (9) and (10a), this implies that $\frac{dCS_{t-1}^*}{dH_{t-1}^*}=\frac{\partial CS_{t-1,P}}{\partial H_{t-1}^*}+\frac{\partial CS_{t-1,P}}{\partial I_{t-1}^*}\frac{\partial I_{t-1,CD}}{\partial H_{t-1}^*}<\frac{\partial CS_{t,P}}{\partial H_{t-1}^*}+\frac{\partial CS_{t,P}}{\partial I_{t-1}^*}\frac{\partial I_{t-1,CD}}{\partial H_{t-1}^*}+\frac{\partial CS_{t,P}}{\partial H_t^*}\frac{\partial H_{t,P}}{\partial H_{t-1}^*}+\frac{\partial CS_{t,P}}{\partial I_t^*}\frac{\partial I_{t,CD}}{\partial A_t^*}\frac{\partial A_{t,CD}}{\partial H_{t-1}^*}$.

9 They are also expected to depend on the nature of parental preferences.

10 Condition $\frac{\partial H_{t,P}}{\partial N_t^*}=0$ expresses that nutrition investments outside the critical period have no impact on nutrition, condition $\frac{\partial H_{t,P}}{\partial H_{t-1}^*}=1$ suggests that the nutritional status in periods following the critical period will be equal to that at the end of the critical period, whereas condition $\frac{\partial CS_{t,P}}{\partial H_t^*}=0$ suggests that nutrition outside the critical period has no direct impact on cognitive skills. Condition $\frac{\partial A_{t,CD}}{\partial H_{t-1}^*}=0$ expresses that, given that nutrition investments in period t-1 have no impact on child nutritional status, there will be no expenditure on child nutrition in period t, i.e. $p_{N,t}N_t^*=0$ and thus $A_t^*=A_{t-1}^*$, and A_{t-1}^*, by assumption, is set prior to the change in H_{t-1}^* and does not respond to a change in H_{t-1}^*.

Therefore, the key implication of this hypothesis is that there is scope for remediation in later periods of cognitive deficits arising from early undernutrition through cognitive skills investments, but not through nutrition investments. The implications are the same, if period $t-1$ is not critical in terms of the impact of nutritional investments on cognitive skills, but the negative effect of early undernutrition on later cognitive skills will be larger.[12] This further implies that, in this case, there is a larger tendency for cognitive deficits arising from early undernutrition to accumulate over the life course and more scope for nutritional investments during the critical period, compared to the previous case. If period $t-1$ is only a critical period for the impact of nutrition on cognitive skills, then the total effect of a change in H_{t-1}^* and H_t^* on CS_t^* will be as given by (10a) and (10b) respectively, with the difference that the second term in (10a) and the first term in (10b) will be equal to zero. Under this scenario, there is scope for remediation of developmental setbacks resulting from early undernutrition through nutrition investments in later periods, but the impact of these investments on cognitive skills is expected to manifest only through behavioural channels related to parental responses to a change in child health in later periods.[13] Finally, when period $t-1$ is not a critical period for investments in nutrition either in terms of their impact on child nutritional status or on cognitive skills, there is more scope compared to the other cases for remediation of cognitive deficits arising from early undernutrition through nutrition investments in later periods, as in this case, nutrition investments are expected to have also a positive direct impact on cognitive skills.

Equations (10a) and (10b) can be alternatively expressed in terms of the effect of child health in each period on the conditional demand for cognitive skills in period t, in (9), as follows:

$$\frac{dCS_t^*}{dH_{t-1}^*} = \frac{\partial CS_{t,CD}}{\partial H_{t-1}^*} + \frac{\partial CS_{t,P}}{\partial H_t^*}\frac{\partial H_{t,CD}}{\partial H_{t-1}^*} + \frac{\partial CS_{t,P}}{\partial I_t^*}\left(\frac{\partial I_{t,CD}}{\partial H_t^*}\frac{\partial H_{t,CD}}{\partial H_{t-1}^*} + \frac{\partial I_{t,CD}}{\partial A_t^*}\frac{\partial A_{t,CD}}{\partial H_{t-1}^*}\right) \quad (12a)$$

$$\frac{dCS_t^*}{dH_t^*} = \frac{\partial CS_{t,CD}}{\partial H_t^*} \quad (12b)$$

where $\frac{\partial CS_{t,CD}}{\partial H_k^*}$ for $k = t-1, t$, is the effect of a change in child health in period k on cognitive skills in period t, holding other arguments of the conditional demand for cognitive skills expressed by equation (9) constant and $\frac{\partial H_{t,CD}}{\partial H_{t-1}^*}$ is the effect of a change in child health in period $t-1$ on the demand of child health in period t using the second equality in (7). This derivation shows, that, although equation (9) can be used to assess the total effect of a contemporaneous change in child health on cognitive skills, the same does not hold for the case of a change in the level of health in a period prior to that cognitive skills are assessed, as the effect identified by equation (9) does not capture the impact of early health on later cognitive skills manifesting through child health and household non-child health expenditure in interim periods. In general, the relationship that can be used to assess the total effect of a change in child health in period τ on cognitive skills in period t, with $\tau < t$ can be derived by

11 This is because, $\frac{dCS_t^*}{dH_t^*}$, expresses the effect of an exogenous change in nutrition in period t, arising from a change in factors outside the control of parents, such as the disease environment, D_t or a health productivity shock, u_t, in that period that are assumed to have no effect on H_t^*. This implies that the result in (11b) holds more generally for the effect of changes in child health in all periods outside the critical period, i.e. $\frac{dCS_t^*}{dH_\tau^*} = 0$, with $j = 1,..,t-2,t$.

12 Under these assumptions, $\frac{dCS_t^*}{dH_{t-1}^*}$ will include, in addition to all effects in (11a), the effect operating through channel ii), that under maintained assumptions becomes $\frac{\partial CS_{t,P}}{\partial H_t^*}$, that is positive by assumption.

13 As discussed above, an improvement in child nutrition arising from a nutrition-promoting intervention in period 2 may lead to an improvement in child cognitive skills in this period, through a behavioural channel operating through the reallocation of resources spent on child health towards cognitive skills investments.

using (7) to substitute for child health in the periods from $\tau+1$ to t in (9) and (6) and the relationship $A_t^*=A_0-\sum_{\tau=1}^{t} p_{N,\tau}N_\tau^*$, with $t=1,\dots T$ to express household non-child health expenditure in the periods from $\tau+1$ to t in (9) in terms of child health in all periods prior to $\tau+1$ as follows:

$$CS^*_{t,CD|H^*_\tau} = CS^\tau_{t,CD}(\{H^*_\rho\}^\tau_{\rho=1}, A^*_\tau, \{p_{N,\rho}, D_\rho, \lambda_\rho, u_\rho\}^t_{\rho=\tau+1}, \{\omega_\rho, v_\rho\}^t_{\rho=1}, \kappa)$$

$$t=1,\dots T \ , \tau=1,\dots T \text{ , and } \tau \le t \quad (13)$$

equations (13) are demand functions of cognitive skills in period t conditional on child health in period τ,[14] with $\tau \le t$, as they include also equation (9) as a special case where $t=\tau$. As in the case of equation (9), it can be shown that for any given period t' with $t' < \tau \le t$, equations (13) can be used to assess the effect of a change in child health in that period on cognitive skills in period t, that does not include effects manifesting through child health and household non-child health expenditure in the periods from $t'+1$ to τ. This further suggests that a comparison of the effect of $H^*_{t'}$ on CS^*_t from (13) with $t'=\tau$ with that from (13) with $t' < \tau$ allows one to assess the importance of the effect of $H^*_{t'}$ on CS^*_t manifesting through child health and household non-child health expenditure in periods from $t'+1$ to τ.

3. Econometric model specification and identification strategy

The aim of the empirical analysis is to identify the independent impact of child nutrition in each of three periods of childhood from conception to middle childhood (8 years old) on cognitive skills in early adolescence (12 years old). In particular, I consider three linear empirical analogues of (13)[15] for $t=4$ and $\tau=1,2,3$, where period 1 is from conception to age 2, period 2 is from ages 2 to 5, period 3 from 5 to 8 years old, and period 4 is from 8 to 12 years old, as follows:

$$CS^*_{i4} = a_0 + \alpha_1 H^*_{i1} + \alpha_2 H^*_{i2} + \alpha_3 H^*_{i3} + \boldsymbol{\alpha'_4 CH_{i1-4}} + \boldsymbol{\alpha'_5 LO_{i1-4}} + \varepsilon_{i4} \ (E.1)$$

$$CS^*_{i4} = \beta_0 + \beta_1 H^*_{i1} + \beta_2 H^*_{i2} + \boldsymbol{\beta'_3 CH^A_{i1-4}} + \boldsymbol{\beta'_4 LO^A_{i1-4}} + \psi_{i4} \ (E.2)$$

$$CS^*_{i4} = \gamma_0 + \gamma_1 H^*_{i1} + \boldsymbol{\gamma'_2 CH^B_{i1-4}} + \boldsymbol{\gamma'_4 LO^B_{i1-4}} + \varphi_{i4} \ (E.3)$$

where CS^*_{i4} stands for a cognitive achievement test score of child i in period 4 and H^*_{i1}, H^*_{i2}, and H^*_{i3} denotes child i's height-for-age[16] in period 1, 2, and 3 respectively, that is a common indicator of a child's nutritional status and summarises nutritional history from conception up to the point of measurement (Glewwe et al. 2001). Moreover, $\boldsymbol{CH_{i1-4}}$, $\boldsymbol{CH^A_{i1-4}}$, $\boldsymbol{CH^B_{i1-4}}$ are

14 Given the nature of the child health production function, conditioning on child health in period τ is equivalent to conditioning on child health in all periods from 1 to τ.

15 Linear empirical analogues of conditional demands can be viewed as linear approximations of the corresponding theoretical relationships or can be derived as a solution of the optimisation programme under the assumption that the utility function is quadratic and additively separable in its arguments and child health and cognitive skills production function are linear functions of their arguments.

16 Height-for-age is the difference between a child's height from the median height of a reference distribution of healthy growing children of the same monthly age and gender provided by WHO (WHO 2006; de Onis et al. 2007). It is usually expressed in terms of standard deviations of the reference distribution.

vectors of child, parental, and household fixed and time-variant characteristics that aim to control for household non-child health expenditure and factors associated with heterogeneity in parental preferences, child cognitive skills technology, and child health technology, whereas $\boldsymbol{LO_{i1-4}}$, $\boldsymbol{LO^{A}_{i1-4}}$, $\boldsymbol{LO^{B}_{i1-4}}$ are vectors of locality characteristics aiming to control for the local economic, school, and disease environment.[17] Provided that observed characteristics provide adequate measures for the theoretical variables they purport to control, the error term, ε_{i4}, in (E.1) includes unobserved child cognitive ability, α, and cognitive skills productivity shocks in all three periods, $\{v_t\}_{t=1}^{4}$, whereas the error term in (E.2), ψ_{i4}, includes factors in ε_{i4} but also child health productivity shocks in periods 3 and 4, $\{u_t\}_{t=3}^{4}$, and the error term in (E.3), φ_{i4}, includes all factors in ψ_{i4} as well as child health productivity shocks in period 2, u_2.

The coefficients of interest in estimation are α_3, β_2, and γ_1 that based on the analysis in the previous section, are expected to capture the total effect of child nutrition in periods 1, 2, and 3 respectively on cognitive skills in period 3. Other coefficients of interest include, β_1 that expresses the effect of H^*_{i1} on CS^*_{i4}, excluding the impact of H^*_{i1} on CS^*_{i4} manifesting through H^*_{i2} and A^*_{i2}, α_1 that expresses the effect of H^*_{i1} on CS^*_{i4}, excluding the impact of H^*_{i1} on CS^*_{i4} manifesting through H^*_{i2}, H^*_{i3}, and A^*_{i3}, and α_2 that captures effect of H^*_{i2} on CS^*_{i4}, excluding the effect of H^*_{i2} on CS^*_{i4} operating through H^*_{i3} and A^*_{i3}. This approach addresses biases in the estimates of total effects of nutrition in periods prior to the assessment of cognitive skills arising in studies that purport to estimate total effects of nutrition in each period by estimating a single specification similar to (E.1), such as that in Glewwe and King (2001). Moreover, it also allows one to investigate some of the causal pathways through which the total effect of early nutrition on later cognitive skills manifests, and in particular those that operate through child nutrition (and household non-child health expenditure) in subsequent periods.

Ordinary least squares (OLS) estimation of equations (E.1), (E.2), and (E.3) is not expected to produce consistent estimates of the coefficients of child nutrition across periods, as nutrition in each period is endogenous because, from (7), is expected to be correlated with child ability and child cognitive skills productivity shocks in previous period, but also other unobservables that are subsumed in the error term. Alternatively, endogeneity of child nutrition measures in each period can arise in the case when observed characteristics do not control adequately for parental preferences and child health and cognitive skills technology shifters, or household non-child health expenditure. Provided that one controls adequately for household non-child health expenditure in all three equations, coefficients in these equations can be estimated consistently by instrumental variables (IV) using as instruments for child nutrition in each period prices of health inputs, p_N, the disease environment, D, child health productivity shifters, λ, and child health productivity shocks, u in the same period that are excluded from the three equations.[18] In the case where one controls for a measure of household income and not for household non-child health expenditure, then the only valid instrument for child health at a given period is child health productivity shocks in this period. This is because in this case, the error term in each equation will include child health expenditure in some or all periods, $p_N N^*$, that, by (6), is expected to be correlated with p_N, D, and λ but not with u in these periods. This exclusion restriction is based on the assumption in

17 In particular, $\boldsymbol{CH_{i1-4}}$ aims to control for A^*_3, δ, ξ, μ, $\{\xi_t, \mu_t\}_{t=1}^{4}$, λ_4 and $\boldsymbol{LO_{i1-4}}$ for r, $\{p_{C,t}, p_{I,t}, w_t, S_t\}_{t=1}^{4}$, $D_4, p_{N,4}$ included in (13) for $t=4$ and $\tau=3$, $\boldsymbol{CH^{A}_{i1-4}}$ for A^*_2, δ, ξ, μ, $\{\xi_t, \mu_t\}_{t=1}^{4}$, $\{\lambda_t\}_{t=2}^{4}$and $\boldsymbol{LO^{A}_{i1-4}}$ for r, $\{p_{C,t}, p_{I,t}, w_t, S_t\}_{t=1}^{4}$, $\{D_t, p_{N,t}\}_{t=3}^{4}$ included in (13) for $t=4$ and $\tau=2$, and $\boldsymbol{CH^{B}_{i1-4}}$ for A^*_1, δ, α, ξ, μ, $\{\xi_t, \mu_t\}_{t=1}^{4}$, $\{\lambda_t\}_{t=2}^{4}$ and $\boldsymbol{LO^{B}_{i1-4}}$ for r, $\{p_{C,t}, p_{I,t}, w_t, S_t\}_{t=1}^{4}$, $\{D_t, p_{N,t}\}_{t=2}^{4}$included in (13) for $t=4$ and $\tau=1$.

18 Other variables affecting child health that are excluded from (13) include fixed health productivity shifters, λ, and child health endowment, H_0,

the conceptual framework that in each period health inputs are chosen and implemented prior to the realisation of shocks in the same period. Nevertheless, it is likely that it holds even in the absence of this assumption, considering that, by construction, the expenditure on child health to be controlled for in conditional demand functions is that incurred prior to the shock, as expenditure after the shock is expected to adjust to the change in child health resulting from the shock, and this adjustment is part of the total effect of the change in child health as suggested by the last term in (10a). Therefore, shocks are expected to be uncorrelated with expenditure on child health in periods before the shock, as the shock was unanticipated at the time of the determination of child health investments in these periods. Note, however, that if health productivity shocks do not affect non-child health expenditure incurred after the shock only through their impact on child health they are not expected to be valid instruments for child health. IV estimation is expected also to address endogeneity of child nutrition in equations (E.1), (E.2), and (E.3) arising from random measurement error in child's height-for-age that may be either due to imprecise measurement of child's height, age, and gender, or due to genetic and environmental factors that affect height but are independent of child's nutrition (Glewwe et al. 2001).[19]

4. Data, descriptive statistics, and instruments for child nutrition across periods

4.1 Dependent and independent variables

The data used in the analysis are collected as part of Young Lives, an international cohort study in Ethiopia, India (Andhra Pradesh and Telangana), Peru, and Vietnam. Young Lives follows around 12,000 children in two cohorts: around 2,000 children in each country born in 2001/02 (Younger Cohort) and around 1,000 children in each country born in 1994/95 (Older Cohort). Young Lives has conducted four rounds of data collection, in 2002, 2006, 2009, and in 2013. The analysis here uses data on the Younger Cohort children for the four survey rounds, including information on children at ages 1, 5, 8, and 12. Because the data does not include information on children at age 2, the periods considered in the empirical analysis deviate somewhat from those in the conceptual framework. Nevertheless, in the following sections we show that this does not affect the inferences drawn from the data analysis on whether the period from conception to age 2 is a critical period for nutritional investments.

19 Another source of bias arises if parental investments in child health and cognitive skills respond to variation in height due to factors unrelated to nutrition (see Dercon and Sanchez 2013 and Scholder et al. 2013). This bias is hard to address, as in this case height is no longer a valid indication for nutrition (Wooldridge 2002). There is also the case, discussed in Glewwe et al. (2001), where genetic variation in height is linked to variation in cognitive functioning. In this case, using shocks directly related to nutrition as instruments for height-for-age could address this bias. Moreover, as highlighted by Glewwe and King (2001), there is also the case of non-random measurement error in child's height stemming from the fact that differences in height may not reflect differences in some micronutrients, suggesting that the measurement error is correlated with the unobserved true measure that is child nutritional status. Although IV cannot address the latter bias, this non-random measurement error will lead to the same bias in coefficient estimates of child growth across periods and thus it is not expected to affect estimates of the relative impact of nutrition across periods on cognitive skills.

The Young Lives data include rich information on household, parental, and community characteristics as well as detailed information on child characteristics and outcomes, including child anthropometry and cognitive achievement that are assessed using the same instruments across the four countries (see Barnett et al. 2012 and Petrou and Kupek 2010 for details of Young Lives sampling and data collection).

Cognitive development of children at age 12 was assessed using the Peabody Picture Vocabulary Test (PPVT), a test of receptive vocabulary that has been widely used as a test of verbal ability in many settings (Rosenzweig and Wolpin 1994; Paxson and Schady 2007), and a mathematics achievement test (MATH henceforth) used as a test of quantitative ability (Cueto and Leon 2012). Because of differences in the native language of children in each country sample, particularly in Ethiopia and to a lesser extent in Peru, the tests were administered in different languages. As suggested by Cueto and Leon (2012), PPVT scores are not meant to be comparable across countries and within country across languages, whereas MATH scores are comparable only across children within country.

Tables 1 and 2 present descriptive statistics of child, household, and community characteristics across rounds. The sample is restricted to children with non-missing information on PPVT and MATH in Round 4, and with no missing or extreme values of HAZ (all values less than -6 or greater than 6 according to WHO standards) in Rounds 1, 2, and 3. The sample in Ethiopia is relatively smaller than in the other countries because tests in Round 4 were mostly administered to children speaking the prevalent ethnic languages in the sample (Amharic, Oromo, Tigrignan). In order to maximise the sample used in estimation, I imputed the values of all variables except of key outcomes, causing variables, and instrumental variables with the sample mean of non-missing values. The number of missing values across all variables for which imputation was performed does not exceed 5 per cent of the sample.

Table 1. *Descriptive statistics of child and household characteristics across countries*

Variable	Ethiopia	India	Peru	Vietnam
PPVT score (% correct) in Round 4	71.65	76.22	68.77	77.02
	(14.88)	(13.33)	(13.94)	(10.49)
MATH score (% correct) in Round 4	38.91	44.16	55.83	48.05
	(21.59)	(22.76)	(18.86)	(16.76)
Tests administered in native language	0.98	0.92	0.99	0.92
	(0.13)	(0.27)	(0.12)	(0.27)
Height-for-age Z-score (HAZ) in Round 1	-1.45	-1.29	-1.27	-1.12
	(1.83)	(1.47)	(1.27)	(1.22)
HAZ in Round 2	-1.33	-1.62	-1.52	-1.34
	(1.07)	(0.97)	(1.09)	(1.01)
HAZ in Round 3	-1.06	-1.42	-1.14	-1.09
	(1.07)	(1.02)	(1.03)	(1.05)
Male	0.53	0.54	0.51	0.51
	(0.50)	(0.50)	(0.50)	(0.50)
First-born	0.25	0.39	0.37	0.46
	(0.44)	(0.49)	(0.48)	(0.50)
Caregiver's age at child's birth (years)	28.21	22.97	26.93	27.82
	(9.21)	(5.42)	(8.05)	(8.62)
Caregiver's education (years)	3.14	3.77	7.72	6.90
	(3.89)	(4.45)	(4.48)	(3.94)
Father's education (years)	5.21	5.72	9.12	7.73
	(4.37)	(5.03)	(3.82)	(3.88)

Variable	Ethiopia	India	Peru	Vietnam
Household's wealth index in Round 1	0.24 (0.17)	0.41 (0.20)	0.43 (0.24)	0.44 (0.21)
Cognitive skills inputs in Round 3				
Expenditure on child's education in the last 12 months	16.41 (39.78)	211.06 (282.49)	33.13 (52.02)	79.64 (176.75)
Hours spent on a typical day in school and studying	6.51 (2.69)	9.60 (1.39)	7.90 (1.28)	7.88 (1.62)
Primary school entry age (months)	87.23 (14.91)	68.00 (11.78)	74.04 (5.26)	73.29 (6.97)
Nutrition inputs in Round 3				
Expenditure on child's health in the last 12 months	2.39 (12.07)	89.68 (232.32)	3.88 (14.06)	36.74 (96.12)
Child's dietary diversity score in the last 24 hours	5.09 (1.81)	6.45 (1.63)	9.00 (1.83)	7.80 (2.29)
Number of meals consumed by the child in the last 24 hours	3.97 (0.68)	4.86 (1.10)	4.88 (0.88)	4.35 (1.08)
Number of observations	1403	1806	1805	1805

Notes: Figures are averages with standard deviations in parentheses. Sample is restricted to children with no missing observations in PPVT and MATH in Round 4 and no missing or extreme values (less than -6 or greater than 6) of HAZ in Rounds 1, 2, and 3. The wealth index takes values from 0 and 1 and combines information on items related to housing quality, household's access to services, and ownership of consumer durables. Expenditure on child's education and health is in national currency units. Expenditure on child's education in the last 12 months includes expenditure on child's school uniform, school fees, tuition, books and stationery, and transport to school, whereas expenditure on child's health in the last 12 months includes expenditure on medical consultation, treatment, and medication. The dietary diversity score is the number of different food groups consumed by the child in the last 24 hours, out of 17 groups in total.

Cognitive skills inputs measures, presented in Table 1, include hours spent in school and studying on a typical day at 8 years old, the age the child was enrolled in school that can provide an indication of how long the child has been attending school, and expenditure on child's education, that includes expenditure on school uniform, school fees, tuition, books and stationery, and transport to school in the 12 months prior to Round 3 of the survey. Nutrition inputs measures include the number of meals consumed by the child, the dietary diversity score of the child in the last 24 hours and expenditure on child's health, as reported in Round 3. The dietary diversity score is the number of different food groups consumed by the child in the last 24 hours, out of 17 food groups in total (see Humphries et al. 2015 for details), that is a well-validated measure of the macro- and micro-nutrient adequacy (Ruel 2002; FAO 2007). Expenditure on child's health includes expenditure on medical consultation, treatment, and medication in the 12 months prior to Round 3 of the survey.

Table 1 includes averages of HAZ scores at age 1, 5, and 8 across countries that indicate that child height is on average at least one standard deviation below that of the WHO reference in all countries and rounds. This suggests that undernutrition is highly prevalent across countries and over time. Nevertheless, there is also an indication that the prevalence of undernutrition is changing with children's age. In particular, the average growth deficit increases between 1 and 5 years old, except for Ethiopia, and falls between ages 5 and 8 in all countries. Moreover, the gender composition of the sample was balanced in all countries and children in Ethiopia were, on average, more likely to have older siblings than children in the other countries. Furthermore, caregivers are younger in India compared to the other countries, where the average caregiver's age at child's birth is 23 years and parental education was the highest in Peru, followed by Vietnam and India and was the lowest for the Ethiopian sample. Table 1 also includes summary statistics of the household's wealth index, a composite variable combining information on housing quality, access to services, and consumer durables (Filmer and Pritchett 2001; see also Woldehanna et al. 2011 for details of the components and methodology used to compute the wealth index in the Young Lives data), that is used as a measure of assets at the beginning of period 1, A_0.

Table 2. *Descriptive statistics of community characteristics across countries*

Variable	Ethiopia	India	Peru	Vietnam
Urban in Round 1	0.46	0.25	0.74	0.19
	(0.50)	(0.43)	(0.44)	(0.39)
Number of preschools in Round 2	1.00	2.60	2.19	1.38
	(1.00)	(1.76)	(0.80)	(0.70)
Number of schools in Round 3	5.62	7.30	1.15	6.14
	(1.60)	(3.32)	(0.69)	(3.34)
Number of schools in Round 4	3.89	2.51	2.88	4.06
	(2.21)	(1.89)	(1.90)	(2.61)
Hospital in Round 1	0.66	0.38	0.52	0.98
	(0.47)	(0.49)	(0.50)	(0.13)
Hospital in Round 2	0.51	0.42	0.58	0.98
	(0.50)	(0.49)	(0.49)	(0.14)
Hospital in Round 3	0.65	0.36	0.55	0.89
	(0.48)	(0.48)	(0.50)	(0.32)
Hospital in Round 4	0.81	0.67	0.56	0.97
	(0.39)	(0.47)	(0.50)	(0.16)
Disease environment index in Round 1	0.57	0.69	0.66	0.54
	(0.19)	(0.17)	(0.18)	(0.17)
Disease environment index in Round 2	0.68	0.72	0.70	0.56
	(0.11)	(0.16)	(0.20)	(0.18)
Disease environment index in Round 3	0.56	0.67	0.73	0.57
	(0.19)	(0.21)	(0.21)	(0.16)
Disease environment index in Round 4	0.44	0.54	0.69	0.63
	(0.22)	(0.21)	(0.17)	(0.28)
Number of credit-providing institutions in Round 1	2.09	2.52	1.54	2.70
	(1.11)	(0.92)	(1.21)	(1.11)
Community rainfall shock between child's conception and Round 1 (mm)	-24.56	-7.33	-20.40	-10.99
	(134.04)	(117.55)	(140.25)	(249.96)
Community rainfall shock between Round 1 and 2	19.49	-20.85	-26.31	-53.79
	(241.17)	(214.87)	(178.98)	(575.92)
Community rainfall shock between Round 2 and 3	-46.57	3.17	14.96	34.86
	(108.11)	(325.18)	(85.01)	(1049.87)
Community temperature shock between child's conception and Round 1 (°C)	-1.36	-0.22	0.89	0.30
	(2.13)	(2.39)	(6.28)	(4.79)
Community temperature shock between Round 1 and 2	1.00	-0.53	2.64	1.99
	(2.24)	(9.82)	(13.69)	(13.39)
Community temperature shock between Round 2 and 3	-2.22	-1.64	-3.57	1.87
	(5.53)	(8.25)	(13.49)	(8.95)
Number of observations	1403	1806	1805	1805

Notes: Figures are averages with standard deviations in parentheses. Sample is restricted to children with no missing observations in PPVT and MATH in Round 4 and no missing or extreme values (less than -6 or greater than 6) of HAZ in Rounds 1, 2, and 3. The disease environment index takes values between 0 and 1 and combines information on items related to air and water pollution, access to drinking water and sanitation, and method of garbage collection in the community (see Table A2 for details). Community rainfall and temperature shocks at each period are deviations from the community, season, and year-specific level, calculated by aggregating, over the period, the residuals from a regression of the level of distance-weighted monthly total precipitation and average temperature on community/calendar month and year fixed effects for the period between 1950-2014 using the Global Climate Database of the University of Delaware (Willmott and Matsuura 2012).

Table 2 includes information on community characteristics, used as measures of the aspects of the local environment considered in the conditional demand function for cognitive skills in (13). In particular, this information includes the number of pre-schools in the locality in 2006 when children were on average 5 years old, and of schools when children were 8 and 12, that are used as proxies of the local school environment, S,[20] and whether there is a hospital in the community in each round, in order to measure an aspect of the local disease environment, D. I also constructed a community disease environment index, as another measure of the local disease environment, that combines information on different aspects of the level of hygiene in the community, such as pollution and method of garbage collection (see Table A2 for details). Moreover, I used information on the number of credit-providing institutions in the locality in Round 1 to construct a proxy of the local interest rate, r. Finally, I used information on local prices of a range of items and wages to calculate price indices for health inputs, p_N (food and medication), cognitive skills inputs p_I (school items), and other consumption items, p_C, and a wage index, w, for all four periods (see Appendix, Tables A1 and A2 for descriptive statistics of all prices and wages and details of how indices were calculated).

4.2 Weather data and instruments for child nutrition across periods

My analysis uses rainfall and temperature deviations from the community season-specific norm from child's conception to Round 3 as instruments for child growth in each period.[21] In particular, precipitation and temperature data from the Global Climate Database of the University of Delaware (UDEL) (Willmott and Matsuura 2012) were matched to the communities where the children were residing in each round using information on the geographical coordinates of the communities. The UDEL data include information on monthly average temperature and total precipitation and have spatial resolution of 0.5x0.5 degrees that corresponds roughly to grids that are 35 miles across at the equator. The datasets use interpolation across space and time to combine available weather station data into a balanced panel of observations on a fixed scale or grid. Each grid approximates a weather measure for the spatial unit by interpolating the daily station data while accounting for elevation, wind direction, rain shadows, and many other factors. In this way, the data deal with one important problem posed by ground station data used in several studies arising from incomplete coverage that may lead to measurement error, particularly in poor countries or areas with sparse population density (Auffhamer et al. 2013). Moreover, detailed cross-validation checks of the quality of interpolation ensure that measurement error is minimised, although not eliminated.

I used the UDEL data to calculate monthly total precipitation and average temperature for each community in the Young Lives survey over the period 1950-2014 as distance-weighted averages of precipitation and rainfall levels in the four nearest grid nodes. I then calculated monthly deviations of weather conditions from the locality and season norm by obtaining the residuals from a regression of the monthly level of precipitation and temperature on locality/calendar month and year fixed effects. In this way, I purged rainfall and temperature

20 Information on the school infrastructure in Round 1, when children were on average around 12 months old, was not included, as the children were not expected to be either in preschool or school at this age.

21 As discussed earlier, other potential instruments for child growth include food and medication prices and aspects of the local disease environment. Nevertheless, these are not expected to be valid if one does not control for non-child health expenditure; that is not possible in my case, as the Young Lives data do not include information on household expenditure and expenditure on child health in Round 1 needed to construct measures of child non-health expenditure in each period.

variation from locality, seasonality, and aggregate fixed effects that may be also correlated with child cognition. These residuals were then aggregated over different periods of each child's life using information of the child's date of birth to produce measures of weather shocks during these periods.

The rationale for using weather shocks as instruments for child growth is based on evidence that weather deviations from the norm are linked to changes in the prevalence of infectious diseases in the locality that are among the major causes of undernutrition and stunting for children in poor contexts (Skoufias and Vinha 2012). In this way, weather shocks provide a direct measure of health productivity shocks, u, identified as potential instruments for child's nutritional status in each period in the previous section, because, through influencing the incidence of infectious diseases, weather shocks impact on the productivity of nutrition inputs by affecting the extent of absorption of nutrients from the body (Fischer Walker et al. 2012). The link between weather variation and disease prevalence is expected to be the case in all areas (rural and urban) with poor public health infrastructure and level of hygiene.

According to Skoufias and Vinha (2012), although, on average, and ruling out extreme conditions, higher precipitation and temperature are likely to lead to an increase in the prevalence of diarrheal diseases and thus growth faltering, in general, the direction of the relationship between weather variation and disease prevalence depends on local climate characteristics as well as child and household characteristics. Nevertheless, if the hypothesis that the first 1,000 days is a critical period for nutritional investments holds, then weather shocks are not expected to be relevant instruments for child growth after the age of 2. Therefore, investigating the responsiveness of child growth to rainfall and temperature shocks realised after the age of 2 provides a direct test of the validity of the hypothesis that the first 1,000 days since conception is a critical period for child nutrition.

A potential concern related to the validity of weather shocks as instruments for child growth, is that, although they may be exogenous to the household's decision-making problem and plausibly unanticipated by the household, it is likely that they impact child cognitive skills also through other channels than child growth. In particular, in rural areas, weather shocks may impact child cognitive development through an income channel, as weather variation is strongly linked to agricultural productivity and rural income (Dell et al. 2014). I address this concern in two ways: first, by controlling for household income (wealth index in Round 1) and local economic conditions such as local prices and wages in all periods in estimation; and second, by measuring shocks as marginal and not extreme deviations from normal conditions. Based on Confalonieri et al. (2007), a slight change in precipitation or temperature could render previously uninhabitable areas suitable for a particular parasitic and infectious species, whereas it expected to have only minor economic implications, if any. Another potential threat to the validity of instrumental variables (IV) estimation using weather shocks as instruments for child growth could be that infectious diseases impact cognition directly and over and above their effect manifesting through child nutrition. Existing evidence, however, does not seem to provide support to this hypothesis. To the contrary, Fischer Walker et al. (2012) find that diarrhoea influences cognition only through the diarrhoea-stunting pathway. Finally, Prendegast et al. (2014) argue that the effects of diarrhoea on growth may be short term, which implies that the impact of a weather shock on child growth operating through the disease channel is expected to impact child growth in the period immediately following the shock, but not in later periods.

Rainfall and temperature shocks averages and standard deviations across countries and periods, reported in Table 2, indicate significant differences across countries in each period and substantial variation in weather conditions across communities within each country.

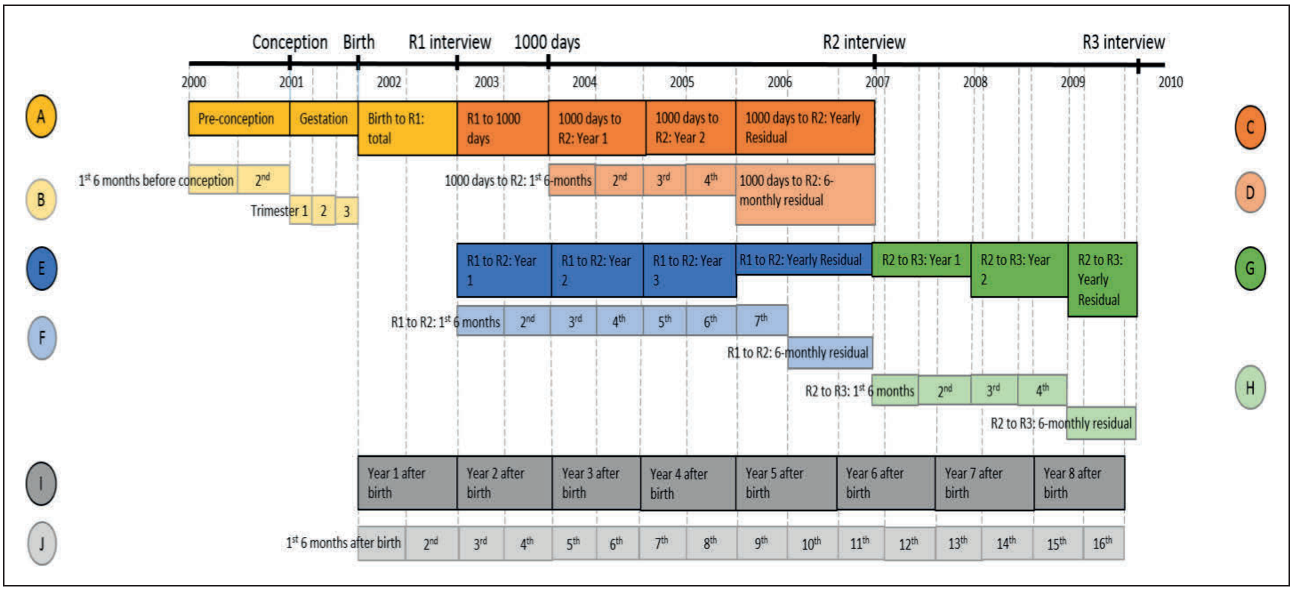
5. Results

5.1 The impact of weather shocks at different stages of childhood on child growth through middle childhood

Estimation of equations (E.1), (E.2), and (E.3) using weather shocks as instruments for child growth across periods by 2SLS requires first an investigation of the relationship between weather shocks and child growth. In all models, height-for-age at each round was measured in centimetres rather than standard deviations of the WHO reference distribution, for two reasons. First, because the standard deviation of the WHO reference distribution does not offer the correct measure for the interpretation of the effects identified, as all effects are to be interpreted as impacts of relative growth (change in height relative to the reference child), whereas the standard deviation is that of the height distribution that is the same as the growth distribution only for height-for-age in Round 1 that measures growth from conception to Round 1. Second, using HAZ would not allow comparisons of the magnitude of the effects of growth across periods on achievement, as standard deviations differ across ages, and in particular, are increasing with age (Leroy et al. 2013).

In the case of 2SLS estimation, there is a different set of potential instruments for child growth in each period depending on how the periods before the first measurement and between consecutive measurements are partitioned. This involves a trade-off, as on the one hand considering shocks during the full periods may minimise weak identification concerns arising from a large number of instruments some of which may be weakly correlated with the endogenous variables; on the other hand, measures of shocks over long periods may dilute the signal in shorter periods that may be predictive of growth and thus also lead to inefficient estimation and weak identification. In order to strike the right balance between these two extremes, I considered as instruments for the three periods of growth of interest for the analysis, rainfall and temperature deviations from the locality/season and year normal levels over a different set of sub-periods and selected among the non-redundant instruments as identified by an LM test of instruments' redundancy (Breusch et al. 1999), those that predict most strongly the endogenous variable (those that most strongly reject the null that the instruments are redundant). Figure 1 illustrates the full period and different sub-periods over which weather shocks were considered as instruments for child growth, and Table 3 presents the instruments identified by this procedure for height-for-age in each round and country.

Figure 1. *Different periods before child's conception through Round 3 over which rainfall and temperature shocks were considered as instruments for height-for-age in each round*



Notes: The period from birth to Round 1 was not partitioned further, as some children were younger than 6 months old at recruitment in Round 1. Residual periods differ across children due to differences in the dates of interview across children withn and across countries.

Table 3. *Selected instruments for child growth in each period across countries*

	Just-identified	Over-identified	Just-identified	Over-identified
	Ethiopia		India	
Height-for-age Round 1	Temperature shock during the second half of the first year after birth	Temperature shock during the second half of the second year after birth, and its square	Rainfall shock one year before conception	Temperature shock one year before conception, temperature shock in the third trimester of pregnancy
Height-for-age Round 2	Rainfall shock between three years after Round 1 and Round 2	Rainfall shock between three years after Round 1 and Round 2 temperature shock in the second half of the second year after the completion of 1,000 days since conception, and rainfall shock in the second half of the fifth year after birth	Temperature shock in the first half of the second year after completion of 1,000 days since conception	
Height-for-age Round 3	Rainfall shock in the seventh year after birth respectively	Temperature shock in the first half of the second year after Round 2	Temperature shock between two years after Round 2 and Round 3	Rainfall shock in the seventh year after birth

	Just-identified	Over-identified	Just-identified	Over-identified
	Peru		Vietnam	
Height-for-age Round 1	Rainfall shock during the first trimester of pregnancy	Rainfall shock during the second trimester of pregnancy	Temperature shock one year before conception	Temperature shock one year before conception and its square
Height-for-age Round 2	Temperature shock in the second half of the fifth year after birth	Temperature shock in the second half of the fifth year after birth, and rainfall shock in the first half of the sixth year after birth	Rainfall shock in the first half of the second year after Round 1	Rainfall shock in the first half of the second year after Round 1, and temperature shock in the second half of the third year after Round 1
Height-for-age Round 3	Rainfall shock in the eighth year after birth	Rainfall shock in the first half of the sixth year after birth	Temperature shock in the second half of the first year after Round 2	Rainfall shock in the first half of the first year after Round 2

Notes: Instruments selected in the over-identified case include those listed under the just-identified case.

Estimates of the impact of the most predictive weather shocks (those presented in the just-identified columns of Table 3) and growth in each period are presented in Table 4. In particular, the first and third columns of the top and bottom panel of Table 4 present the first-stage results of 2SLS estimation of equation (E.1), whereas the other columns present results from a regression of height-for-age in Round 2 and 3 on the most predictive weather shock in the period between Rounds 1 and 2 and Rounds 2 and 3 respectively, height-for-age in the previous round, and all exogenous variables in the structural equations (E.2) and (E.3) respectively.[22] Coefficient estimates and partial F-statistics presented in Table 4 indicate that weather shocks across different periods have a significant effect and strongly explain variations in child growth in these periods across countries. Since weather shocks between Rounds 2 and 3, when all children were around 5 and 8 years old, and the relevant weather shocks for height-for-age in Round 2, as suggested by Table 3, are realised in a period during which children in all countries were older than 1,000 days (24 months),[23] these results seem to cast doubt to the hypothesis that child (relative) growth and nutritional status are determined during the first 1,000 days since conception and remain fixed thereafter. Nevertheless, a comparison of the partial F-statistics from the regressions of growth on the selected weather shock in each period, suggests that, on average, growth in early years is more responsive to weather shocks than later years.

22 These regressions slightly deviate from the independent first stage regressions for height-for-age in Rounds 2 and 3 of the 2SLS estimation of (E.2) and (E.3), as they include height-for-age in the previous period and only the relevant instrument (weather shock in the period just preceding height measurement) for height-for-age in Rounds 2 and 3. This is because the main purpose is to assess the direction and magnitude of the association between the relevant instrument and growth (not height) in these periods, but also because, in the case of (E.2) and (E.3), where there is more than one endogenous variable, the independent first-stages results provide necessary but sufficient conditions for identification (Shea 1997; Stock et al. 2002).

23 The only exception is Vietnam, where 50 per cent of the sample were younger than 24 months old during the period the rainfall shock considered has realised (the first six months a year after Round 1). Nevertheless, restricting the "first-stage" regression sample to include only children older than 24 months old produced similar results to those in the full sample.

Table 4. *Impact of weather shocks on child growth at different periods of life across countries*

	Ethiopia			India		
	Height-for-age Round 1	Height-for-age Round 2	Height-for-age Round 3	Height-for-age Round 1	Height-for-age Round 2	Height-for-age Round 3
Weather shock before Round 1	0.513*** (0.067)			-0.004*** (0.001)		
Weather shock between Round 1 and 2		0.025*** (0.006)			0.184*** (0.060)	
Weather shock between Round 2 and 3			0.007*** (0.002)			-0.276*** (0.083)
R-squared	0.18	0.27	0.46	0.13	0.37	0.62
Partial F statistic	56.17	14.94	11.04	25.01	9.13	10.84
Observations	1403	1403	1403	1806	1806	1806

	Peru			Vietnam		
	Height-for-age Round 1	Height-for-age Round 2	Height-for-age Round 3	Height-for-age Round 1	Height-for-age Round 2	Height-for-age Round 3
Weather shock before Round 1	0.011*** (0.002)			0.358*** (0.052)		
Weather shock between Round 1 and 2		-0.165*** (0.030)			-0.005*** (0.001)	
Weather shock between Round 2 and 3			0.004*** (0.002)			0.336*** (0.074)
R-squared	0.23	0.49	0.67	0.20	0.57	0.70
Partial F statistic	35.86	29.01	8.64	46.68	13.5	20.35
Observations	1805	1805	1805	1805	1805	1805

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. Height-for-age is measured as the difference of the child's height from the WHO reference child of the same monthly age and gender in centimetres. The partial F statistic is the Kleibergen-Paap rk Wald F statistic of the first-stage of 2SLS estimation of the impact of height-for-age on PPVT score implemented separately for each period using as an instrument for height-for-age the relevant to the period weather shock. Weather shocks before Round 1, between Rounds 1 and 2, and Rounds 2 and 3 in each country are those presented in the just-identified column of Table 3. The full set of controls included in each specification and results are in Tables A3 and A4.

The direction of the impact of weather shocks on growth, however, is not the same in all periods and countries, and in most of the cases suggests a positive relationship between precipitation and temperature shocks and child growth. This is consistent with the hypothesis that the impact of weather shocks on child growth manifesting through a disease prevalence channel is heterogeneous and depends on locality, child, and household characteristics (Vinha and Skoufias 2012). In order to test this hypothesis, I estimated, separately for the urban and rural sub-samples across countries, the first-stage regression for height-for-age in Round 1 and a regression of whether the child has suffered from an infectious illness before Round 1, as reported by the child's caregiver in Round 1, on the relevant weather shock and other controls.[24] Estimation results from these regressions across countries, reported in Table 5, suggest that the direction of the impact of weather shocks on the incidence of infectious disease in both urban and rural areas across countries is always in the opposite

24 The reason I investigated this only for height-for-age in Round 1 is that this is the only round when there is information on whether the child has suffered from infectious illness at some point before the survey. Children who had an infectious illness are those for whom the caregiver reported that the child suffered from high fever, malaria, diarrhoea, stomach ache, tuberculosis, or hepatitis.

direction of that on child growth.[25] Moreover, results suggest that weather shocks have a significant impact on child growth in urban areas across countries, where disease prevalence is expected to be the only relevant mechanism linking weather variations and child growth. These results together seem to be consistent with the hypothesis that the impact of weather shocks on child growth manifests through the impact of shocks on disease prevalence and thus that the heterogeneous impacts of weather shocks on child growth across countries and rounds reflect heterogeneous impacts of weather shocks on disease prevalence.[26]

Table 5. *Impact of weather shocks on child growth and the incidence of child illness through Round 1 in urban and rural communities across countries*

	Height-for-age in Round 1		Child illness before Round 1	
	Urban	Rural	Urban	Rural
Ethiopia				
Weather shock before Round 1	0.651***	0.450***	-0.019*	-0.031***
	(0.101)	(0.087)	(0.011)	(0.009)
R-squared	0.24	0.18	0.09	0.08
Partial F statistic	32.22	25.11		
Observations	648	755	648	755
India				
Weather shock before Round 1	-0.007***	-0.004***	0.001	0.001
	(0.002)	(0.001)	(0.001)	(0.001)
R-squared	0.17	0.14	0.13	0.06
Partial F statistic	17.60	14.68		
Observations	449	1357	449	1357
Peru				
Weather shock before Round 1	0.010***	0.011***	-0.001	-0.001
	(0.002)	(0.004)	(0.001)	(0.001)
R-squared	0.17	0.25	0.04	0.10
Partial F statistic	27.88	6.87		
Observations	1337	468	1337	468
Vietnam				
Weather shock before Round 1	0.264**	0.419***	-0.016**	-0.010**
	(0.113)	(0.060)	(0.008)	(0.005)
R-squared	0.27	0.18	0.13	0.10
Partial F statistic	4.95	47.35		
Observations	342	1463	342	1463

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. Height-for-age is measured as the difference of the child's height from the WHO reference child of the same monthly age and gender in centimetres. Child illness is defined as the situation where the caregiver reported that the child suffered from high fever, malaria, diarrhoea, stomach ache, tuberculosis, or hepatitis at some point before the Round 1 interview. The partial F statistic is the Kleibergen-Paap rk Wald F statistic of the first-stage of 2SLS estimation of the impact of height-for-age in Round 1 on PPVT score using as an instrument for height-for-age the weather shock before Round 1. Weather shocks before Round 1 in each country are those presented in the row for height-for-age in Round 1 and the just-identified column of Table 3. The full set of controls included in each specification are in Tables A3 and A4. Full set of results available on request.

25 Results suggest that, in India and Peru, although weather shock has an insignificant impact on the incidence of infectious disease in both rural and urban areas, its impact on child growth is significant. A potential explanation of this is recall or misreporting error in caregivers' responses.

26 Potential explanations of heterogeneous effects of weather shocks on child illness and growth include heterogeneous parental health investment responses to the shock (i.e. compensating versus reinforcing), or that the variation in one weather indicator (e.g. rainfall) also reflects the impact of unobserved indicators, such as relative humidity, solar radiation, wind speed and direction, that are strongly correlated with the observed indicator, and may also affect heterogeneously disease prevalence and through that child nutrition (Auffhammer et al. 2013).

5.2 The impact of child nutrition at different stages of childhood on cognitive achievement in early adolescence

Tables 6 and 7 present coefficient estimates of nutrition measures at age 1, 5, and 8 produced from the estimation of equations (E.1), (E.2), and (E.3) respectively by OLS and 2SLS. Dependent variables used in estimation are (monthly) age-standardised test scores. OLS estimates of the total effect of growth across periods on PPVT and MATH presented in Tables 6 and 7 indicate that achievement scores are positively and significantly associated with growth between conception and Round 1 across countries, whereas they are positively and associated in almost half of the cases with growth between Rounds 1 and 2, and in most of the cases with growth between Rounds 2 and 3 (see Tables A5-A12 for the full results).

Table 6. *Impact of child growth at different stages of childhood on PPVT score at age 12 across countries*

	Ethiopia					
	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.017***	0.042**	0.015***	0.035	0.012**	0.011
	(0.004)	(0.021)	(0.005)	(0.022)	(0.005)	(0.018)
Height-for-age Round 2			0.006	0.084*	-0.003	0.068
			(0.004)	(0.049)	(0.005)	(0.058)
Height-for-age Round 3					0.014***	0.023
					(0.004)	(0.051)
R-squared	0.51		0.51		0.50	
Kleibergen-Paap F statistic		56.18		7.38		3.40
Stock and Yogo critical value		16.38		7.03		
Observations	1403	1403	1403	1403	1403	1403

	India					
	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.037***	0.052	0.033***	0.130*	0.031***	0.076
	(0.005)	(0.052)	(0.007)	(0.076)	(0.007)	(0.113)
Height-for-age Round 2			0.005	-0.095	-0.004	-0.188*
			(0.006)	(0.083)	(0.007)	(0.108)
Height-for-age Round 3					0.010**	0.162
					(0.005)	(0.104)
R-squared	0.28		0.28		0.27	
Kleibergen-Paap F statistic		25.02		3.99		1.83
Stock and Yogo critical value		16.38		7.03		
Observations	1806	1806	1806	1806	1806	1806

	Peru					
	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.021***	0.067	0.005	-0.065*	0.001	-0.045
	(0.006)	(0.044)	(0.007)	(0.036)	(0.007)	(0.040)
Height-for-age Round 2			0.021***	0.160***	0.015**	0.229**
			(0.005)	(0.061)	(0.006)	(0.116)
Height-for-age Round 3					0.009*	-0.121
					(0.005)	(0.103)
R-squared	0.42		0.43		0.449	
Kleibergen-Paap F statistic		35.86		6.29		2.44
Stock and Yogo critical value		16.38		7.03		
Observations	1805	1805	1805	1805	1805	1805

	Vietnam					
	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.025***	0.184***	0.023***	0.159***	0.024***	0.222***
	(0.006)	(0.043)	(0.008)	(0.034)	(0.008)	(0.051)
Height-for-age Round 2			0.003	-0.099**	-0.001	0.022
			(0.006)	(0.041)	(0.007)	(0.077)
Height-for-age Round 3					0.004	-0.182**
					(0.004)	(0.086)
R-squared	0.36		0.34		0.34	
Kleibergen-Paap F statistic		46.68		11.63		3.25
Stock and Yogo critical value		16.38		7.03		
Observations	1805	1805	1805	1805	1805	1805

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. The dependent variable is the age-standardised PPVT score. Height-for-age is measured as the difference of the child's height from the WHO reference child of the same monthly age and gender in centimetres. The Stock and Yogo critical value is the one for a 10% maximal 2SLS test size distortion. Excluded instruments for height-for-age in Rounds 1, 2, and 3 across countries include those presented in the just-identified column of Table 3. The full set of controls included in each specification and results are in Tables A5 to A8.

Table 7. *Impact of child growth at different stages of childhood on MATH score at age 12 across countries*

	Ethiopia					
	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.012**	-0.012	0.010*	-0.010	0.006	0.015
	(0.005)	(0.024)	(0.006)	(0.022)	(0.006)	(0.020)
Height-for-age Round 2			0.004	-0.014	-0.006	-0.073
			(0.005)	(0.048)	(0.006)	(0.066)
Height-for-age Round 3					0.015***	0.042
					(0.005)	(0.060)
R-squared	0.33		0.33		0.33	
Kleibergen-Paap F statistic		56.69		7.975		3.538
Stock and Yogo critical value		16.38		7.03		
Observations	1403	1403	1403	1403	1403	1403

	India					
	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.022***	0.116**	0.013*	0.252***	0.011	0.188
	(0.006)	(0.053)	(0.007)	(0.092)	(0.007)	(0.137)
Height-for-age Round 2			0.013**	-0.129	0.004	-0.249*
			(0.005)	(0.102)	(0.007)	(0.130)
Height-for-age Round 3					0.010*	0.192
					(0.006)	(0.132)
R-squared	0.29		0.28		0.28	
Kleibergen-Paap F statistic		25.02		3.99		1.83
Stock and Yogo critical value		16.38		7.03		
Observations	1806	1806	1806	1806	1806	1806

	Peru					
	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.013*	-0.036	0.001	-0.031	0.001	-0.020
	(0.007)	(0.050)	(0.008)	(0.036)	(0.008)	(0.039)
Height-for-age Round 2			0.016***	-0.014	0.016**	0.017
			(0.005)	(0.059)	(0.006)	(0.112)
Height-for-age Round 3					0.001	-0.062
					(0.006)	(0.103)
R-squared	0.28		0.28		0.27	
Kleibergen-Paap F statistic		35.95		6.34		2.44
Stock and Yogo critical value		16.38		7.03		
Observations	1805	1805	1805	1805	1805	1805

	Vietnam					
	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.021***	0.123***	0.020**	0.061	0.021**	0.083*
	(0.007)	(0.041)	(0.009)	(0.043)	(0.009)	(0.050)
Height-for-age Round 2			0.001	-0.195***	-0.010	-0.206**
			(0.006)	(0.056)	(0.009)	(0.082)
Height-for-age Round 3					0.012**	-0.018
					(0.005)	(0.090)
R-squared	0.30		0.29		0.29	
Kleibergen-Paap F statistic		46.68		11.63		3.25
Stock and Yogo critical value		16.38		7.03		
Observations	1805	1805	1805	1805	1805	1805

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. The dependent variable is the age-standardised MATH score. Height-for-age is measured as the difference of the child's height from the WHO reference child of the same monthly age and gender in centimetres. The Stock and Yogo critical value is the one for a 10% maximal 2SLS test size distortion. Excluded instruments for height-for-age in Rounds 1, 2, and 3 across countries include those presented in the just-identified column of Table 3. The full set of controls included in each specification and results are in Tables A9 to A12.

2SLS estimates of the total effect of growth across periods and countries on achievement test scores, using as instruments those listed in the just-identified columns in Table 3, suggest that the effect of growth from conception to Round 1 on PPVT is positive in all countries, but significant in Ethiopia and Vietnam, whereas the effect on MATH is positive and significant in India and Vietnam and negative and insignificant in Ethiopia and Peru. Moreover, growth between Rounds 1 and 2 has a positive and significant effect on PPVT in Ethiopia and Peru, but a negative effect on MATH in all countries, that is significant only in Vietnam, whereas growth between Rounds 2 and 3 has a significant, but negative, effect only on PPVT in Vietnam. Overall, 2SLS estimates of growth impacts across periods are, in most cases, much larger in magnitude, in absolute terms, than OLS, and suggest a quite large impact of growth on cognitive achievement. For example, in Vietnam 1 cm higher growth than the reference child between conception and Round 1 led to around 12 per cent of standard deviation increase in MATH in India and Vietnam, whereas 1 cm higher relative growth between Round 1 and 2 increased PPVT in Peru by 16 per cent of a standard deviation.

Results in Tables 6 and 7 indicate that Kleibergen-Paap F-statistics decrease markedly in models with more than one endogenous variable that would be indicative of problems related to weak instruments, that in turns would render 2SLS estimates in these models unreliable. Nevertheless, standard weak identification tests based on Stock and Yogo critical values are not possible in the case of models including height-for-age in the three rounds in Tables 6 and 7, because these are based on just-identified 2SLS estimation for which Stock and Yogo critical values are not available. Moreover, in the case of models including height-for-age in Round 1 and 2, although Stock and Yogo critical values are available, weak identification tests based on these values are likely not to be valid, as these values are predicated on i.i.d. errors in the reduced form equations (first-stage) (Stock and Yogo 2005), that is not expected to hold in this case, as the endogenous variables, and thus the errors in the independent first-stage regressions, are expected to be correlated. Therefore, as weak-identification tests for the case of non i.i.d. reduced form errors is still a work in progress (Sanderson and Windmeijer 2015), in order to detect and guard as much as possible against 2SLS problems related to weak identification, I employ the following strategy suggested by Angrist and Pichke (2009). First, I report results based on just-identified 2SLS estimation, presented in Tables 6 and 7, that is expected to deal with IV small sample bias, under weak instruments, as just-identified 2SLS is median-unbiased. Second, because just-identified 2SLS, although unbiased, is still expected to be imprecise and unstable under weak instruments, I also use additional instruments to that of the just-identified case, that are listed under the over-identified columns in Table 3 across countries, in order to produce estimates of the coefficients in (E.1), (E.2), and (E.3) using over-identified 2SLS and the GMM Continuously Updated Estimator (CUE) (Hansen et al. 1996).

GMM CUE is preferred to the Limited Information Maximum Likelihood (LIML) estimator, that performs at least as well as all estimators with better small sample properties than 2SLS under weak instruments, because it is equivalent to LIML under the assumption that errors in the structural equation are i.i.d., but, unlike LIML, is robust to deviations from this assumption (that is the case here, as robust standard errors are used in estimation of all models). According to Angrist and Pischke (2009), marked deviations of over-identified 2SLS from GMM CUE estimates can be used as a way to detect potential problems in 2SLS estimation related to weak instruments.

Over-identified 2SLS and GMM CUE estimates of models (E.1), (E.2), and (E.3) for PPVT and MATH are presented in Tables 6a and 7a respectively. Comparisons of coefficient estimates based on the two estimators indicate that the two estimators produce very similar results that in turns limit concerns over 2SLS estimates related to weak identification.[27] Moreover, Hansen J tests of the validity of over-identifying restrictions cannot reject the null that over-identifying restrictions are valid in all cases. Estimates of the total effects of growth across periods on PPVT and MATH across countries seem to suggest that, although results are similar to those of the just-identified case, in several cases, additional identifying restrictions are more likely to lead to statistically significant estimates. In particular, in contrast to just-identified 2SLS estimates, over-identified 2SLS estimates are consistent with a positive and statistically significant effect of growth from conception to Round 1 on PPVT across all countries, and positive and statistically significant impact of child growth between Rounds 2 and 3 on PPVT and MATH in India.

Table 6a. *2SLS and GMM CUE estimates of the impact of child growth at different stages of childhood on PPVT score at age 12 across countries*

	Ethiopia					
	2SLS	GMM CUE	2SLS	GMM CUE	2SLS	GMM CUE
Height-for-age Round 1	0.033** (0.015)	0.036** (0.015)	0.027 (0.019)	0.026 (0.019)	0.011 (0.018)	0.011 (0.018)
Height-for-age Round 2			0.094** (0.039)	0.102*** (0.040)	0.069 (0.057)	0.069 (0.057)
Height-for-age Round 3					0.016 (0.048)	0.016 (0.048)
Kleibergen-Paap F statistic	42.22	42.22	5.81	5.81	3.14	3.14
Stock and Yogo critical value	9.08	6.46	7.56	4.72		
Hansen J-statistic	2.274 (0.321)	2.254 (0.324)	1.223 (0.542)	1.187 (0.552)	0.169 (0.681)	0.169 (0.681)
Observations	1403	1403	1403	1403	1403	1403

27 Angrist and Pischke (2009) deal with the case of a single endogenous variable and argue that in the case that 2SLS and LIML estimates are similar then this implies limited concerns with weak instruments, even if first-stage F-statistics are much lower than conventional levels used to detect weak instruments.

	India					
	2SLS	GMM CUE	2SLS	GMM CUE	2SLS	GMM CUE
Height-for-age Round 1	0.092**	0.093***	0.120*	0.122*	0.059	0.061
	(0.036)	(0.036)	(0.072)	(0.072)	(0.103)	(0.103)
Height-for-age Round 2			-0.069	-0.071	-0.189*	-0.190*
			(0.068)	(0.069)	(0.109)	(0.109)
Height-for-age Round 3					0.176*	0.177*
					(0.096)	(0.096)
Kleibergen-Paap F statistic	22.29	22.29	3.73	3.73	1.86	1.86
Stock and Yogo critical value	19.93	8.68	13.43	5.44		
Hansen J-statistic	1.081	1.080	0.445	0.445	0.0882	0.0879
	(0.298)	(0.299)	(0.505)	(0.505)	(0.767)	(0.767)
Observations	1806	1806	1806	1806	1806	1806

	Peru					
	2SLS	GMM CUE	2SLS	GMM CUE	2SLS	GMM CUE
Height-for-age Round 1	0.067**	0.067**	-0.060*	-0.061*	-0.043	-0.041
	(0.033)	(0.033)	(0.033)	(0.034)	(0.036)	(0.037)
Height-for-age Round 2			0.129***	0.133***	0.177*	0.195**
			(0.045)	(0.045)	(0.091)	(0.094)
Height-for-age Round 3					-0.071	-0.086
					(0.080)	(0.082)
Kleibergen-Paap F statistic	32.38	32.38	6.76	6.76	2.51	2.51
Stock and Yogo critical value	19.93	8.68	13.43	5.44		
Hansen J-statistic	0.001007	0.001007	0.860	0.854	0.810	0.779
	(0.998)	(0.998)	(0.354)	(0.355)	(0.368)	(0.378)
Observations	1805	1805	1805	1805	1805	1805

	Vietnam					
	2SLS	GMM CUE	2SLS	GMM CUE	2SLS	GMM CUE
Height-for-age Round 1	0.165***	0.172***	0.157***	0.158***	0.222***	0.223***
	(0.039)	(0.040)	(0.033)	(0.033)	(0.051)	(0.052)
Height-for-age Round 2			-0.089**	-0.091**	0.016	0.015
			(0.039)	(0.039)	(0.074)	(0.074)
Height-for-age Round 3					-0.183**	-0.184**
					(0.004)	(0.086)
Kleibergen-Paap F statistic	32.32	32.32	9.19	9.19	2.55	2.55
Stock and Yogo critical value	19.93	8.68	13.43	5.44		
Hansen J-statistic	1.197	1.170	0.457	0.455	0.120	0.120
	(0.274)	(0.279)	(0.499)	(0.500)	(0.729)	(0.729)
Observations	1805	1805	1805	1805	1805	1805

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. The dependent variable is the age-standardised PPVT score. Height-for-age is measured as the difference of the child's height from the WHO reference child of the same monthly age and gender in centimetres. The Stock and Yogo critical value for 2SLS and GMM CUE are those for a 10% maximal 2SLS and LIML test size distortion respectively. Hansen J test p-values in parentheses below Hansen J statistics. Excluded instruments in specifications including only height-for-age in Round 1 across countries include those in just-identified and over-identified columns of Table 3. Excluded instruments in specifications including height-for-age in Round 1 and 2 for Ethiopia, Peru, and Vietnam include those in the just-identified column for height-for-age in Round 1 and the just-identified and over-identified columns of Table 3, and for India those in the just-identified and over-identified column for height-for-age in Round 1 and the just-identified column for height-for-age in Round 2 in Table 3. Excluded instruments in specifications including height-for-age in Rounds 1, 2, and 3 across countries include those in the just-identified column for height-for-age in Rounds 1 and 2 and just-identified and over-identified columns for height-for-age in Round 3 in Table 3. The full set of controls included in each specification is the same as those Tables A5 to A8. Full set of results available on request.

Table 7a. *2SLS and GMM CUE estimates of the impact of child growth at different stages of childhood on MATH score at age 12 across countries*

	Ethiopia					
	2SLS	GMM CUE	2SLS	GMM CUE	2SLS	GMM CUE
Height-for-age Round 1	0.004 (0.018)	0.003 (0.018)	-0.012 (0.019)	-0.012 (0.019)	0.015 (0.021)	0.016 (0.021)
Height-for-age Round 2			-0.011 (0.037)	-0.011 (0.037)	-0.074 (0.066)	-0.078 (0.066)
Height-for-age Round 3					0.050 (0.057)	0.052 (0.057)
Kleibergen-Paap F statistic	41.11	41.11	5.83	5.83	3.13	3.13
Stock and Yogo critical value	9.08	6.46	7.56	4.72		
Hansen J-statistic	1.499 (0.473)	1.499 (0.473)	0.0478 (0.976)	0.0478 (0.976)	0.229 (0.632)	0.228 (0.633)
Observations	1403	1403	1403	1403	1403	1403

	India					
	2SLS	GMM CUE	2SLS	GMM CUE	2SLS	GMM CUE
Height-for-age Round 1	0.090** (0.038)	0.093** (0.038)	0.249*** (0.089)	0.249*** (0.089)	0.131 (0.119)	0.129 (0.123)
Height-for-age Round 2			-0.121 (0.088)	-0.121 (0.088)	-0.254* (0.131)	-0.259* (0.135)
Height-for-age Round 3					0.238** (0.120)	0.256** (0.124)
Kleibergen-Paap F statistic	22.29	22.29	3.73	3.73	1.86	1.86
Stock and Yogo critical value	19.93	8.68	13.43	5.44		
Hansen J-statistic	0.463 (0.496)	0.461 (0.497)	0.0240 (0.877)	0.0239 (0.877)	0.615 (0.433)	0.590 (0.433)
Observations	1806	1806	1806	1806	1806	1806

	Peru					
	2SLS	GMM CUE	2SLS	GMM CUE	2SLS	GMM CUE
Height-for-age Round 1	-0.035 (0.038)	-0.035 (0.038)	-0.031 (0.035)	-0.031 (0.035)	-0.020 (0.040)	-0.020 (0.040)
Height-for-age Round 2			-0.014 (0.047)	-0.014 (0.047)	0.029 (0.094)	0.029 (0.094)
Height-for-age Round 3					-0.073 (0.084)	-0.073 (0.084)
Kleibergen-Paap F statistic	32.26	32.38	6.91	6.91	2.50	2.50
Stock and Yogo critical value	19.93	8.68	13.43	5.44		
Hansen J-statistic	0.00194 (0.965)	0.00194 (0.965)	0.001102 (0.992)	0.001102 (0.992)	0.0348 (0.852)	0.0348 (0.852)
Observations	1805	1805	1805	1805	1805	1805

	Vietnam					
	2SLS	GMM CUE	2SLS	GMM CUE	2SLS	GMM CUE
Height-for-age Round 1	0.120*** (0.035)	0.120*** (0.035)	0.058 (0.042)	0.059 (0.042)	0.083 (0.052)	0.084 (0.054)
Height-for-age Round 2			-0.181*** (0.050)	-0.183*** (0.051)	-0.225*** (0.084)	-0.228*** (0.086)
Height-for-age Round 3					-0.021 (0.094)	-0.032 (0.097)
Kleibergen-Paap F statistic	32.32	32.32	9.19	9.19	2.55	2.55
Stock and Yogo critical value	19.93	8.68	13.43	5.44		
Hansen J-statistic	0.0266 (0.870)	0.0266 (0.870)	0.467 (0.494)	0.466 (0.495)	0.956 (0.328)	0.926 (0.336)
Observations	1805	1805	1805	1805	1805	1805

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. The dependent variable is the age-standardised MATH score. Height-for-age is measured as the difference of the child's height from the WHO reference child of the same monthly age and gender in centimetres. The Stock and Yogo critical value for 2SLS and GMM CUE are those for a 10% maximal 2SLS and LIML test size distortion respectively. Hansen J test p-values in parentheses below Hansen J statistics. Excluded instruments in specifications including height-for-age in Rounds 1, 2, and 3 across countries include those in the just-identified column for height-for-age in Rounds 1 and 2 and just-identified and over-identified columns for height-for-age in Round 3 in Table 3. The full set of controls included in each specification is the same as those in Tables A9 to A12. Full set of results available on request.

Moreover, based on 2SLS estimates presented in Tables 6, 6a, 7, and 7a, there is a marked change in the coefficients of height-for-age in Round 1 and 2 after conditioning for height-for-age in subsequent rounds. For example, a comparison of the 2SLS estimated coefficients of height-for-age in Round 1 in the second, fourth, and sixth column of Table 6a for Ethiopia, suggests that 66 per cent of the total effect of growth between conception and Round 1 on PPVT at age 12 manifests through growth in subsequent periods. This supports that the causal link between early nutrition and later cognitive development is partly mediated through biological or behavioural mechanisms linking nutrition in later periods with cognition.

Finally, another concern in estimation may arise from bias due to sample selection resulting from attrition or missing values in PPVT or MATH at age 12, or height in Rounds 1, 2, and 3. A simple way to investigate this is to test whether sample selection is correlated with child growth that is the key causing variable in my case, as according to Greene (2007), a sufficient condition for OLS estimates to be unbiased under sample selection is that sample selection, conditional on other factors that are taken into account in estimation, is uncorrelated with the key causing variable or the outcome in the structural equation. In order to investigate this, I regressed an indicator of whether an observation is included in estimation on dummies constructed based on caregiver's perceptions of the size of the child at birth and child's height relative to other children of the same age reported in Round 1 and other controls. These two subjective indicators of child's size were chosen because, in contrast to child height, they are available for the full sample across countries and are valid proxies for child's growth as they are strongly and positively correlated with child height-for-age in Round 1. Results (see Tables A14 and A15 in the Appendix) do not seem to suggest a systematic relationship between sample selection and child's growth, except perhaps for Peru, where estimates suggest that shorter children are more likely to be excluded from the estimation sample. To the extent, however, that the children experiencing slower physical growth, excluded from the sample in Peru perform, on average, less well in achievement tests, then sample selection bias is expected to be negative and thus, identified effects for Peru provide lower bounds of actual total effects of growth on achievement.

5.3 The impact of child nutrition at different stages of childhood on parental nutrition and cognitive skills investments in middle childhood

Estimates of the impact of nutrition at different periods on cognitive achievement are expected to reflect, at least partly, behavioural responses by parents who may increase or decrease investments on nutrition and cognitive skills as a response to changes in child growth. For example, according to the conceptual framework, the negative effects of nutrition in some cases on cognitive achievement, as suggested by 2SLS estimates presented in Tables 6, 6a, 7, and 7a, could only reconcile with compensatory nutrition and cognitive skills investment responses that more than offset any positive direct effect of nutrition on cognitive achievement. Identifying the direction of parental investment responses to changes in child growth and nutrition is important, as it may allow one, under certain conditions, to infer whether there is a direct (biological) effect of growth after the first 1,000 days on cognitive achievement that may provide a direct test of the hypothesis that the first 1,000 days is a critical period for the impact of nutrition on cognitive development.

Table 8. *2SLS estimates of the total effect of child growth at different stages of childhood on cognitive skills and nutrition inputs demands at age 8 across countries*

	Cognitive skills inputs			Nutrition inputs		
	Education expenditure	Time in school and studying	School entry age	Health expenditure	Dietary diversity	Number of meals
Ethiopia						
Height-for-age Round 1	-0.038** (0.019)	-0.082 (0.060)	-0.079 (0.371)	0.014 (0.020)	0.041 (0.043)	0.022 (0.019)
Height-for-age Round 2	0.083 (0.057)	-0.313** (0.148)	2.120** (1.019)	-0.089 (0.070)	0.159* (0.094)	0.046 (0.039)
Height-for-age Round 3	0.109 (0.084)	0.004 (0.160)	0.398 (1.102)	0.056 (0.084)	-0.029 (0.120)	0.007 (0.049)
India						
Height-for-age Round 1	0.051 (0.049)	0.026 (0.087)	0.155 (0.644)	0.104* (0.054)	-0.267** (0.106)	-0.099 (0.067)
Height-for-age Round 2	-0.007 (0.079)	-0.173 (0.118)	0.024 (1.018)	0.030 (0.105)	0.094 (0.167)	0.045 (0.113)
Height-for-age Round 3	-0.116 (0.108)	0.486** (0.219)	-0.618 (1.202)	0.080 (0.108)	-0.215 (0.175)	0.176 (0.139)
Peru						
Height-for-age Round 1	0.099 (0.135)	-0.440 (0.311)	8.428* (4.508)	0.177 (0.135)	0.231 (0.235)	-0.137 (0.139)
Height-for-age Round 2	0.072 (0.080)	-0.174 (0.150)	4.429** (1.831)	0.104 (0.071)	0.146 (0.134)	-0.086 (0.073)
Height-for-age Round 3	-0.123 (0.085)	-1.038*** (0.397)	1.793 (2.255)	-0.152* (0.086)	-1.537*** (0.516)	-0.670*** (0.239)
Vietnam						
Height-for-age Round 1	-0.006 (0.024)	0.036 (0.056)	0.486 (0.343)	-0.001 (0.021)	-0.001 (0.083)	0.001 (0.039)
Height-for-age Round 2	0.009 (0.048)	-0.338*** (0.098)	0.551 (0.410)	0.007 (0.028)	0.225** (0.103)	0.182*** (0.059)
Height-for-age Round 3	0.111 (0.069)	0.022 (0.160)	0.196 (0.526)	-0.043 (0.054)	-0.010 (0.152)	-0.033 (0.083)

Notes: ***significant at 1%, **significant at 5%, *significant at 10%. The first, second, and third row of each country panel presents coefficient estimates, with associated robust standard errors in parentheses, of the impact of height-for-age in Round 1 from equation (E.3), in Round 2 from equation (E.2), and in Round 3 from equation (E.3) respectively using as outcomes the inputs listed in the third row. Height-for-age is measured as the difference of the child's height from the WHO reference child of the same monthly age and gender in centimetres. Diagnostics test results, the sample size, and excluded instruments for height-for-age in each Round are the same as those from the estimation of the associated equations for PPVT and MATH presented in Tables 6 and 7 respectively. The full set of controls included in each specification is the same as those Tables A5 to A8. Full results available on request.

Table 8 presents 2SLS estimates of the total effect of nutrition in each period on the different cognitive skills and nutrition inputs implemented in the Round 3 survey when children were around 8 years old across the four countries. These estimates are produced by estimating variants of equations (E.1), (E.2), and (E.3) using as outcomes the different cognitive skills and nutrition inputs and the same instruments for height-for-age in each round employed in the just-identified 2SLS estimation of (E.1), (E.2), and (E.3), presented in Tables 6 and 7. In particular, the first row of each panel in Table 8 reports just-identified 2SLS estimates of the coefficient of height-for-age in Round 1 from (E.3) for all inputs across the four countries. Similarly, the second row of each panel in Table 8 includes estimates of the coefficient of height-for-age in Round 2 from (E.2) for all inputs and the third row includes estimates of the coefficient of height-for-age in Round 3 from (E.1) across inputs.

To the extent that there are no unobserved investment responses or that unobserved investment responses are in the same direction as those observed, results in Table 8 are consistent with a direct effect of nutrition from conception to age 1, and ages 1 to 5, on cognitive development. For example, observed responses to child growth from conception to Round 1 in all countries, presented in Table 8, are consistent with either neutral or compensatory investment responses (with the exception of health expenditure in India), that further imply that the identified effects of growth during this period on PPVT across countries and MATH in India and Vietnam may provide lower bounds of biological effects running from nutrition in these periods on cognition. The same is the case for the effect of growth between Round 1 and 2 on PPVT in Peru, whereas in Ethiopia, results suggest that the identified positive effect of growth between 1 and 5 years old on PPVT may be either the result of a direct effect or reinforcing nutrition investments, or both. Given that nutrition investments are implemented well after the first 1,000 days (between 7 and 8 years) and the identifying variation in growth between ages 1 and 5 in all countries arises from weather shocks realised after the first 1,000 days, none of these results seem to provide support to the hypothesis that the first 1,000 days is the only period during which investments in nutrition are effective in promoting cognitive development.

In the face of compensatory or counteracting cognitive skills and nutrition parental investment responses to child growth across period, differential magnitudes of effects of growth on PPVT and MATH could be explained in terms of differential production technologies for verbal and quantitative skills (McGrew 2009).

Moreover, the negative and significant effect of growth between Rounds 1 and 2 on PPVT and MATH in Vietnam could be potentially explained by compensatory cognitive skills investments that more than offset observed compensatory responses in child nutrition. The same is not the case, however, for the case of the negative effect of growth between Rounds 2 and 3 on PPVT in Vietnam, as, according to results in Table 8, there is no evidence of significant compensatory investment responses to child growth in this period. The latter could be either explained in terms of the larger imprecision of 2SLS estimates in models including height-for-age in the three rounds, or in terms of unobserved investment responses that are not in the same direction as those observed. I have investigated this hypothesis for Peru, as in the third round of the Young Lives survey in Peru only, there is information on a range of additional cognitive skills inputs related to the home environment, parental assessment of teachers' effort, and parental involvement in school activities when the child was around 8 years old. Results suggest that, although the impact of child growth across periods on most of these additional inputs is in the same direction as the impacts on cognitive skills inputs included in Table 8, there is at least one input that responds to the opposite direction.[28] This finding further implies that the evidence here cannot be conclusive on whether or not any positive and significant effects of growth across periods on achievement test scores provide lower or upper bounds of biological effects.

There are also other patterns, as suggested by results in Table 8, consistent with heterogeneous parental investment responses over several dimensions that seem to provide support to the latter conclusion more generally. First, in several cases, health and cognitive skills investments respond in opposite directions to changes in child growth during a given period. For example, there is evidence of compensatory cognitive skills, but reinforcing nutrition investments in Ethiopia and Vietnam, as a response to changes in growth between conception and Round 1, and Round 1 and 2 respectively. Recent evidence by Yi et al. (2015) also supports counteracting parental cognitive skills and health investments, although Yi et al. (2015) find that parents compensate in terms of health, but reinforce in terms of education as a response to a health insult. Second, not all inputs in the production of a given human capital dimension, for example, health, respond in the same direction. This is the case in India, where higher child growth from conception to Round 1 leads to an increase in the expenditure on child health, but to a decrease in child's dietary diversity.[29] Third, the same input may respond differently to a change in child health realised at different stages of the child's development. For example, changes in nutrition between 5 and 8 years old has a strong negative effect on the time the child spent in school and studying and across all nutrition inputs in Round 3, and growth changes before age 1 and between 1 and 5 years old have no effect on these inputs, whereas in Vietnam, there are significant input responses to changes in growth in the period between Rounds 1 and 2 but not in other periods.

Overall, these results may explain the mixed evidence and the current lack of consensus in the literature on whether parents compensate or reinforce the impact of child health insults in early life (Pitt et al. 1990; Behrman et al. 1994) and highlight that, under heterogeneous and partially observed parental investment responses to changes in child health, it is very difficult to infer whether reduced form estimates provide lower or upper bounds of biological effects of health on cognitive skills.

6. Conclusion

Child undernutrition is highly prevalent in low- and middle-income countries and has deleterious implications for child development. Nutrition-promoting interventions in poor contexts focus mainly on the first 1,000 days since conception, as it has been suggested that nutritional insults during this period may lead to physical growth deficits and cognitive developmental setbacks that are irreversible beyond this period. The evidence, however, in support of these hypotheses is rather thin because there are few studies purporting to identify critical periods for the impact of nutrition on cognitive development, and those that do suffer from various methodological limitations. Moreover, these studies produce results reflecting both biological and behavioural effects of nutrition at different stages of the child's life course on cognitive development, and do not produce evidence on the direction of

28 Results available from the author on request.

29 This is also the case of the impact of growth in all three periods on cognitive skills investments in Peru, when considering the additional cognitive skills inputs in Round 3.

behavioural effects that depend on whether parents increase or decrease investments in the face of changes of child nutrition. Therefore, it is very difficult to infer from the results of these studies the magnitude of biological effects of nutrition in each period on cognitive development that is needed for the identification of critical periods. The question of how parents respond to changes in child health is little investigated, the existing evidence is rather mixed (Pitt et al. 1990; Behrman et al. 1994), and we know very little on whether and how parental investment responses depend on the timing of changes in child health.

In this paper, I investigate the impact of child nutrition at different stages from conception to middle childhood on cognitive achievement in early adolescence using data from Ethiopia, India, Peru, and Vietnam. In order to identify the independent effect of nutrition in each period on cognitive achievement, I develop a conceptual framework of the determination of child health and cognitive skills over different periods of childhood that I use to guide the specification of the econometric model and the choice of the identification strategy and use exogenous variation in child nutritional status, as measure by growth, across periods arising from weather shocks.

My key finding is that, although early undernutrition has negative implications for child growth and cognitive development, these implications are not irreversible and there is scope for remediation of physical growth and cognitive deficits arising from early undernutrition through nutrition investments in later stages of childhood. Another novel result is that parental investment responses to a change in child health are heterogeneous across multiple dimensions. In particular, I find that the direction of investment responses may differ: (a) across human capital dimensions; (b) across inputs within a given human capital dimension; and (c) with the timing of the change in child health. The heterogeneity of parental investment responses and the fact that these responses are imperfectly observed may explain the mixed evidence and the current lack of consensus in the literature on whether parents compensate or reinforce the impact of child health insults in early life, and highlight that it is very difficult to infer whether reduced form estimates provide lower or upper bounds of biological effects of health on cognitive skills.

Overall, my findings have important policy implications. On the one hand, results indicate that nutrition early in life is important for physical growth and cognitive development in subsequent stages of childhood, but on the other hand they suggest that nutrition-promoting investments after infancy and early childhood can act as a remedy for early nutrition and cognitive deficits and protect from nutritional insults in later stages that may also lead to developmental setbacks. The evidence here also highlights the importance of parental behavioural responses for the causal link between child nutrition and cognitive development and thus that these responses, which may counteract the impact of interventions, should be taken into account in the design of policies aiming to promote child growth and development. This evidence suggests that nutrition-promoting interventions that start early in life and continue to subsequent stages of childhood, combined with support in other areas such as cognitive stimulation and parental involvement, may hold the most promise for the promotion of child development.

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Appendices

Table A1. *Descriptive statistics of community prices of food, medication, education, and other consumption items*

Variable	Round 1				Round 2				Round 3				Round 4			
	Ethiopia	India	Peru	Vietnam	Ethiopia	India	Peru	Vietnam	Ethiopia	India	Peru	Vietnam	Ethiopia	India	Peru	Vietnam
Food items																
Cereals	1.67				2.45				6.69				10.37			
	(0.38)				(0.86)				(0.96)				(1.73)			
Rice		9.81	1.49	3.08		11.78	1.71	5.10		20.39	1.96	8.39			34.00	2.33
		(2.55)	(0.31)	(0.35)		(2.29)	(0.27)	(0.55)		(5.29)	(0.45)	(1.79)			(7.67)	(0.36)
Potato			0.63				0.86				1.02			1.42		
			(0.27)				(0.15)				(0.20)			(0.34)		
Pasta			2.61				2.67				3.18			3.23		
			(0.46)				(0.38)				(0.34)			(0.42)		
Coffee	6.87	86.72	6.79	40.06	14.12	117.19	9.39	16.07	38.03	206.29	11.76	58.93	70.27	280.12	0.87	123.93
	(1.18)	(44.95)	(4.42)	(6.73)	(8.12)	(44.02)	(3.25)	(18.15)	(9.15)	(73.52)	(3.68)	(22.34)	(10.31)	(87.89)	(0.19)	(83.73)
Sugar	4.93	15.24	1.74	6.07	8.27	19.77	2.05	9.43	14.36	34.04	2.04	15.32	18.50	37.90	2.12	18.88
	(0.38)	(0.71)	(0.31)	(0.57)	(0.80)	(1.59)	(0.19)	(1.27)	(0.63)	(2.66)	(0.24)	(1.03)	(4.44)	(5.34)	(0.35)	(2.37)
Oil	10.76	45.89	3.76	13.93	8.82	53.79	3.99	17.61	20.06	56.55	5.88	26.25	31.27	72.34	5.87	36.64
	(1.61)	(3.80)	(0.51)	(1.12)	(5.82)	(4.39)	(0.46)	(1.70)	(2.86)	(9.51)	(0.68)	(3.89)	(8.58)	(8.92)	(0.33)	(7.95)
Salt	1.52	4.59	0.80	1.06	1.92	5.80	0.60	1.46	3.10	8.12	0.79	4.63	5.05	11.58	1.01	9.78
	(0.56)	(1.46)	(0.78)	(0.23)	(3.10)	(1.83)	(0.18)	(0.55)	(0.57)	(2.02)	(0.20)	(2.78)	(0.60)	(3.64)	(0.16)	(10.00)
Medication																
Oral rehydration salts	1.24	11.09	1.01	0.91	1.65	8.40	1.01	1.08	1.78	12.95	0.83	1.35	5.24	12.89	0.81	28.10
	(0.25)	(5.59)	(0.41)	(0.17)	(0.78)	(4.06)	(0.32)	(0.24)	(0.41)	(7.66)	(0.22)	(0.32)	(6.40)	(7.17)	(0.28)	(98.81)
Paracetamol	0.10	0.53	0.01	0.10	0.73	0.99	0.15	0.92	0.21	1.18	0.13	2.16	1.21	1.42	0.13	3.91
	(0.02)	(0.17)	(0.01)	(0.06)	(0.60)	(0.95)	(0.07)	(0.58)	(0.17)	(1.25)	(0.05)	(1.36)	(1.65)	(0.74)	(0.13)	(24.17)
Amoxicillin	0.83	3.69	0.01	0.26	1.16	3.48	0.27	2.43	0.52	3.67	0.29	1.67	5.06	4.35	0.26	3.21
	(0.25)	(1.04)	(0.01)	(0.20)	(0.88)	(0.90)	(0.13)	(1.50)	(0.23)	(0.82)	(0.13)	(1.50)	(7.85)	(1.86)	(0.16)	(3.00)
Mebendazole	2.43	4.29	0.30	0.58	1.50	7.24	0.36	1.97	0.19	13.06	0.16	3.35	3.32	9.08	0.20	6.71
	(0.11)	(3.92)	(0.27)	(0.46)	(1.59)	(4.79)	(0.21)	(1.81)	(0.07)	(3.53)	(0.10)	(1.80)	(2.76)	(4.43)	(0.20)	(5.96)
Education items																
Notebook	2.01	4.47	1.04	0.94	2.56	5.36	1.31	2.46	3.39	6.14	1.43	4.18	6.45	10.83	1.51	259.42
	(0.85)	(1.06)	(0.21)	(0.17)	(0.41)	(1.40)	(0.20)	(0.80)	(0.90)	(2.59)	(0.18)	(1.97)	(1.67)	(3.54)	(0.57)	(1095.77)
School shoes	25.13	110.62	28.76	15.00	30.00	110.33	30.79	32.71	57.40	128.68	37.21	25.39	90.76	187.90	42.50	77.27
	(18.02)	(78.49)	(4.26)	(5.92)	(20.73)	(36.95)	(3.70)	(19.29)	(28.29)	(33.63)	(6.83)	(15.24)	(56.38)	(69.71)	(7.36)	(36.74)
Boy's shirt	19.42	94.60	12.74	14.75	20.98	68.12	10.87	26.43	30.63	112.63	13.80	30.74	75.83	201.66	17.11	73.65
	(10.44)	(32.59)	(3.37)	(3.76)	(9.06)	(32.18)	(2.45)	(6.97)	(15.37)	(48.19)	(2.72)	(8.10)	(38.06)	(66.23)	(3.68)	(29.82)
Girl's shirt	17.16	105.23	12.59	15.31	25.44	73.98	10.55	25.58	38.11	109.82	13.71	32.09	85.51	141.24	16.81	71.62
	(8.75)	(54.33)	(3.00)	(4.11)	(10.11)	(45.64)	(2.62)	(6.55)	(17.46)	(56.15)	(2.65)	(8.43)	(35.46)	(61.10)	(3.66)	(23.17)
Boy's shorts	19.53	102.12	20.39	9.15	26.20	100.97	24.16	9.92	52.74	183.19	27.22	15.73	128.69	256.04	29.55	92.76
	(12.52)	(69.68)	(5.35)	(1.41)	(18.81)	(42.23)	(4.36)	(4.30)	(47.07)	(69.85)	(3.89)	(6.89)	(78.38)	(79.08)	(4.53)	(38.63)
Girl's skirt	19.75	110.47	18.06	17.07	29.69	91.67	20.78	28.53	54.24	162.91	23.95	30.21	93.63	222.90	27.39	84.48
	(9.48)	(59.59)	(4.84)	(6.62)	(14.75)	(30.22)	(3.04)	(11.20)	(48.61)	(75.58)	(3.53)	(7.73)	(29.80)	(84.35)	(5.02)	(27.56)
Other consumption items																
Cigarettes	3.91	29.38	3.19	1.99	1.75	18.29	3.77	6.39	5.77	24.06	3.79	10.23	12.76	36.96	5.27	12.43
	(0.63)	(14.81)	(0.87)	(0.03)	(1.76)	(2.70)	(0.87)	(3.08)	(0.76)	(7.18)	(1.05)	(3.85)	(5.23)	(13.37)	(1.83)	(5.39)
Detergent	4.66	14.32	2.06	13.07	1.63	6.18	1.62	17.53	23.79	8.17	1.18	25.77	37.67	9.93	1.15	47.30
	(4.94)	(7.40)	(1.02)	(1.46)	(1.02)	(2.91)	(0.42)	(2.94)	(8.05)	(4.25)	(0.19)	(2.89)	(14.87)	(2.44)	(0.24)	(24.30)
Kerosene	2.51	14.61	1.86	4.35	4.05	16.46	12.62	10.22	8.95	12.63	14.34	15.77	17.96	28.87	36.16	24.47
	(0.73)	(2.02)	(0.35)	(0.40)	(1.33)	(4.81)	(2.02)	(3.28)	(0.93)	(4.19)	(1.81)	(1.42)	(3.31)	(7.16)	(2.68)	(3.59)
Observations	1403	1806	1805	1805	1403	1806	1805	1805	1403	1806	1805	1805	1403	1806	1805	1805

Notes: Figures are averages with standard deviations in parentheses. Prices are in national currency units. Prices of food items are per kg except for oil for which price is per lt. Price of cereals in Ethiopia is the average of the prices of white teff, sorghum, and barley. Prices of medication are per tablet except for oral rehydration salts for which price is per sachet. Price for cigarettes is for one pack of 20 and price for kerosene is per lt. Prices were combined to calculate Paasche price indices for food, medication, education, and other consumption items using equal weights except for the food price index, for which weights used were the share of each item in the total consumption expenditure in the community, computed using information on household consumption expenditure. Base prices in the price index were the median prices of the items used.

Table A2. *Descriptive statistics of community wages and disease environment items*

Variable	Round 1				Round 2				Round 3				Round 4			
	Ethiopia	India	Peru	Vietnam	Ethiopia	India	Peru	Vietnam	Ethiopia	India	Peru	Vietnam	Ethiopia	India	Peru	Vietnam
Average wage of adult male agricultural worker	5.40	45.70	11.40	20.41	9.99	61.01	12.58	35.28	19.20	119.81	17.28	73.30	79.91	207.18	27.71	146.44
	(1.82)	(10.20)	(3.31)	(4.93)	(2.18)	(11.23)	(4.02)	(5.84)	(4.82)	(29.26)	(4.44)	(15.52)	(57.04)	(37.68)	(9.45)	(25.02)
Average wage of adult male unskilled factory worker	8.18	50.02	21.58	22.66	8.59	70.56	15.74	27.75	508.49	135.77	23.00	57.92	967.27	227.42	15.79	117.34
	(2.11)	(3.01)	(1.24)	(4.88)	(1.54)	(14.18)	(3.80)	(7.76)	(131.55)	(23.37)	(3.14)	(10.51)	(518.52)	(52.03)	(2.98)	(26.01)
Air pollution is a severe problem	0.68	0.79	0.90	0.48	0.62	0.59	0.35	0.15	0.44	0.57	0.41	0.15	0.30	0.41	0.17	0.28
	(0.41)	(0.30)	(0.50)	(0.50)	(0.49)	(0.49)	(0.48)	(0.36)	(0.50)	(0.50)	(0.49)	(0.36)	(0.46)	(0.49)	(0.38)	(0.45)
Water pollution is a severe problem	0.52	0.49	0.80	0.40	0.61	0.82	0.50	0.44	0.48	0.72	0.62	0.21	0.48	0.64	0.55	0.43
	(0.50)	(0.40)	(0.49)	(0.48)	(0.49)	(0.38)	(0.50)	(0.50)	(0.50)	(0.45)	(0.49)	(0.41)	(0.50)	(0.48)	(0.50)	(0.50)
Access to improved drinking water	0.69	0.93	0.99	0.71	0.95	0.98	0.94	0.83	0.80	0.78	0.93	0.98	0.94	0.87	1.00	0.77
	(0.46)	(0.25)	(0.09)	(0.46)	(0.21)	(0.13)	(0.23)	(0.38)	(0.40)	(0.41)	(0.25)	(0.14)	(0.23)	(0.34)	(0.05)	(0.42)
Access to improved sanitation	0.65	0.63	0.94	0.79	1.00	0.92	0.96	1.00	0.84	0.98	0.96	0.97	0.31	0.61	1.00	0.86
	(0.48)	(0.48)	(0.24)	(0.41)	(0.00)	(0.26)	(0.19)	(0.00)	(0.37)	(0.14)	(0.20)	(0.17)	(0.46)	(0.49)	(0.05)	(0.34)
Garbage collection by truck	0.13	0.19	0.51	0.25	0.20	0.28	0.67	0.36	0.10	0.27	0.69	0.54	0.29	0.26	0.74	0.83
	(0.34)	(0.39)	(0.50)	(0.43)	(0.40)	(0.45)	(0.47)	(0.48)	(0.30)	(0.45)	(0.46)	(0.50)	(0.46)	(0.44)	(0.44)	(0.37)
Observations	1403	1806	1805	1805	1403	1806	1805	1805	1403	1806	1805	1805	1403	1806	1805	1805

Notes: Figures are averages with standard deviations in parentheses. Wages are in national currency units. A wage index was constructed by dividing the average wage of adult male agricultural worker in rural communities and the average wage for adult male unskilled factory worker in urban communities with their median analogue. An index of the level of hygiene in the community was constructed by taking the average of all disease environment items. Access to improved drinking water here means that, during data collection, the household had access to improved drinking water and toilets as defined by WHO/UNICEF (see http://www.wssinfo.org/definitions-methods/watsan-categories/), not that access to drinking water and sanitation improved between rounds of data collection.

Table A3. *OLS estimates of the impact of weather shocks on child growth at different stages of childhood in Ethiopia and India*

	Ethiopia			India		
	Height-for-age Round 1	Height-for-age Round 2	Height-for-age Round 3	Height-for-age Round 1	Height-for-age Round 2	Height-for-age Round 3
Weather shock before Round 1	0.513*** (0.067)			-0.004*** (0.001)		
Weather shock between Round 1 and 2		0.025*** (0.006)			0.184*** (0.060)	
Weather shock between Round 2 and 3			0.006*** (0.002)			-0.276*** (0.083)
Height-for-age Round 1		0.437*** (0.031)			0.659*** (0.028)	
Height-for-age Round 2			0.784*** (0.033)			0.895*** (0.036)
Male	-0.728*** (0.222)	-0.099 (0.240)	-0.229 (0.257)	-0.087 (0.164)	-0.114 (0.174)	0.147 (0.171)
Second-born	0.260 (0.320)	-1.101*** (0.357)	0.590 (0.406)	0.218 (0.182)	-0.167 (0.204)	-0.509** (0.208)
Third- or later-born	0.155 (0.271)	-0.742** (0.305)	0.153 (0.315)	-0.177 (0.236)	-0.720*** (0.258)	-0.771*** (0.277)
Caregiver's age at child's birth	0.017 (0.013)	0.019 (0.015)	-0.001 (0.014)	0.042** (0.017)	0.018 (0.019)	0.050** (0.022)
Caregiver's education	0.049 (0.039)	0.017 (0.043)	0.026 (0.048)	0.049* (0.025)	0.020 (0.029)	0.077*** (0.028)
Father's education	0.063* (0.035)	0.098*** (0.035)	-0.040 (0.034)	0.036* (0.021)	0.059** (0.024)	-0.028 (0.024)
Wealth index in Round 1	4.764*** (1.304)	-0.541 (1.384)	2.408* (1.450)	1.457** (0.602)	1.595** (0.634)	2.331*** (0.612)
Community consumption price index in Round 1	-1.674 (1.243)	4.025*** (1.145)	-0.742 (0.834)	0.605 (0.422)	1.013** (0.456)	1.069** (0.444)
Community consumption price index in Round 2	1.054 (0.820)	0.250 (0.843)	-0.190 (0.955)	0.075 (0.856)	1.159 (0.781)	-0.078 (0.844)
Community consumption price index in Round 3	1.490 (1.804)	-1.817 (2.431)	0.219 (1.212)	-2.249*** (0.797)	-1.520** (0.732)	-0.830 (0.539)
Community education inputs price index in Round 4	-2.311** (1.082)	2.409** (1.080)	-1.056 (1.119)	0.558 (0.626)	-0.709 (0.650)	-0.310 (0.584)
Community cognitive skills inputs price index in Round 1	-0.606 (0.989)	0.336 (0.836)	-1.063 (1.079)	-0.013 (0.504)	0.612 (0.474)	0.220 (0.435)
Community cognitive skills inputs price index in Round 2	-0.272 (1.467)	-5.684*** (1.227)	2.621* (1.496)	-0.213 (0.658)	-0.126 (0.663)	0.879 (0.661)
Community cognitive skills inputs price index in Round 3	0.021 (1.437)	-0.097 (1.407)	-1.380 (1.024)	-0.199 (0.489)	0.063 (0.571)	-0.915** (0.458)
Community cognitive skills inputs price index in Round 4	0.076 (0.900)	2.475*** (0.894)	-0.790 (0.901)	-0.828* (0.437)	-0.505 (0.445)	0.006 (0.380)
Community wage index in Round 1	-1.591 (0.979)	0.181 (1.168)	0.611 (0.900)	-2.494*** (0.748)	2.298*** (0.762)	0.557 (0.773)
Community wage index in Round 2	-0.976 (1.208)	-0.065 (1.273)	1.104 (1.748)	-0.514 (0.623)	1.504** (0.670)	-0.784 (0.706)
Community wage index in Round 3	-0.261 (0.913)	0.201 (1.146)	-1.126 (0.989)	0.721 (0.724)	-0.364 (0.712)	0.088 (0.718)
Community wage index in Round 4	-0.276 (0.723)	0.636 (0.752)	-0.552 (0.558)	0.360 (0.529)	1.676*** (0.586)	-0.887 (0.559)

	Ethiopia			India		
	Height-for-age Round 1	Height-for-age Round 2	Height-for-age Round 3	Height-for-age Round 1	Height-for-age Round 2	Height-for-age Round 3
Number of credit-providing institutions in the community in Round 1	-0.231 (0.331)	-0.031 (0.355)	-0.002 (0.198)	0.102 (0.122)	0.199 (0.126)	0.044 (0.117)
Number of schools in the community Round 2	0.276 (0.660)	-1.728*** (0.511)	0.280 (0.511)	-0.251* (0.131)	0.144 (0.134)	0.549*** (0.146)
Number of schools in the community in Round 3	0.053 (0.245)	0.049 (0.216)	-0.434* (0.225)	0.069* (0.041)	0.038 (0.044)	-0.224*** (0.041)
Number of schools in the community in Round 4	0.118 (0.092)	-0.164 (0.102)	-0.080 (0.129)	0.034 (0.064)	-0.082 (0.060)	0.023 (0.067)
Community has hospital in Round 2	-1.584 (1.285)			0.233 (0.236)		
Community has hospital in Round 3	0.417 (0.776)	0.304 (0.822)		-0.640** (0.280)	-0.422 (0.274)	
Community has hospital in Round 4	1.252 (1.277)	-1.096 (1.246)	0.244 (1.314)	0.335 (0.218)	0.127 (0.224)	-0.257 (0.219)
Community disease environment index in Round 2	-9.733*** (2.788)			-0.141 (0.698)		
Community disease environment index in Round 3	-0.549 (1.896)	3.507* (1.923)		-1.415** (0.569)	-1.316** (0.630)	
Community disease environment index in Round 4	0.166 (1.279)	-2.198 (1.388)	3.528** (1.393)	-0.754 (0.579)	0.483 (0.600)	0.328 (0.582)
Price index for medication in Round 2	1.281 (0.792)			-2.333*** (0.637)		
Price index for medication in Round 3	-2.447 (2.300)	0.533 (2.646)		1.300** (0.615)	-0.392 (0.636)	
Price index for medication in Round 4	0.602 (0.778)	-1.646** (0.662)	0.597 (0.664)	-1.580*** (0.446)	0.119 (0.424)	-0.460 (0.411)
Price index for food in Round 2	-2.230 (1.709)			1.308 (1.084)		
Price index for food in Round 3	10.156** (4.881)	-4.627 (4.172)		3.366*** (0.883)	0.367 (0.907)	
Price index for food in Round 4	0.039 (3.170)	5.420* (3.017)	2.003 (2.978)	-2.219** (0.979)	1.215 (1.014)	-0.602 (0.899)
R-squared	0.18	0.27	0.46	0.13	0.37	0.62
Partial F statistic	56.17	14.94	11.04	25.01	9.13	10.84
Observations	1403	1403	1403	1806	1806	1806

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. Height-for-age is measured as the difference of the child's height from the WHO reference child of the same monthly age and gender in centimetres. All specifications include dummies for caregiver's ethnicity, and whether the PPVT was administered in the child's native language, and for Ethiopia dummies for the language at which the PPVT was administered, but estimates are not reported. The partial F statistic is the Kleibergen-Paap rk Wald F statistic of the first-stage of 2SLS estimation of the impact of height-for-age on PPVT score implemented separately for each period using as an instrument for height-for-age the relevant to the period weather shock. Weather shocks before Round 1 include deviations from locality, season, and year norm of temperature during the second half of the first year after birth in Ethiopia and rainfall one year before conception in India. Weather shocks between Round 1 and 2 are rainfall between three years after Round 1 and Round 2 in Ethiopia and temperature in the first half of the second year after completion of 1,000 days since conception in India. Weather shocks between Round 2 and 3 include rainfall in the seventh year after birth in Ethiopia and temperature between two years after Round 2 and Round 3 in India.

Table A4. *OLS estimates of the impact of weather shocks on child growth at different stages of childhood in Peru and Vietnam*

	Peru			Vietnam		
	Height-for-age Round 1	Height-for-age Round 2	Height-for-age Round 3	Height-for-age Round 1	Height-for-age Round 2	Height-for-age Round 3
Weather shock before Round 1	0.011*** (0.002)			0.358*** (0.052)		
Weather shock between Round 1 and 2		-0.165*** (0.030)			-0.005*** (0.001)	
Weather shock between Round 2 and 3			0.004*** (0.002)			0.336*** (0.074)
Height-for-age Round 1		0.804*** (0.040)			0.889*** (0.038)	
Height-for-age Round 2			0.852*** (0.030)			1.021*** (0.023)
Male	-0.339** (0.135)	0.614*** (0.174)	-0.312** (0.156)	-0.331** (0.134)	0.581*** (0.148)	-0.457*** (0.152)
Second-born	0.156 (0.168)	-0.553** (0.233)	-0.295 (0.211)	0.009 (0.152)	-0.437*** (0.169)	-0.132 (0.177)
Third- or later-born	-0.053 (0.198)	-0.687*** (0.248)	-0.297 (0.233)	0.066 (0.204)	-0.899*** (0.220)	0.076 (0.239)
Caregiver's age at child's birth	-0.014 (0.011)	0.033** (0.014)	0.018 (0.013)	-0.002 (0.009)	-0.002 (0.010)	-0.014 (0.010)
Caregiver's education	0.092*** (0.022)	0.140*** (0.029)	0.062** (0.027)	0.063** (0.026)	0.100*** (0.027)	0.013 (0.027)
Father's education	0.067*** (0.024)	0.031 (0.032)	0.057** (0.028)	0.057** (0.027)	0.054* (0.029)	0.028 (0.031)
Wealth index in Round 1	0.948** (0.459)	3.527*** (0.607)	0.448 (0.550)	1.298** (0.562)	2.029*** (0.600)	-0.033 (0.726)
Community consumption price index in Round 1	1.268** (0.504)	-0.705 (0.561)	-0.280 (0.526)	-0.958 (2.679)	6.514*** (2.337)	5.301*** (1.977)
Community consumption price index in Round 2	1.084** (0.512)	-0.617 (0.631)	2.381*** (0.543)	-1.085 (0.941)	1.248 (0.815)	0.141 (0.710)
Community consumption price index in Round 3	-0.106 (0.761)	1.699* (0.921)	1.177 (0.812)	1.814* (0.988)	-0.350 (1.123)	-1.412* (0.814)
Community education inputs price index in Round 4	2.238 (1.389)	0.218 (1.732)	-0.919 (1.381)	0.667 (0.704)	0.535 (0.753)	1.390** (0.686)
Community cognitive skills inputs price index in Round 1	0.511 (0.510)	1.452** (0.663)	-0.033 (0.533)	2.399** (1.145)	0.034 (1.094)	2.065** (1.049)
Community cognitive skills inputs price index in Round 2	0.996* (0.523)	-1.080 (0.681)	1.045* (0.590)	-1.444*** (0.490)	0.272 (0.592)	0.816* (0.455)
Community cognitive skills inputs price index in Round 3	-0.133 (0.759)	-1.442 (0.898)	0.529 (0.724)	0.329 (1.052)	-0.297 (1.116)	-0.914 (0.848)
Community cognitive skills inputs price index in Round 4	0.122 (0.585)	-1.309* (0.767)	0.760 (0.773)	-0.551 (0.553)	1.369** (0.538)	-0.765 (0.507)
Community wage index in Round 1	-1.484** (0.618)	-1.533* (0.794)	0.680 (0.679)	3.032*** (0.642)	3.265*** (0.715)	-1.040* (0.572)
Community wage index in Round 2	0.364 (0.358)	2.230*** (0.456)	-0.305 (0.397)	-1.538 (1.307)	-1.399 (1.012)	-0.015 (0.930)
Community wage index in Round 3	0.759* (0.440)	-0.543 (0.597)	0.733 (0.563)	-0.197 (0.849)	1.542* (0.874)	2.732** (1.078)
Community wage index in	-0.430	-0.179	0.012	0.484	-0.590	-1.074

	Peru			Vietnam		
	Height-for-age Round 1	Height-for-age Round 2	Height-for-age Round 3	Height-for-age Round 1	Height-for-age Round 2	Height-for-age Round 3
Round 4	(0.452)	(0.508)	(0.451)	(0.603)	(0.680)	(0.725)
Number of credit-providing institutions in the community in Round 1	0.114 (0.082)	0.094 (0.089)	0.220*** (0.084)	-0.051 (0.156)	-0.319** (0.135)	0.313*** (0.112)
Number of schools in the community Round 2	0.253* (0.134)	-0.048 (0.151)	0.254 (0.159)	0.514** (0.200)	-0.134 (0.221)	-0.094 (0.202)
Number of schools in the community in Round 3	0.188 (0.131)	-0.097 (0.179)	0.185 (0.164)	-0.102 (0.070)	0.182** (0.072)	-0.041 (0.070)
Number of schools in the community in Round 4	0.098 (0.061)	-0.186** (0.075)	-0.005 (0.065)	-0.068 (0.068)	-0.022 (0.066)	-0.020 (0.062)
Community has hospital in Round 2	-0.011 (0.259)			-0.123 (0.807)		
Community has hospital in Round 3	-0.347 (0.221)	0.269 (0.269)		1.115** (0.437)	-0.939* (0.539)	
Community has hospital in Round 4	-0.117 (0.189)	-0.058 (0.243)	0.027 (0.214)	-0.778 (0.860)	-0.829 (0.648)	0.561 (0.493)
Community disease environment index in Round 2	0.295 (0.474)			0.667 (0.783)		
Community disease environment index in Round 3	0.525 (0.491)	-0.990* (0.590)		0.188 (0.919)	1.273 (0.786)	
Community disease environment index in Round 4	0.313 (0.542)	0.425 (0.669)	-1.581*** (0.553)	0.137 (0.442)	0.101 (0.473)	0.272 (0.448)
Price index for medication in Round 2	-0.082 (0.307)			0.580 (0.378)		
Price index for medication in Round 3	-0.220 (0.286)	-0.080 (0.383)		-0.089 (0.561)	-0.430 (0.552)	
Price index for medication in Round 4	0.156 (0.101)	0.273** (0.139)	-0.227** (0.115)	0.106 (0.250)	0.048 (0.265)	0.109 (0.247)
Price index for food in Round 2	0.424 (0.569)			-0.990 (0.805)		
Price index for food in Round 3	0.563 (0.410)	0.217 (0.500)		2.372*** (0.842)	1.529 (0.960)	
Price index for food in Round 4	-1.014** (0.472)	-0.096 (0.604)	-0.504 (0.396)	0.062 (0.847)	-1.171 (0.871)	0.395 (0.634)
R-squared	0.23	0.49	0.67	0.20	0.57	0.70
Partial F statistic	35.86	29.01	8.64	46.68	13.5	20.35
Observations	1805	1805	1805	1805	1805	1805

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. Height-for-age is measured as the difference of the child's height from the WHO reference child of the same monthly age and gender in centimetres. All specifications include dummies for caregiver's ethnicity, and whether the PPVT was administered in the child's native language, and for Peru dummy for whether the PPVT was administered in Spanish, but estimates are not reported. The partial F statistic is the Kleibergen-Paap rk Wald F statistic of the first-stage of 2SLS estimation of the impact of height-for-age on PPVT score implemented separately for each period using as an instrument for height-for-age the relevant to the period weather shock. Weather shocks before Round 1 include deviations from locality, season, year norm of rainfall during the first trimester of pregnancy in Peru and temperature one year before conception in Vietnam. Similarly, weather shocks between Round 1 and 2 are temperature in the second half of the fifth year after birth in Peru and rainfall in the first half of the second year after Round 1 in Vietnam. Finally, weather shocks between Round 2 and 3 include rainfall in the eighth year after birth in Peru and temperature in the second half of the first year after Round 2 in Vietnam.

Table A5. *Impact of child growth at different stages of childhood on PPVT score at age 12 in Ethiopia*

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.017***	0.042**	0.015***	0.035	0.012**	0.011
	(0.004)	(0.021)	(0.005)	(0.022)	(0.005)	(0.018)
Height-for-age Round 2			0.006	0.084*	-0.003	0.068
			(0.004)	(0.049)	(0.005)	(0.058)
Height-for-age Round 3					0.014***	0.023
					(0.004)	(0.051)
Male	-0.339**	0.614***	-0.312**	-0.331**	0.581***	-0.424***
	(0.135)	(0.174)	(0.156)	(0.134)	(0.148)	(0.151)
Second-born	0.156	-0.553**	-0.295	0.009	-0.437***	-0.141
	(0.168)	(0.233)	(0.211)	(0.152)	(0.169)	(0.175)
Third- or later-born	-0.053	-0.687***	-0.297	0.066	-0.899***	0.054
	(0.198)	(0.248)	(0.233)	(0.204)	(0.220)	(0.237)
Caregiver's age at child's birth	-0.014	0.033**	0.018	-0.002	-0.002	-0.014
	(0.011)	(0.014)	(0.013)	(0.009)	(0.010)	(0.010)
Caregiver's education	0.092***	0.140***	0.062**	0.063**	0.100***	0.016
	(0.022)	(0.029)	(0.027)	(0.026)	(0.027)	(0.028)
Father's education	0.067***	0.031	0.057**	0.057**	0.054*	0.022
	(0.024)	(0.032)	(0.028)	(0.027)	(0.029)	(0.031)
Wealth index in Round 1	0.948**	3.527***	0.448	1.298**	2.029***	0.021
	(0.459)	(0.607)	(0.550)	(0.562)	(0.600)	(0.741)
Community consumption price index in Round 1	1.268**	-0.705	-0.280	-0.958	6.514***	2.861
	(0.504)	(0.561)	(0.526)	(2.679)	(2.337)	(2.514)
Community consumption price index in Round 2	1.084**	-0.617	2.381***	-1.085	1.248	0.202
	(0.512)	(0.631)	(0.543)	(0.941)	(0.815)	(0.855)
Community consumption price index in Round 3	-0.106	1.699*	1.177	1.814*	-0.350	-2.828**
	(0.761)	(0.921)	(0.812)	(0.988)	(1.123)	(1.268)
Community education inputs price index in Round 4	2.238	0.218	-0.919	0.667	0.535	1.234*
	(1.389)	(1.732)	(1.381)	(0.704)	(0.753)	(0.733)
Community cognitive skills inputs price index in Round 1	0.511	1.452**	-0.033	2.399**	0.034	2.931***
	(0.510)	(0.663)	(0.533)	(1.145)	(1.094)	(1.093)
Community cognitive skills inputs price index in Round 2	0.996*	-1.080	1.045*	-1.444***	0.272	1.841***
	(0.523)	(0.681)	(0.590)	(0.490)	(0.592)	(0.693)
Community cognitive skills inputs price index in Round 3	-0.133	-1.442	0.529	0.329	-0.297	-2.741**
	(0.759)	(0.898)	(0.724)	(1.052)	(1.116)	(1.089)
Community cognitive skills inputs price index in Round 4	0.122	-1.309*	0.760	-0.551	1.369**	-1.725**
	(0.585)	(0.767)	(0.773)	(0.553)	(0.538)	(0.691)
Community wage index in Round 1	-1.484**	-1.533*	0.680	3.032***	3.265***	-1.708**
	(0.618)	(0.794)	(0.679)	(0.642)	(0.715)	(0.761)
Community wage index in Round 2	0.364	2.230***	-0.305	-1.538	-1.399	1.532
	(0.358)	(0.456)	(0.397)	(1.307)	(1.012)	(1.452)
Community wage index in Round 3	0.759*	-0.543	0.733	-0.197	1.542*	3.060***
	(0.440)	(0.597)	(0.563)	(0.849)	(0.874)	(1.159)
Community wage index in Round 4	-0.430	-0.179	0.012	0.484	-0.590	-1.172
	(0.452)	(0.508)	(0.451)	(0.603)	(0.680)	(0.825)
Number of credit-providing institutions in the community in Round 1	0.114	0.094	0.220***	-0.051	-0.319**	0.156
	(0.082)	(0.089)	(0.084)	(0.156)	(0.135)	(0.163)
Number of schools in the community Round 2	0.253*	-0.048	0.254	0.514**	-0.134	-0.125
	(0.134)	(0.151)	(0.159)	(0.200)	(0.221)	(0.236)
Number of schools in the community in Round 3	0.188	-0.097	0.185	-0.102	0.182**	0.031
	(0.131)	(0.179)	(0.164)	(0.070)	(0.072)	(0.077)

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Number of schools in the community in Round 4	0.098	-0.186**	-0.005	-0.068	-0.022	-0.002
	(0.061)	(0.075)	(0.065)	(0.068)	(0.066)	(0.073)
Community has hospital in Round 2	-0.011			-0.123		0.786
	(0.259)			(0.807)		(0.778)
Community has hospital in Round 3	-0.347	0.269		1.115**	-0.939*	-0.333
	(0.221)	(0.269)		(0.437)	(0.539)	(0.625)
Community has hospital in Round 4	-0.117	-0.058	0.027	-0.778	-0.829	-0.627
	(0.189)	(0.243)	(0.214)	(0.860)	(0.648)	(0.680)
Community disease environment index in Round 2	0.295			0.667		0.894
	(0.474)			(0.783)		(0.867)
Community disease environment index in Round 3	0.525	-0.990*		0.188	1.273	0.733
	(0.491)	(0.590)		(0.919)	(0.786)	(0.843)
Community disease environment index in Round 4	0.313	0.425	-1.581***	0.137	0.101	0.699
	(0.542)	(0.669)	(0.553)	(0.442)	(0.473)	(0.485)
Price index for medication in Round 2	-0.082			0.580		-0.817**
	(0.307)			(0.378)		(0.342)
Price index for medication in Round 3	-0.220	-0.080		-0.089	-0.430	0.622
	(0.286)	(0.383)		(0.561)	(0.552)	(0.524)
Price index for medication in Round 4	0.156	0.273**	-0.227**	0.106	0.048	-0.156
	(0.101)	(0.139)	(0.115)	(0.250)	(0.265)	(0.266)
Price index for food in Round 2	0.424			-0.990		0.370
	(0.569)			(0.805)		(0.807)
Price index for food in Round 3	0.563	0.217		2.372***	1.529	-3.501***
	(0.410)	(0.500)		(0.842)	(0.960)	(1.039)
Price index for food in Round 4	-1.014**	-0.096	-0.504	0.062	-1.171	2.059***
	(0.472)	(0.604)	(0.396)	(0.847)	(0.871)	(0.764)
R-squared	0.51		0.51		0.50	
Kleibergen-Paap F statistic		56.18		7.38		3.40
Stock and Yogo critical value		16.38		7.03		
Observations	1403	1403	1403	1403	1403	1403

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. The dependent variable is the age-standardised PPVT score. Height-for-age is measured as the difference of the child's height from the WHO reference of the same monthly age and gender in centimetres. All specifications include dummies for caregiver's ethnicity, whether the PPVT was administered in the child's native language, and dummies for the language at which PPVT was administered, but estimates are not reported. The Stock and Yogo critical value is the one for a 10% maximal 2SLS test size distortion. Excluded instruments for height-for-age in Rounds 1, 2, and 3 across countries include those presented in the just-identified column of Table 3.

Table A6. *Impact of child growth at different stages of childhood on PPVT score at age 12 in India*

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.037***	0.052	0.033***	0.130*	0.031***	0.076
	(0.005)	(0.052)	(0.007)	(0.076)	(0.007)	(0.113)
Height-for-age Round 2			0.005	-0.095	-0.004	-0.188*
			(0.006)	(0.083)	(0.007)	(0.108)
Height-for-age Round 3					0.010**	0.162
					(0.005)	(0.104)
Male	0.135***	0.136***	0.132***	0.124***	0.132***	0.107*
	(0.040)	(0.040)	(0.040)	(0.046)	(0.040)	(0.056)
Second-born	-0.066	-0.069	-0.066	-0.089*	-0.065	0.003
	(0.043)	(0.045)	(0.043)	(0.051)	(0.044)	(0.091)
Third- or later-born	-0.182***	-0.180***	-0.183***	-0.252***	-0.181***	-0.092
	(0.063)	(0.064)	(0.064)	(0.093)	(0.065)	(0.146)
Caregiver's age at child's birth	-0.001	-0.002	-0.002	-0.001	-0.002	-0.009
	(0.004)	(0.005)	(0.004)	(0.006)	(0.005)	(0.008)
Caregiver's education	0.029***	0.028***	0.030***	0.030***	0.030***	0.018
	(0.006)	(0.006)	(0.006)	(0.008)	(0.006)	(0.011)
Father's education	0.021***	0.020***	0.020***	0.025***	0.021***	0.028***
	(0.005)	(0.005)	(0.005)	(0.008)	(0.005)	(0.009)
Wealth index in Round 1	0.347**	0.326**	0.342**	0.455*	0.283**	0.012
	(0.142)	(0.160)	(0.142)	(0.238)	(0.139)	(0.346)
Community consumption price index in Round 1	0.066	0.057	0.043	0.126	0.027	-0.125
	(0.104)	(0.111)	(0.104)	(0.151)	(0.101)	(0.234)
Community consumption price index in Round 2	0.031	0.013	-0.087	-0.030	-0.222	-0.170
	(0.207)	(0.213)	(0.188)	(0.244)	(0.186)	(0.295)
Community consumption price index in Round 3	0.156	0.185	0.209	0.112	-0.059	0.088
	(0.171)	(0.197)	(0.170)	(0.282)	(0.147)	(0.245)
Community education inputs price index in Round 4	0.297**	0.302**	0.198	0.132	0.123	0.226
	(0.149)	(0.151)	(0.134)	(0.159)	(0.129)	(0.197)
Community cognitive skills inputs price index in Round 1	-0.225**	-0.229**	-0.174	-0.087	-0.111	-0.123
	(0.112)	(0.114)	(0.107)	(0.132)	(0.093)	(0.145)
Community cognitive skills inputs price index in Round 2	-0.190	-0.182	-0.199	-0.184	-0.259*	-0.308
	(0.169)	(0.172)	(0.158)	(0.172)	(0.149)	(0.213)
Community cognitive skills inputs price index in Round 3	0.063	0.068	0.078	0.118	0.110	0.266*
	(0.114)	(0.114)	(0.113)	(0.133)	(0.111)	(0.155)
Community cognitive skills inputs price index in Round 4	-0.017	-0.005	-0.008	-0.032	-0.009	-0.046
	(0.099)	(0.108)	(0.100)	(0.132)	(0.095)	(0.136)
Community wage index in Round 1	-0.280	-0.244	-0.310*	0.009	-0.343**	-0.249
	(0.171)	(0.205)	(0.171)	(0.284)	(0.166)	(0.360)
Community wage index in Round 2	-0.093	-0.090	-0.075	0.070	-0.026	0.167
	(0.163)	(0.162)	(0.162)	(0.201)	(0.163)	(0.240)
Community wage index in Round 3	0.860***	0.858***	0.852***	0.816***	0.748***	0.810***
	(0.171)	(0.172)	(0.162)	(0.181)	(0.154)	(0.219)
Community wage index in Round 4	0.050	0.046	0.037	0.205	0.116	0.293
	(0.131)	(0.131)	(0.128)	(0.205)	(0.118)	(0.222)
Number of credit-providing institutions in the community in Round 1	-0.050*	-0.051*	-0.031	-0.010	-0.040	-0.039
	(0.029)	(0.030)	(0.027)	(0.034)	(0.026)	(0.045)
Number of schools in the community Round 2	-0.138***	-0.134***	-0.141***	-0.112***	-0.126***	-0.179**
	(0.031)	(0.034)	(0.031)	(0.039)	(0.029)	(0.072)
Number of schools in the community in Round 3	0.007	0.007	0.008	0.009	0.003	0.035
	(0.010)	(0.010)	(0.010)	(0.012)	(0.009)	(0.025)

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Number of schools in the community in Round 4	0.023* (0.013)	0.022* (0.013)	0.027** (0.013)	0.015 (0.016)	0.029** (0.013)	0.009 (0.018)
Community has hospital in Round 2	0.004 (0.056)	-0.002 (0.061)				
Community has hospital in Round 3	0.122* (0.069)	0.130* (0.075)	0.148** (0.067)	0.117 (0.088)		
Community has hospital in Round 4	0.100* (0.052)	0.095* (0.054)	0.091* (0.051)	0.094 (0.064)	0.145*** (0.047)	0.162** (0.068)
Community disease environment index in Round 2	0.432*** (0.163)	0.434*** (0.164)				
Community disease environment index in Round 3	0.153 (0.141)	0.174 (0.154)	0.137 (0.140)	0.061 (0.220)		
Community disease environment index in Round 4	-0.448*** (0.145)	-0.439*** (0.148)	-0.421*** (0.142)	-0.370** (0.156)	-0.408*** (0.136)	-0.465*** (0.180)
Price index for medication in Round 2	0.183 (0.153)	0.207 (0.179)				
Price index for medication in Round 3	-0.040 (0.139)	-0.063 (0.159)	0.061 (0.130)	-0.051 (0.172)		
Price index for medication in Round 4	0.229** (0.102)	0.245** (0.116)	0.198** (0.097)	0.235* (0.140)	0.216** (0.097)	0.265 (0.175)
Price index for food in Round 2	-0.467* (0.272)	-0.476* (0.275)				
Price index for food in Round 3	-0.527** (0.223)	-0.566** (0.261)	-0.632*** (0.211)	-0.640** (0.296)		
Price index for food in Round 4	0.236 (0.225)	0.270 (0.256)	0.274 (0.222)	0.495 (0.313)	0.144 (0.216)	0.395 (0.330)
R-squared	0.28		0.28		0.27	
Kleibergen-Paap F statistic		25.02		3.99		1.83
Stock and Yogo critical value		16.38		7.03		
Observations	1806	1806	1806	1806	1806	1806

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. The dependent variable is the age-standardised PPVT score. Height-for-age is measured as the difference of the child's height from the WHO reference of the same monthly age and gender in centimetres. All specifications include dummies for caregiver's ethnicity and whether the PPVT was administered in the child's native language, but estimates are not reported. The Stock and Yogo critical value is the one for a 10% maximal 2SLS test size distortion. Excluded instruments for height-for-age in Rounds 1, 2, and 3 across countries include those presented in the just-identified column of Table 3.

Table A7. *Impact of child growth at different stages of childhood on PPVT score at age 12 in Peru*

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.021***	0.067	0.005	-0.065*	0.001	-0.045
	(0.006)	(0.044)	(0.007)	(0.036)	(0.007)	(0.040)
Height-for-age Round 2			0.021***	0.160***	0.015**	0.229**
			(0.005)	(0.061)	(0.006)	(0.116)
Height-for-age Round 3					0.009*	-0.121
					(0.005)	(0.103)
Male	0.172***	0.186***	0.157***	0.084*	0.157***	0.065
	(0.036)	(0.038)	(0.035)	(0.051)	(0.035)	(0.061)
Second-born	0.031	0.024	0.041	0.104*	0.041	0.056
	(0.046)	(0.047)	(0.046)	(0.060)	(0.046)	(0.067)
Third- or later-born	-0.090*	-0.089*	-0.079	0.009	-0.080*	-0.052
	(0.049)	(0.049)	(0.048)	(0.071)	(0.048)	(0.072)
Caregiver's age at child's birth	0.006**	0.006**	0.005*	0.001	0.005*	0.004
	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)	(0.004)
Caregiver's education	0.056***	0.051***	0.052***	0.031**	0.053***	0.044***
	(0.006)	(0.007)	(0.006)	(0.014)	(0.006)	(0.012)
Father's education	0.026***	0.023***	0.025***	0.018*	0.025***	0.026***
	(0.007)	(0.008)	(0.007)	(0.009)	(0.007)	(0.010)
Wealth index in Round 1	0.678***	0.630***	0.610***	0.093	0.646***	0.353
	(0.116)	(0.127)	(0.115)	(0.298)	(0.113)	(0.246)
Community consumption price index in Round 1	-0.301**	-0.344***	-0.315***	-0.292**	-0.259**	-0.258*
	(0.124)	(0.129)	(0.120)	(0.144)	(0.118)	(0.155)
Community consumption price index in Round 2	0.106	0.062	0.114	0.153	0.123	0.444
	(0.129)	(0.136)	(0.127)	(0.155)	(0.125)	(0.279)
Community consumption price index in Round 3	0.191	0.189	0.126	0.043	0.147	0.261
	(0.189)	(0.192)	(0.181)	(0.217)	(0.179)	(0.250)
Community education inputs price index in Round 4	0.374	0.306	0.412	0.539	0.315	0.344
	(0.368)	(0.378)	(0.353)	(0.416)	(0.344)	(0.424)
Community cognitive skills inputs price index in Round 1	0.174	0.166	0.174	-0.004	0.175	0.030
	(0.135)	(0.138)	(0.133)	(0.185)	(0.130)	(0.177)
Community cognitive skills inputs price index in Round 2	-0.187	-0.242	-0.135	0.063	-0.153	0.164
	(0.153)	(0.167)	(0.147)	(0.193)	(0.144)	(0.232)
Community cognitive skills inputs price index in Round 3	0.006	0.013	0.067	0.150	0.116	0.201
	(0.184)	(0.188)	(0.178)	(0.220)	(0.173)	(0.223)
Community cognitive skills inputs price index in Round 4	0.225	0.217	0.234	0.412*	0.204	0.447*
	(0.177)	(0.177)	(0.174)	(0.218)	(0.173)	(0.248)
Community wage index in Round 1	0.072	0.137	0.133	0.393	0.142	0.423
	(0.164)	(0.172)	(0.162)	(0.242)	(0.162)	(0.259)
Community wage index in Round 2	0.122	0.098	0.078	-0.193	0.096	-0.135
	(0.094)	(0.097)	(0.093)	(0.176)	(0.093)	(0.174)
Community wage index in Round 3	0.017	-0.008	0.022	0.017	0.032	0.108
	(0.130)	(0.133)	(0.128)	(0.148)	(0.127)	(0.158)
Community wage index in Round 4	0.427***	0.444***	0.436***	0.473***	0.489***	0.513***
	(0.116)	(0.117)	(0.112)	(0.130)	(0.111)	(0.142)
Number of credit-providing institutions in the community in Round 1	0.040**	0.036*	0.035*	0.009	0.030*	0.038
	(0.019)	(0.020)	(0.019)	(0.027)	(0.018)	(0.030)
Number of schools in the community Round 2	-0.010	-0.020	0.006	0.002	0.016	0.050
	(0.036)	(0.038)	(0.033)	(0.040)	(0.033)	(0.050)
Number of schools in the community in Round 3	-0.083**	-0.090**	-0.078**	-0.071	-0.086**	-0.074
	(0.039)	(0.039)	(0.038)	(0.046)	(0.037)	(0.048)

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Number of schools in the community in Round 4	0.003	-0.001	0.004	0.023	0.011	0.020
	(0.016)	(0.017)	(0.016)	(0.020)	(0.015)	(0.019)
Community has hospital in Round 2	0.064	0.066				
	(0.065)	(0.067)				
Community has hospital in Round 3	0.096	0.109*	0.115**	0.096		
	(0.063)	(0.066)	(0.056)	(0.069)		
Community has hospital in Round 4	0.056	0.062	0.066	0.072	0.103**	0.121**
	(0.052)	(0.053)	(0.051)	(0.061)	(0.047)	(0.060)
Community disease environment index in Round 2	0.012	0.008				
	(0.122)	(0.123)				
Community disease environment index in Round 3	0.093	0.070	0.116	0.234		
	(0.127)	(0.132)	(0.124)	(0.156)		
Community disease environment index in Round 4	0.099	0.082	0.096	0.059	0.161	-0.053
	(0.139)	(0.140)	(0.134)	(0.161)	(0.133)	(0.233)
Price index for medication in Round 2	0.055	0.060				
	(0.069)	(0.068)				
Price index for medication in Round 3	0.098	0.108	0.101	0.103		
	(0.077)	(0.078)	(0.076)	(0.090)		
Price index for medication in Round 4	0.051*	0.042	0.048*	0.008	0.058**	0.004
	(0.029)	(0.030)	(0.028)	(0.040)	(0.027)	(0.046)
Price index for food in Round 2	-0.038	-0.058				
	(0.149)	(0.152)				
Price index for food in Round 3	0.091	0.073	0.077	0.017		
	(0.107)	(0.110)	(0.099)	(0.125)		
Price index for food in Round 4	0.212	0.248*	0.222*	0.241	0.286***	0.194
	(0.134)	(0.139)	(0.127)	(0.153)	(0.099)	(0.126)
R-squared	0.42		0.43		0.449	
Kleibergen-Paap F statistic		35.86		6.29		2.44
Stock and Yogo critical value		16.38		7.03		
Observations	1805	1805	1805	1805	1805	1805

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. The dependent variable is the age-standardised PPVT score. Height-for-age is measured as the difference of the child's height from the WHO reference of the same monthly age and gender in centimetres. All specifications include dummies for caregiver's ethnicity, whether the PPVT was administered in the child's native language, and a dummy for whether the PPVT was administered in Spanish, but estimates are not reported. The Stock and Yogo critical value is the one for a 10% maximal 2SLS test size distortion. Excluded instruments for height-for-age in Rounds 1, 2, and 3 across countries include those presented in the just-identified column of Table 3.

Table A8. *Impact of child growth at different stages of childhood on PPVT score at age 12 in Vietnam*

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.025***	0.184***	0.023***	0.159***	0.024***	0.222***
	(0.006)	(0.043)	(0.008)	(0.034)	(0.008)	(0.051)
Height-for-age Round 2			0.003	-0.099**	-0.001	0.022
			(0.006)	(0.041)	(0.007)	(0.077)
Height-for-age Round 3					0.004	-0.182**
					(0.004)	(0.086)
Male	0.042	0.099**	0.046	0.121***	0.050	0.082
	(0.036)	(0.046)	(0.037)	(0.044)	(0.037)	(0.060)
Second-born	-0.044	-0.036	-0.057	-0.098**	-0.061	-0.150**
	(0.040)	(0.047)	(0.041)	(0.049)	(0.041)	(0.073)
Third- or later-born	-0.199***	-0.206***	-0.209***	-0.302***	-0.221***	-0.355***
	(0.058)	(0.065)	(0.059)	(0.073)	(0.059)	(0.103)
Caregiver's age at child's birth	0.002	0.002	0.002	0.002	0.002	-0.001
	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.004)
Caregiver's education	0.026***	0.016**	0.025***	0.032***	0.025***	0.041***
	(0.007)	(0.008)	(0.007)	(0.010)	(0.007)	(0.015)
Father's education	0.022***	0.013	0.023***	0.025***	0.023***	0.033**
	(0.007)	(0.008)	(0.007)	(0.009)	(0.007)	(0.013)
Wealth index in Round 1	0.602***	0.407**	0.580***	0.733***	0.555***	0.869***
	(0.141)	(0.175)	(0.144)	(0.208)	(0.142)	(0.326)
Community consumption price index in Round 1	1.510**	1.779**	2.605***	3.332***	1.919***	3.786***
	(0.705)	(0.799)	(0.656)	(0.731)	(0.595)	(0.999)
Community consumption price index in Round 2	1.117***	1.178***	1.149***	1.230***	1.293***	1.552***
	(0.225)	(0.266)	(0.207)	(0.222)	(0.194)	(0.283)
Community consumption price index in Round 3	-0.016	-0.172	-0.087	-0.135	-0.397*	-0.739**
	(0.225)	(0.279)	(0.235)	(0.263)	(0.203)	(0.343)
Community education inputs price index in Round 4	0.260	0.247	0.265	0.299	0.199	0.552*
	(0.187)	(0.222)	(0.176)	(0.185)	(0.171)	(0.286)
Community cognitive skills inputs price index in Round 1	0.445	0.065	-0.236	-0.257	-0.404	-0.118
	(0.290)	(0.367)	(0.271)	(0.335)	(0.267)	(0.460)
Community cognitive skills inputs price index in Round 2	0.345***	0.456***	0.417***	0.484***	0.458***	0.789***
	(0.119)	(0.142)	(0.119)	(0.133)	(0.104)	(0.186)
Community cognitive skills inputs price index in Round 3	-0.476*	-0.493	-0.791***	-0.936***	-1.312***	-1.767***
	(0.287)	(0.344)	(0.284)	(0.320)	(0.220)	(0.427)
Community cognitive skills inputs price index in Round 4	0.377***	0.338**	-0.031	0.094	-0.155	-0.148
	(0.138)	(0.163)	(0.118)	(0.137)	(0.113)	(0.182)
Community wage index in Round 1	-0.175	-0.599**	-0.041	0.125	0.092	0.183
	(0.198)	(0.246)	(0.163)	(0.269)	(0.124)	(0.334)
Community wage index in Round 2	-0.471	-0.227	-0.536**	-0.559**	-0.268	-0.275
	(0.329)	(0.374)	(0.237)	(0.255)	(0.218)	(0.309)
Community wage index in Round 3	-0.280	-0.226	0.232	0.348	0.098	0.593*
	(0.212)	(0.258)	(0.189)	(0.223)	(0.176)	(0.359)
Community wage index in Round 4	0.315**	0.249	0.224	0.154	0.282*	-0.041
	(0.154)	(0.186)	(0.152)	(0.170)	(0.153)	(0.261)
Number of credit-providing institutions in the community in Round 1	0.047	0.063	0.020	-0.001	0.025	0.047
	(0.036)	(0.043)	(0.033)	(0.039)	(0.029)	(0.044)
Number of schools in the community Round 2	-0.108**	-0.141**	-0.229***	-0.202***	-0.251***	-0.256***
	(0.049)	(0.058)	(0.048)	(0.056)	(0.047)	(0.069)
Number of schools in the community in Round 3	0.010	0.011	0.036**	0.048**	0.032**	0.043*
	(0.017)	(0.021)	(0.015)	(0.019)	(0.015)	(0.025)

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Number of schools in the community in Round 4	-0.008	0.002	-0.015	-0.019	-0.003	-0.013
	(0.015)	(0.019)	(0.015)	(0.017)	(0.014)	(0.022)
Community has hospital in Round 2	-0.237	-0.111				
	(0.228)	(0.246)				
Community has hospital in Round 3	0.294***	0.118	0.308***	0.215*		
	(0.112)	(0.138)	(0.110)	(0.126)		
Community has hospital in Round 4	0.750***	0.917***	1.213***	1.259***	1.125***	1.300***
	(0.256)	(0.292)	(0.226)	(0.251)	(0.216)	(0.285)
Community disease environment index in Round 2	-0.667***	-0.644***				
	(0.191)	(0.221)				
Community disease environment index in Round 3	0.299	0.183	0.122	0.245		
	(0.218)	(0.262)	(0.200)	(0.237)		
Community disease environment index in Round 4	0.114	0.102	0.091	0.132	0.165	0.223
	(0.114)	(0.134)	(0.110)	(0.125)	(0.108)	(0.171)
Price index for medication in Round 2	-0.465***	-0.494***				
	(0.091)	(0.109)				
Price index for medication in Round 3	0.033	0.076	-0.324**	-0.351**		
	(0.147)	(0.172)	(0.134)	(0.152)		
Price index for medication in Round 4	-0.091	-0.105	-0.062	-0.081	-0.089	-0.060
	(0.075)	(0.087)	(0.067)	(0.077)	(0.065)	(0.096)
Price index for food in Round 2	-0.874***	-0.762***				
	(0.194)	(0.230)				
Price index for food in Round 3	0.615**	0.128	0.691***	0.698**		
	(0.256)	(0.309)	(0.238)	(0.291)		
Price index for food in Round 4	0.123	0.180	0.009	-0.129	0.115	0.113
	(0.213)	(0.262)	(0.214)	(0.242)	(0.192)	(0.270)
R-squared	0.36		0.34		0.34	
Kleibergen-Paap F statistic		46.68		11.63		3.25
Stock and Yogo critical value		16.38		7.03		
Observations	1805	1805	1805	1805	1805	1805

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. The dependent variable is the age-standardised PPVT score. Height-for-age is measured as the difference of the child's height from the WHO reference of the same monthly age and gender in centimetres. All specifications include dummies for caregiver's ethnicity and whether the PPVT was administered in the child's native language, but estimates are not reported. The Stock and Yogo critical value is the one for a 10% maximal 2SLS test size distortion. Excluded instruments for height-for-age in Rounds 1, 2, and 3 across countries include those presented in the just-identified column of Table 3.

Table A9. *Impact of child growth at different stages of childhood on MATH score at age 12 in Ethiopia*

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.012**	-0.012	0.010*	-0.010	0.006	0.015
	(0.005)	(0.024)	(0.006)	(0.022)	(0.006)	(0.020)
Height-for-age Round 2			0.004	-0.014	-0.006	-0.073
			(0.005)	(0.048)	(0.006)	(0.066)
Height-for-age Round 3					0.015***	0.042
					(0.005)	(0.060)
Male	-0.006	-0.024	-0.008	-0.032	-0.014	-0.023
	(0.044)	(0.048)	(0.045)	(0.050)	(0.045)	(0.054)
Second-born	0.068	0.073	0.068	0.056	0.069	0.008
	(0.068)	(0.069)	(0.068)	(0.084)	(0.068)	(0.093)
Third- or later-born	-0.001	0.002	-0.007	-0.016	-0.003	-0.034
	(0.058)	(0.058)	(0.058)	(0.065)	(0.057)	(0.066)
Caregiver's age at child's birth	-0.001	-0.001	-0.001	-0.001	-0.001	0.001
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Caregiver's education	0.016*	0.017*	0.015*	0.017*	0.016*	0.017*
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Father's education	0.031***	0.032***	0.030***	0.034***	0.031***	0.037***
	(0.008)	(0.008)	(0.008)	(0.010)	(0.008)	(0.011)
Wealth index in Round 1	1.068***	1.169***	1.111***	1.237***	1.160***	1.116***
	(0.263)	(0.291)	(0.261)	(0.288)	(0.253)	(0.313)
Community consumption price index in Round 1	-0.378	-0.415*	-0.459**	-0.494***	-0.203	-0.156
	(0.248)	(0.252)	(0.188)	(0.190)	(0.133)	(0.144)
Community consumption price index in Round 2	0.015	0.036	0.001	0.019	-0.260*	-0.220
	(0.181)	(0.183)	(0.173)	(0.179)	(0.139)	(0.151)
Community consumption price index in Round 3	0.031	0.069	0.176	0.213	0.356*	0.406*
	(0.422)	(0.429)	(0.407)	(0.418)	(0.205)	(0.211)
Community education inputs price index in Round 4	0.220	0.160	0.243	0.203	0.361**	0.453**
	(0.213)	(0.223)	(0.210)	(0.224)	(0.173)	(0.198)
Community cognitive skills inputs price index in Round 1	0.079	0.056	0.030	-0.004	-0.016	0.027
	(0.226)	(0.226)	(0.166)	(0.168)	(0.151)	(0.180)
Community cognitive skills inputs price index in Round 2	-0.714**	-0.714**	-0.603**	-0.623**	-0.556**	-0.825**
	(0.342)	(0.344)	(0.234)	(0.317)	(0.226)	(0.336)
Community cognitive skills inputs price index in Round 3	0.048	0.032	0.069	0.038	0.138	0.191
	(0.281)	(0.284)	(0.242)	(0.241)	(0.158)	(0.187)
Community cognitive skills inputs price index in Round 4	-0.137	-0.128	-0.046	-0.002	-0.038	0.079
	(0.167)	(0.167)	(0.159)	(0.184)	(0.133)	(0.179)
Community wage index in Round 1	0.241	0.200	0.286	0.284	0.073	0.133
	(0.193)	(0.196)	(0.174)	(0.201)	(0.151)	(0.176)
Community wage index in Round 2	0.371	0.352	0.410*	0.321	0.192	0.191
	(0.258)	(0.261)	(0.232)	(0.242)	(0.226)	(0.242)
Community wage index in Round 3	-0.304	-0.311	-0.161	-0.152	0.027	-0.008
	(0.214)	(0.217)	(0.202)	(0.204)	(0.179)	(0.194)
Community wage index in Round 4	0.077	0.071	0.091	0.088	-0.002	0.045
	(0.157)	(0.158)	(0.136)	(0.148)	(0.103)	(0.116)
Number of credit-providing institutions in the community in Round 1	-0.078	-0.080	-0.098	-0.098	0.060*	0.055
	(0.085)	(0.084)	(0.081)	(0.083)	(0.034)	(0.040)
Number of schools in the community Round 2	0.164*	0.160	0.242***	0.222**	0.236***	0.191**
	(0.098)	(0.099)	(0.079)	(0.092)	(0.079)	(0.090)
Number of schools in the community in Round 3	0.041	0.039	0.052	0.056	0.020	0.049
	(0.042)	(0.043)	(0.037)	(0.042)	(0.034)	(0.045)

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Number of schools in the community in Round 4	0.009	0.012	0.021	0.023	0.027	0.024
	(0.021)	(0.021)	(0.020)	(0.020)	(0.018)	(0.021)
Community has hospital in Round 2	-0.095	-0.111				
	(0.255)	(0.261)				
Community has hospital in Round 3	0.453**	0.458**	0.371**	0.390**		
	(0.200)	(0.198)	(0.189)	(0.189)		
Community has hospital in Round 4	0.104	0.135	-0.229	-0.176	-0.044	-0.065
	(0.306)	(0.306)	(0.243)	(0.261)	(0.206)	(0.219)
Community disease environment index in Round 2	0.202	-0.025				
	(0.539)	(0.599)				
Community disease environment index in Round 3	-0.316	-0.345	-0.255	-0.272		
	(0.409)	(0.414)	(0.351)	(0.357)		
Community disease environment index in Round 4	-0.187	-0.169	-0.248	-0.215	-0.186	-0.373
	(0.310)	(0.313)	(0.277)	(0.327)	(0.204)	(0.320)
Price index for medication in Round 2	0.296**	0.321**				
	(0.134)	(0.139)				
Price index for medication in Round 3	0.585	0.518	0.254	0.182		
	(0.486)	(0.494)	(0.456)	(0.470)		
Price index for medication in Round 4	0.324*	0.335*	0.161	0.152	0.158	0.104
	(0.174)	(0.175)	(0.126)	(0.148)	(0.114)	(0.132)
Price index for food in Round 2	0.120	0.080				
	(0.348)	(0.354)				
Price index for food in Round 3	-1.666**	-1.368	-1.591**	-1.446**		
	(0.790)	(0.845)	(0.659)	(0.661)		
Price index for food in Round 4	1.321**	1.295**	0.784	0.741	0.183	0.498
	(0.634)	(0.643)	(0.545)	(0.664)	(0.475)	(0.608)
R-squared	0.33		0.33		0.33	
Kleibergen-Paap F statistic		56.69		7.975		3.538
Stock and Yogo critical value		16.38		7.03		
Observations	1403	1403	1403	1403	1403	1403

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. The dependent variable is the age-standardised MATH score. Height-for-age is measured as the difference of the child's height from the WHO reference of the same monthly age and gender in centimetres. All specifications include dummies for caregiver's ethnicity, whether the PPVT was administered in the child's native language, and dummies for the language at which MATH was administered, but estimates are not reported. The Stock and Yogo critical value is the one for a 10% maximal 2SLS test size distortion. Excluded instruments for height-for-age in Rounds 1, 2, and 3 across countries include those presented in the just-identified column of Table 3.

Table A10. *Impact of child growth at different stages of childhood on MATH score at age 12 in India*

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.022***	0.116**	0.013*	0.252***	0.011	0.188
	(0.006)	(0.053)	(0.007)	(0.092)	(0.007)	(0.137)
Height-for-age Round 2			0.013**	-0.129	0.004	-0.249*
			(0.005)	(0.102)	(0.007)	(0.130)
Height-for-age Round 3					0.010*	0.192
					(0.006)	(0.132)
Male	0.038	0.047	0.036	0.035	0.035	0.014
	(0.040)	(0.043)	(0.040)	(0.055)	(0.040)	(0.068)
Second-born	-0.039	-0.062	-0.038	-0.095	-0.038	0.015
	(0.045)	(0.050)	(0.045)	(0.062)	(0.045)	(0.113)
Third- or later-born	-0.187***	-0.174***	-0.181***	-0.265**	-0.178***	-0.082
	(0.061)	(0.066)	(0.062)	(0.107)	(0.062)	(0.178)
Caregiver's age at child's birth	0.001	-0.003	0.001	-0.002	0.001	-0.011
	(0.004)	(0.005)	(0.004)	(0.007)	(0.004)	(0.009)
Caregiver's education	0.044***	0.039***	0.045***	0.039***	0.044***	0.025*
	(0.006)	(0.007)	(0.006)	(0.010)	(0.006)	(0.014)
Father's education	0.032***	0.029***	0.033***	0.036***	0.034***	0.040***
	(0.005)	(0.006)	(0.005)	(0.010)	(0.005)	(0.011)
Wealth index in Round 1	0.624***	0.495***	0.600***	0.606**	0.518***	0.080
	(0.152)	(0.179)	(0.152)	(0.302)	(0.150)	(0.439)
Community consumption price index in Round 1	-0.015	-0.070	0.027	0.083	0.038	-0.198
	(0.107)	(0.115)	(0.107)	(0.182)	(0.106)	(0.287)
Community consumption price index in Round 2	0.043	-0.066	0.052	-0.003	-0.052	-0.090
	(0.208)	(0.232)	(0.182)	(0.284)	(0.174)	(0.339)
Community consumption price index in Round 3	0.094	0.274	0.167	0.243	-0.028	0.247
	(0.180)	(0.224)	(0.178)	(0.347)	(0.156)	(0.297)
Community education inputs price index in Round 4	0.317**	0.352**	0.223	0.130	0.225	0.299
	(0.151)	(0.164)	(0.141)	(0.204)	(0.139)	(0.257)
Community cognitive skills inputs price index in Round 1	0.126	0.098	0.095	0.244	0.262***	0.265
	(0.112)	(0.123)	(0.103)	(0.163)	(0.089)	(0.187)
Community cognitive skills inputs price index in Round 2	0.236	0.290*	0.041	0.085	0.118	0.085
	(0.160)	(0.174)	(0.150)	(0.204)	(0.134)	(0.248)
Community cognitive skills inputs price index in Round 3	-0.212*	-0.179	-0.213*	-0.097	-0.147	0.073
	(0.114)	(0.128)	(0.114)	(0.175)	(0.112)	(0.198)
Community cognitive skills inputs price index in Round 4	-0.073	0.003	-0.065	-0.021	-0.009	-0.028
	(0.103)	(0.119)	(0.104)	(0.162)	(0.100)	(0.166)
Community wage index in Round 1	0.152	0.380*	0.137	0.833**	0.086	0.503
	(0.174)	(0.228)	(0.172)	(0.360)	(0.166)	(0.451)
Community wage index in Round 2	-0.122	-0.100	-0.050	0.194	0.021	0.324
	(0.157)	(0.167)	(0.157)	(0.243)	(0.156)	(0.280)
Community wage index in Round 3	0.177	0.161	0.176	0.085	0.105	0.101
	(0.177)	(0.191)	(0.162)	(0.217)	(0.158)	(0.270)
Community wage index in Round 4	0.173	0.149	0.028	0.224	0.106	0.374
	(0.132)	(0.143)	(0.127)	(0.258)	(0.121)	(0.283)
Number of credit-providing institutions in the community in Round 1	0.001	-0.007	0.030	0.062	0.025	0.038
	(0.029)	(0.032)	(0.027)	(0.042)	(0.026)	(0.060)
Number of schools in the community Round 2	-0.154***	-0.128***	-0.130***	-0.063	-0.128***	-0.160*
	(0.030)	(0.036)	(0.030)	(0.050)	(0.028)	(0.091)
Number of schools in the community in Round 3	-0.006	-0.011	0.002	-0.002	-0.008	0.027
	(0.010)	(0.011)	(0.010)	(0.014)	(0.009)	(0.031)

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Number of schools in the community in Round 4	0.019	0.015	0.025*	0.002	0.027*	-0.007
	(0.015)	(0.015)	(0.014)	(0.021)	(0.014)	(0.023)
Community has hospital in Round 2	0.207***	0.168**				
	(0.058)	(0.065)				
Community has hospital in Round 3	-0.039	0.012	0.017	0.010		
	(0.069)	(0.080)	(0.068)	(0.107)		
Community has hospital in Round 4	0.001	-0.026	0.003	-0.031	0.020	0.016
	(0.051)	(0.058)	(0.051)	(0.078)	(0.048)	(0.082)
Community disease environment index in Round 2	0.446***	0.463***				
	(0.170)	(0.178)				
Community disease environment index in Round 3	-0.052	0.080	-0.094	-0.055		
	(0.142)	(0.172)	(0.142)	(0.273)		
Community disease environment index in Round 4	-0.430***	-0.374**	-0.331**	-0.211	-0.303**	-0.345
	(0.149)	(0.158)	(0.143)	(0.189)	(0.138)	(0.213)
Price index for medication in Round 2	0.547***	0.698***				
	(0.162)	(0.194)				
Price index for medication in Round 3	0.056	-0.093	0.301**	0.007		
	(0.144)	(0.181)	(0.132)	(0.217)		
Price index for medication in Round 4	0.245**	0.349***	0.290***	0.480***	0.319***	0.516**
	(0.107)	(0.131)	(0.102)	(0.173)	(0.101)	(0.208)
Price index for food in Round 2	-0.042	-0.094				
	(0.279)	(0.297)				
Price index for food in Round 3	-0.406*	-0.655**	-0.448**	-0.692**		
	(0.218)	(0.272)	(0.204)	(0.348)		
Price index for food in Round 4	-0.101	0.117	-0.130	0.468	-0.158	0.408
	(0.248)	(0.304)	(0.250)	(0.392)	(0.243)	(0.411)
R-squared	0.29		0.28		0.28	
Kleibergen-Paap F statistic		25.02		3.99		1.83
Stock and Yogo critical value		16.38		7.03		
Observations	1806	1806	1806	1806	1806	1806

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. The dependent variable is the age-standardised MATH score. Height-for-age is measured as the difference of the child's height from the WHO reference child of the same monthly age and gender in centimetres. All specifications include dummies for caregiver's ethnicity and whether the MATH was administered in the child's native language, but estimates are not reported. The Stock and Yogo critical value is the one for a 10% maximal 2SLS test size distortion. Excluded instruments for height-for-age in Rounds 1, 2, and 3 across countries include those presented in the just-identified column of Table 3.

Table A11. *Impact of child growth at different stages of childhood on MATH score at age 12 in Peru*

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.013* (0.007)	-0.036 (0.050)	0.001 (0.008)	-0.031 (0.036)	0.001 (0.008)	-0.020 (0.039)
Height-for-age Round 2			0.016*** (0.005)	-0.014 (0.059)	0.016** (0.006)	0.017 (0.112)
Height-for-age Round 3					0.001 (0.005)	-0.062 (0.103)
Male	0.046 (0.040)	0.030 (0.043)	0.035 (0.040)	0.037 (0.051)	0.033 (0.040)	0.026 (0.062)
Second-born	0.011 (0.051)	0.019 (0.053)	0.017 (0.051)	0.010 (0.058)	0.017 (0.051)	-0.019 (0.064)
Third- or later-born	-0.012 (0.059)	-0.014 (0.059)	-0.004 (0.059)	-0.026 (0.072)	-0.009 (0.059)	-0.068 (0.073)
Caregiver's age at child's birth	0.003 (0.003)	0.003 (0.003)	0.003 (0.003)	0.003 (0.004)	0.003 (0.003)	0.005 (0.004)
Caregiver's education	0.053*** (0.007)	0.058*** (0.008)	0.051*** (0.007)	0.060*** (0.014)	0.051*** (0.007)	0.069*** (0.012)
Father's education	0.032*** (0.007)	0.035*** (0.008)	0.031*** (0.007)	0.036*** (0.009)	0.032*** (0.007)	0.042*** (0.010)
Wealth index in Round 1	0.384*** (0.134)	0.439*** (0.148)	0.346** (0.134)	0.517* (0.287)	0.424*** (0.133)	0.729*** (0.243)
Community consumption price index in Round 1	0.161 (0.148)	0.211 (0.158)	0.167 (0.145)	0.213 (0.152)	0.243* (0.142)	0.266* (0.158)
Community consumption price index in Round 2	0.478*** (0.152)	0.528*** (0.160)	0.498*** (0.150)	0.539*** (0.156)	0.524*** (0.146)	0.721** (0.284)
Community consumption price index in Round 3	0.315 (0.212)	0.321 (0.218)	0.206 (0.205)	0.235 (0.218)	0.293 (0.203)	0.429* (0.258)
Community education inputs price index in Round 4	0.831* (0.425)	0.914** (0.444)	0.926** (0.412)	0.981** (0.429)	0.903** (0.406)	0.918** (0.459)
Community cognitive skills inputs price index in Round 1	-0.105 (0.154)	-0.095 (0.156)	-0.110 (0.146)	-0.064 (0.171)	-0.122 (0.144)	-0.065 (0.170)
Community cognitive skills inputs price index in Round 2	0.082 (0.166)	0.148 (0.182)	0.132 (0.159)	0.144 (0.181)	0.102 (0.156)	0.172 (0.232)
Community cognitive skills inputs price index in Round 3	-0.414** (0.209)	-0.424** (0.215)	-0.326 (0.202)	-0.358* (0.213)	-0.200 (0.193)	-0.264 (0.219)
Community cognitive skills inputs price index in Round 4	0.106 (0.214)	0.116 (0.219)	0.073 (0.213)	0.042 (0.226)	0.073 (0.214)	0.064 (0.245)
Community wage index in Round 1	-0.121 (0.187)	-0.196 (0.202)	-0.049 (0.187)	-0.183 (0.245)	-0.047 (0.187)	-0.173 (0.256)
Community wage index in Round 2	-0.002 (0.109)	0.027 (0.115)	-0.032 (0.109)	0.060 (0.177)	0.001 (0.109)	0.123 (0.174)
Community wage index in Round 3	0.163 (0.133)	0.189 (0.137)	0.162 (0.133)	0.184 (0.137)	0.196 (0.134)	0.253* (0.150)
Community wage index in Round 4	0.226* (0.133)	0.208 (0.138)	0.239* (0.130)	0.214 (0.139)	0.301** (0.131)	0.253* (0.151)
Number of credit-providing institutions in the community in Round 1	0.005 (0.022)	0.010 (0.023)	-0.003 (0.022)	0.008 (0.027)	-0.001 (0.022)	0.030 (0.031)
Number of schools in the community Round 2	-0.046 (0.042)	-0.033 (0.045)	-0.026 (0.039)	-0.013 (0.041)	-0.018 (0.038)	0.016 (0.048)
Number of schools in the community in Round 3	-0.050 (0.042)	-0.041 (0.043)	-0.041 (0.042)	-0.034 (0.043)	-0.037 (0.039)	-0.030 (0.044)

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Number of schools in the community in Round 4	-0.023 (0.018)	-0.019 (0.019)	-0.025 (0.018)	-0.025 (0.020)	-0.026* (0.015)	-0.031* (0.018)
Community has hospital in Round 2	0.044 (0.071)	0.041 (0.072)				
Community has hospital in Round 3	0.063 (0.069)	0.050 (0.072)	0.070 (0.062)	0.061 (0.064)		
Community has hospital in Round 4	-0.059 (0.058)	-0.064 (0.058)	-0.048 (0.056)	-0.054 (0.058)	-0.013 (0.054)	-0.013 (0.060)
Community disease environment index in Round 2	0.128 (0.136)	0.132 (0.139)				
Community disease environment index in Round 3	0.336** (0.145)	0.361** (0.151)	0.350** (0.141)	0.347** (0.151)		
Community disease environment index in Round 4	0.038 (0.161)	0.060 (0.167)	0.069 (0.159)	0.101 (0.168)	0.153 (0.156)	0.076 (0.246)
Price index for medication in Round 2	0.127* (0.075)	0.121 (0.079)				
Price index for medication in Round 3	0.098 (0.091)	0.086 (0.094)	0.099 (0.091)	0.086 (0.094)		
Price index for medication in Round 4	0.057* (0.032)	0.068** (0.034)	0.061* (0.032)	0.080** (0.040)	0.077** (0.031)	0.086* (0.047)
Price index for food in Round 2	0.089 (0.167)	0.112 (0.168)				
Price index for food in Round 3	0.031 (0.122)	0.052 (0.125)	0.045 (0.114)	0.084 (0.124)		
Price index for food in Round 4	-0.112 (0.144)	-0.154 (0.152)	-0.060 (0.142)	-0.101 (0.150)	-0.035 (0.110)	-0.078 (0.127)
R-squared	0.28		0.28		0.27	
Kleibergen-Paap F statistic		35.95		6.34		2.44
Stock and Yogo critical value		16.38		7.03		
Observations	1805	1805	1805	1805	1805	1805

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. The dependent variable is the age-standardised MATH score. Height-for-age is measured as the difference of the child's height from the WHO reference child of the same monthly age and gender in centimetres. All specifications include dummies for caregiver's ethnicity and whether the MATH test was administered in the child's native language, but estimates are not reported. The Stock and Yogo critical value is the one for a 10% maximal 2SLS test size distortion. Excluded instruments for height-for-age in Rounds 1, 2, and 3 across countries include those presented in the just-identified column of Table 3.

Table A12. *Impact of child growth at different stages of childhood on MATH score at age 12 in Vietnam*

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Height-for-age Round 1	0.021***	0.123***	0.020**	0.061	0.021**	0.083*
	(0.007)	(0.041)	(0.009)	(0.043)	(0.009)	(0.050)
Height-for-age Round 2			0.001	-0.195***	-0.010	-0.206**
			(0.006)	(0.056)	(0.009)	(0.082)
Height-for-age Round 3					0.012**	-0.018
					(0.005)	(0.090)
Male	-0.099**	-0.062	-0.096**	-0.032	-0.088**	-0.016
	(0.039)	(0.045)	(0.040)	(0.056)	(0.040)	(0.064)
Second-born	0.019	0.025	0.010	-0.081	0.006	-0.104
	(0.044)	(0.047)	(0.045)	(0.065)	(0.045)	(0.077)
Third- or later-born	-0.082	-0.086	-0.089	-0.257***	-0.098*	-0.299***
	(0.056)	(0.060)	(0.057)	(0.088)	(0.057)	(0.103)
Caregiver's age at child's birth	0.001	0.001	0.001	0.001	0.001	0.001
	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)
Caregiver's education	0.037***	0.031***	0.038***	0.065***	0.038***	0.071***
	(0.007)	(0.008)	(0.007)	(0.013)	(0.008)	(0.016)
Father's education	0.041***	0.035***	0.043***	0.060***	0.043***	0.063***
	(0.007)	(0.008)	(0.007)	(0.012)	(0.007)	(0.014)
Wealth index in Round 1	0.572***	0.448***	0.553***	1.127***	0.561***	1.228***
	(0.159)	(0.170)	(0.160)	(0.292)	(0.160)	(0.353)
Community consumption price index in Round 1	-0.348	-0.177	1.293**	2.145***	1.040*	1.730*
	(0.685)	(0.752)	(0.569)	(0.814)	(0.533)	(0.980)
Community consumption price index in Round 2	-0.224	-0.185	0.053	0.042	0.119	0.422
	(0.250)	(0.265)	(0.219)	(0.298)	(0.205)	(0.303)
Community consumption price index in Round 3	0.031	-0.069	0.132	0.188	-0.159	-0.081
	(0.267)	(0.289)	(0.253)	(0.370)	(0.215)	(0.380)
Community education inputs price index in Round 4	0.387*	0.380*	0.551***	0.634**	0.506***	0.502
	(0.212)	(0.228)	(0.196)	(0.270)	(0.188)	(0.327)
Community cognitive skills inputs price index in Round 1	0.075	-0.167	-0.638**	-0.096	-0.661**	-0.136
	(0.333)	(0.362)	(0.297)	(0.457)	(0.294)	(0.514)
Community cognitive skills inputs price index in Round 2	-0.395***	-0.323**	-0.337**	-0.334*	-0.228**	-0.056
	(0.140)	(0.153)	(0.135)	(0.190)	(0.115)	(0.203)
Community cognitive skills inputs price index in Round 3	-0.142	-0.153	-0.258	-0.605	-0.653***	-1.454***
	(0.291)	(0.319)	(0.281)	(0.399)	(0.231)	(0.457)
Community cognitive skills inputs price index in Round 4	0.230	0.205	-0.036	0.183	-0.177	-0.035
	(0.153)	(0.160)	(0.130)	(0.191)	(0.124)	(0.203)
Community wage index in Round 1	-0.215	-0.486**	0.154	1.009***	0.102	0.954**
	(0.212)	(0.246)	(0.179)	(0.379)	(0.135)	(0.375)
Community wage index in Round 2	0.449	0.605	-0.288	-0.453	-0.164	-0.207
	(0.349)	(0.388)	(0.241)	(0.338)	(0.225)	(0.326)
Community wage index in Round 3	-0.990***	-0.955***	-0.793***	-0.579*	-0.795***	-0.636*
	(0.263)	(0.276)	(0.231)	(0.318)	(0.222)	(0.376)
Community wage index in Round 4	0.461**	0.419**	0.416**	0.326	0.477***	0.281
	(0.192)	(0.196)	(0.185)	(0.244)	(0.178)	(0.278)
Number of credit-providing institutions in the community in Round 1	-0.034	-0.024	0.005	-0.077	0.007	-0.026
	(0.040)	(0.044)	(0.036)	(0.057)	(0.031)	(0.049)
Number of schools in the community Round 2	-0.205***	-0.226***	-0.316***	-0.230***	-0.323***	-0.264***
	(0.055)	(0.058)	(0.052)	(0.074)	(0.051)	(0.074)
Number of schools in the community in Round 3	-0.017	-0.016	-0.025	0.005	-0.032*	-0.002
	(0.019)	(0.022)	(0.017)	(0.024)	(0.017)	(0.025)

	OLS	2SLS	OLS	2SLS	OLS	2SLS
Number of schools in the community in Round 4	0.060***	0.066***	0.054***	0.033	0.066***	0.046**
	(0.017)	(0.019)	(0.016)	(0.023)	(0.016)	(0.023)
Community has hospital in Round 2	-0.247	-0.167				
	(0.214)	(0.224)				
Community has hospital in Round 3	0.242*	0.130	0.296**	0.325*		
	(0.128)	(0.144)	(0.124)	(0.179)		
Community has hospital in Round 4	-0.298	-0.192	0.535***	0.289	0.531***	0.356
	(0.250)	(0.271)	(0.194)	(0.272)	(0.180)	(0.265)
Community disease environment index in Round 2	-0.466**	-0.451**				
	(0.216)	(0.230)				
Community disease environment index in Round 3	0.397*	0.323	-0.050	0.402		
	(0.235)	(0.252)	(0.204)	(0.325)		
Community disease environment index in Round 4	0.224*	0.216	0.116	0.220	0.241**	0.400**
	(0.127)	(0.137)	(0.123)	(0.168)	(0.115)	(0.178)
Price index for medication in Round 2	-0.656***	-0.675***				
	(0.110)	(0.120)				
Price index for medication in Round 3	0.400**	0.428**	-0.037	-0.117		
	(0.163)	(0.180)	(0.140)	(0.185)		
Price index for medication in Round 4	-0.091	-0.100	0.035	-0.015	0.006	-0.021
	(0.076)	(0.082)	(0.070)	(0.090)	(0.066)	(0.092)
Price index for food in Round 2	-0.409*	-0.338				
	(0.224)	(0.242)				
Price index for food in Round 3	0.501*	0.190	0.769***	1.343***		
	(0.260)	(0.309)	(0.235)	(0.383)		
Price index for food in Round 4	0.025	0.061	-0.255	-0.539*	-0.147	-0.150
	(0.234)	(0.252)	(0.207)	(0.300)	(0.188)	(0.275)
R-squared	0.30		0.29		0.29	
Kleibergen-Paap F statistic		46.68		11.63		3.25
Stock and Yogo critical value		16.38		7.03		
Observations	1805	1805	1805	1805	1805	1805

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. The dependent variable is the age-standardised MATH score. Height-for-age is measured as the difference of the child's height from the WHO reference child of the same monthly age and gender in centimetres. All specifications include dummies for caregiver's ethnicity and whether the MATH was administered in the child's native language, but estimates are not reported. The Stock and Yogo critical value is the one for a 10% maximal 2SLS test size distortion. Excluded instruments for height-for-age in Rounds 1, 2, and 3 across countries include those presented in the just-identified column of Table 3.

Table A13. *Estimates of linear probability model of the Round 1 correlates of sample selection in Ethiopia and India*

	Ethiopia		India	
Child was very large at birth	0.030		-0.058*	
	(0.028)		(0.035)	
Child was large at birth	-0.010		0.005	
	(0.024)		(0.016)	
Child was small at birth	0.010		-0.030	
	(0.023)		(0.019)	
Child was very small at birth	0.038		-0.022	
	(0.034)		(0.035)	
Child is taller than children at the same age		0.002		-0.025
		(0.021)		(0.016)
Child is shorter than children at the same age		-0.031		-0.019
		(0.026)		(0.020)
Male	0.002	-0.001	0.008	0.008
	(0.017)	(0.017)	(0.013)	(0.013)
Second-born	0.067**	0.065**	0.060***	0.062***
	(0.026)	(0.026)	(0.015)	(0.015)
Third- or later-born	0.055**	0.054**	0.034	0.036*
	(0.023)	(0.023)	(0.021)	(0.021)
Caregiver's age at child's birth	-0.001	-0.001	-0.002	-0.002
	(0.001)	(0.001)	(0.001)	(0.001)
Caregiver's education	0.001	0.001	0.004**	0.004**
	(0.003)	(0.003)	(0.002)	(0.002)
Father's education	0.008***	0.007***	0.005***	0.005***
	(0.003)	(0.003)	(0.002)	(0.002)
Wealth index in Round 1	0.488***	0.486***	0.024	0.027
	(0.090)	(0.089)	(0.046)	(0.046)
Community consumption price index in Round 1	-0.036	-0.034	0.077***	0.077***
	(0.037)	(0.037)	(0.026)	(0.026)
Community cognitive skills inputs price index in Round 1	-0.183***	-0.185***	0.053*	0.052*
	(0.037)	(0.038)	(0.029)	(0.029)
Community wage index in Round 1	0.018	0.014	-0.027	-0.019
	(0.041)	(0.041)	(0.042)	(0.042)
Number of credit-providing institutions in the community in Round 1	0.006	0.007	0.015*	0.015*
	(0.010)	(0.010)	(0.008)	(0.008)
Community has hospital in Round 1	0.063**	0.064**	0.008	0.010
	(0.027)	(0.027)	(0.015)	(0.015)
Community disease environment index in Round 1	0.128*	0.132*	0.015	0.011
	(0.072)	(0.072)	(0.046)	(0.046)
Price index for medication in Round 1	-1.155***	-1.172***	-0.071*	-0.068*
	(0.256)	(0.256)	(0.036)	(0.036)
Price index for food in Round 1	-0.366***	-0.351***	-0.132***	-0.126***
	(0.092)	(0.092)	(0.048)	(0.048)
R-squared	0.32	0.32	0.04	0.04
Observations	1999	1999	2011	2011

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. The dependent variable is an indicator taking the value 1 if the observation was included in the estimation and 0 otherwise. All specifications include dummies for caregiver's ethnicity, but estimates are not reported.

Table A14. *Estimates of linear probability model of the Round 1 correlates of sample selection in Peru and Vietnam*

	Peru		Vietnam	
Child was very large at birth	0.050*		-0.025	
	(0.026)		(0.074)	
Child was large at birth	0.046**		0.003	
	(0.019)		(0.019)	
Child was small at birth	0.018		-0.002	
	(0.021)		(0.018)	
Child was very small at birth	0.064***		-0.052	
	(0.021)		(0.046)	
Child is taller than children at the same age		0.042***		0.013
		(0.016)		(0.016)
Child is shorter than children at the same age		-0.005		-0.014
		(0.020)		(0.017)
Male	0.017	0.014	-0.006	-0.007
	(0.014)	(0.014)	(0.013)	(0.013)
Second-born	0.050***	0.050***	0.003	0.004
	(0.018)	(0.018)	(0.015)	(0.014)
Third- or later-born	0.031	0.031	0.018	0.019
	(0.019)	(0.019)	(0.019)	(0.019)
Caregiver's age at child's birth	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Caregiver's education	-0.002	-0.002	0.003	0.003
	(0.002)	(0.002)	(0.002)	(0.002)
Father's education	0.002	0.002	0.002	0.002
	(0.002)	(0.002)	(0.003)	(0.003)
Wealth index in Round 1	0.066	0.060	-0.088*	-0.090*
	(0.043)	(0.043)	(0.050)	(0.051)
Community consumption price index in Round 1	-0.195***	-0.203***	-0.083	-0.080
	(0.047)	(0.046)	(0.160)	(0.159)
Community cognitive skills inputs price index in Round 1	0.168***	0.164***	-0.207***	-0.210***
	(0.052)	(0.052)	(0.072)	(0.071)
Community wage index in Round 1	0.152**	0.152**	0.060	0.060
	(0.069)	(0.069)	(0.037)	(0.037)
Number of credit-providing institutions in the community in Round 1	0.026***	0.027***	-0.011	-0.011*
	(0.006)	(0.006)	(0.007)	(0.006)
Community has hospital in Round 1	0.022	0.025	-0.040	-0.042
	(0.016)	(0.016)	(0.050)	(0.050)
Community disease environment index in Round 1	-0.014	-0.015	0.147***	0.147***
	(0.040)	(0.040)	(0.048)	(0.048)
Price index for medication in Round 1	-0.012	-0.010	-0.043	-0.043
	(0.028)	(0.028)	(0.029)	(0.029)
Price index for food in Round 1	0.039	0.045	-0.136*	-0.129*
	(0.038)	(0.038)	(0.077)	(0.077)
R-squared	0.32	0.32	0.04	0.04
Observations	1999	1999	2011	2011

Notes: Robust standard errors in parentheses, ***significant at 1%, **significant at 5%, *significant at 10%. The dependent variable is an indicator taking the value 1 if the observations were included in the estimation and 0 otherwise. All specifications include dummies for caregiver's ethnicity, but estimates are not reported.

The Sooner The Better But It's Never Too Late: The Impact of Nutrition at Different Periods of Childhood on Cognitive Development

Although it has been argued that undernutrition and its consequences for child development are irreversible after the age of 2, the evidence in support of these hypotheses is inconclusive. This working paper investigates the impact of nutrition at different periods from conception to middle childhood on cognitive achievement in early adolescence using data from Ethiopia, India, Peru, and Vietnam. In order to address estimation problems the paper develops a conceptual framework that delineates the channels through which child health impacts cognitive development and uses exogenous variation in nutritional status arising from weather shocks.

Results suggest that child growth both before and after the first 1,000 days is responsive to weather shocks and impacts cognitive achievement in early adolescence. The research also finds that part of the effect of early growth on later cognitive achievement manifests through growth in interim periods. Another novel result is that parental investment responses to a change in child health depend on the timing of this change.

These findings have important policy implications. On the one hand, results indicate that nutrition early in life is important for physical growth and cognitive development in subsequent stages of childhood, but on the other hand they suggest that nutrition-promoting investments after infancy and early childhood can act as a remedy for early nutrition and cognitive deficits and protect from nutritional insults in later stages that may also lead to developmental setbacks. Overall, the evidence suggests that nutrition-promoting interventions that start early in life and continue to subsequent stages of childhood, combined with support in other areas such as cognitive stimulation and parental involvement, may hold the most promise for the promotion of child development.

Young Lives

Young Lives
An International Study of Childhood Poverty

About Young Lives

Young Lives is an international study of childhood poverty, involving 12,000 children in 4 countries over 15 years. It is led by a team in the Department of International Development at the University of Oxford in association with research and policy partners in the 4 study countries: Ethiopia, India, Peru and Vietnam.

Through researching different aspects of children's lives, we seek to improve policies and programmes for children.

Young Lives Partners

Young Lives is coordinated by a small team based at the University of Oxford, led by Professor Jo Boyden.

- *Ethiopian Development Research Institute, Ethiopia*
- *Pankhurst Development Research and Consulting plc, Ethiopia*
- *Centre for Economic and Social Studies, Hyderabad, India*
- *Save the Children India*
- *Sri Padmavathi Mahila Visvavidyalayam (Women's University), Andhra Pradesh, India*
- *Grupo de Análisis para el Desarollo (GRADE), Peru*
- *Instituto de Investigación Nutricional, Peru*
- *Centre for Analysis and Forecasting, Vietnamese Academy of Social Sciences, Vietnam*
- *General Statistics Office, Vietnam*
- *Oxford Department of International Development, University of Oxford, UK*

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