Production of Health and Cognition for Children in Developing Countries

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Introduction and motivation

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- A recent literature has focused on the role of human capital development in the early years on long run outcomes.
- The process of human capital is complex for several reasons.
  1. The process is a complex and dynamic one.
  2. Different factors (cognitive, non-cognitive, health) interact in potentially complex ways.
  3. The level of human capital at a point in time affects subsequent development as well as the productivity of other inputs.
  4. Investments are endogenous to the process of accumulation.
  5. Several factors (resources, knowledge) might limit investment choices.
  6. Measurements can be difficult and rarely available.

Introduction and motivation

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- Characterization of the process of human capital accumulation is key to the design of effective policies to foster it among vulnerable children.
- Much evidence indicates that human capital in early years is malleable (but also vulnerable)

Today's talk

- I will focus on results from two of my own papers:
  1. "Human Capital Development and Parental Investment in India", Review of Economic Studies
  2. "Human Capital Growth and Poverty: Evidence from Ethiopia and Peru", Review of Economic Dynamics
- And will close with some thoughts on where the literature is going

Papers that originally inspired us

- Almond and Currie (2011)
- Hanushek and Woessman (JEL, 2008)
- Cunha, Heckman and Schennach (ECA, 2010); Heckman and collaborators.
- The Lancet Series (2007, 2011)
- Developing countries evidence:
  - Attanasio et al. (2013): 1400 children in Bogota.
  - Schady et al. (2013): evidence from five Latin American countries
  - Fernald et al. (2012): Madagascar
  - Grantham- McGregor et al. (2012): Bangladesh

Data

Young Lives: A big opportunity

- Development of health and cognition are particularly salient in Developing Countries.

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  - The data are rich and comprehensive (including many individual and household variables);

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- The Young Lives project and data constitute a unique opportunity for several reasons.
  - The (comparable) data cover four different developing countries;
  - The data are longitudinal;
  - The data are rich and comprehensive (including many individual and household variables);
  - Environmental variables (locality level information) are also available.

Young Lives: Basic structure

- Four countries are covered:
  - India
  - Ethiopia
  - Peru
  - Vietnam

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  - They cover two different cohorts of children, we focus on the younger cohort
    - 1000 children born in 1994-1995 (older cohort)
    - 2000 children born in 2001-2002 (younger cohort)

Young Lives: Basic structure

- Four countries are covered:
  - India
  - Ethiopia
  - Peru
  - Vietnam
- Data were collected at different points in time:
  - They cover two different cohorts of children, we focus on the younger cohort
    - 1000 children born in 1994-1995 (older cohort)
    - 2000 children born in 2001-2002 (younger cohort)
  - Children are then observed at:
    - 1, 5 , 8, 12 for the younger cohort

First paper: India

- Estimates a rich model of child development
- Yields important new insights on child development that can be used to inform policy

Some descriptive statistics from India

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- I will also document how wealth gaps associate with cognitive and health development, as well as parental background and with investment in children.

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- I will also document how wealth gaps associate with cognitive and health development, as well as parental background and with investment in children.
- I will then propose a model to frame all the available data and interpret the evidence.

Descriptive statistics

Table 2: Descriptive Statistics: Across Rounds

	Age 1	Age 5	Age 8	Age 12
Child Characteristics				
Fraction stunted	0.31	0.36	0.30	0.29
Fraction underweight	0.32	0.45	0.46	
Fraction wasted		0.19	0.28	0.33
Height for age Z-score	-1.30	-1.66	-1.45	-1.45
	1.48	*0.99*	*1.04*	*1.03*
Standardized PPVT test		0.01	0.74	1.75
		1.00	*0.88*	*1.01*
Amount spent on books		3.48	8.98	13.00
		5.40	*13.02*	*16.97*
Household Economic Wellbeing				
Annual income		873.57	1407.98	1749.95
		1219.24	*2033.67*	*1841.78*
Wealth index	0.40	0.46	0.51	0.59
	0.20	*0.20*	*0.18*	*0.17*
Percent below $2/day		0.63	0.45	0.27
Child Work				
Daily hours chores		0.06	0.34	0.82
Daily hours family business		0.00	0.01	0.12
Daily hours paid work			0.01	0.05

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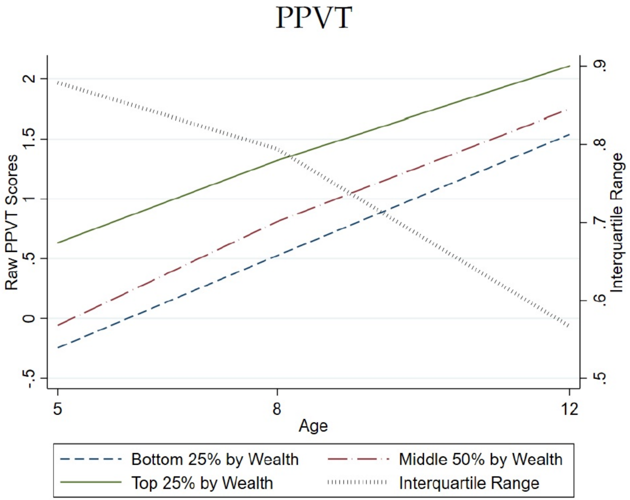
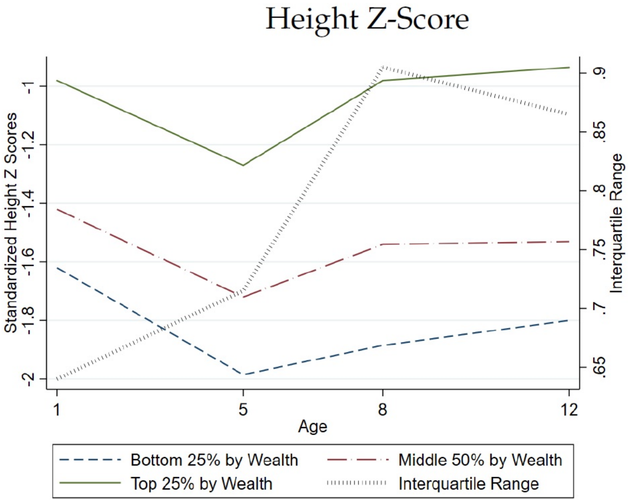
Wealth gradients cognitive development



Wealth gradients in health capital



Association between investment and development

VARIABLES	PPVT Score at 5	PPVT Score at 5	With Investments
Wealth	1.289**		
	(0.112)		
Mom Education			
Dad Education			
Gender	0.021		
	(0.045)		
Age in Months	0.034**		
	(0.006)		
Number of Children	-0.093**		
	(0.021)		
Constant	-2.231**		
	(0.380)		
Observations	1,851		
R-squared	0.100		

Standard errors in parentheses

** $p<0.01$, * $p<0.05$, + $p<0.1$

Association between investment and development

VARIABLES	PPVT Score at 5	PPVT Score at 5	With Investments
Wealth	1.289**	0.259+	
	(0.112)	(0.134)	
Mom Education		0.062**	
		(0.007)	
Dad Education		0.027**	
		(0.006)	
Gender	0.021	0.025	
	(0.045)	(0.044)	
Age in Months	0.034**	0.037**	
	(0.006)	(0.006)	
Number of Children	-0.093**	-0.038+	
	(0.021)	(0.021)	
Constant	-2.231**	-2.464**	
	(0.380)	(0.376)	
Observations	1,851	1,747	
R-squared	0.100	0.186	

Standard errors in parentheses

** $p<0.01$, * $p<0.05$, + $p<0.1$

Association between investment and development

VARIABLES	PPVT Score at 5	PPVT Score at 5	With Investments
Wealth	1.289**	0.259+	0.307
	(0.112)	(0.134)	(0.236)
Mom Education		0.062**	0.077**
		(0.007)	(0.011)
Dad Education		0.027**	0.022*
		(0.006)	(0.010)
Gender	0.021	0.025	0.036
	(0.045)	(0.044)	(0.074)
Age in Months	0.034**	0.037**	0.020+
	(0.006)	(0.006)	(0.011)
Number of Children	-0.093**	-0.038+	-0.057
	(0.021)	(0.021)	(0.039)
Constant	-2.231**	-2.464**	-0.800
	(0.380)	(0.376)	(0.746)
Observations	1,851	1,747	872
R-squared	0.100	0.186	0.189

Standard errors in parentheses

** $p<0.01$, * $p<0.05$, + $p<0.1$

Association between investment and development

VARIABLES	PPVT at 8	PPVT at 8	With Investments	Investments + Previous Period
Wealth	1.316**			
	(0.108)			
Mom Education				
Dad Education				
PPVT Age 5				
Gender	0.183**			
	(0.044)			
Age in Months	0.017**			
	(0.006)			
Number of Children	-0.104**			
	(0.021)			
Constant	-1.222**			
	(0.372)			
Observations	1,900			
R-squared	0.106			

Standard errors in parentheses

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

Association between investment and development

VARIABLES	PPVT at 8	PPVT at 8	With Investments	Investments + Previous Period
Wealth	1.316**	0.801**		
	(0.108)	(0.133)		
Mom Education		0.028**		
		(0.007)		
Dad Education		0.021**		
		(0.006)		
PPVT Age 5				
Gender	0.183**	0.209**		
	(0.044)	(0.044)		
Age in Months	0.017**	0.019**		
	(0.006)	(0.006)		
Number of Children	-0.104**	-0.086**		
	(0.021)	(0.021)		
Constant	-1.222**	-1.400**		
	(0.372)	(0.376)		
Observations	1,900	1,794		
R-squared	0.106	0.146		

Standard errors in parentheses

** $p<0.01$, * $p<0.05$, + $p<0.1$

Association between investment and development

VARIABLES	PPVT at 8	PPVT at 8	With Investments	Investments + Previous Period
Wealth	1.316**	0.801**	0.849**	
	(0.108)	(0.133)	(0.201)	
Mom Education		0.028**	0.033**	
		(0.007)	(0.010)	
Dad Education		0.021**	0.012	
		(0.006)	(0.009)	
PPVT Age 5				
Gender	0.183**	0.209**	0.277**	
	(0.044)	(0.044)	(0.063)	
Age in Months	0.017**	0.019**	0.020*	
	(0.006)	(0.006)	(0.009)	
Number of Children	-0.104**	-0.086**	-0.064+	
	(0.021)	(0.021)	(0.034)	
Constant	-1.222**	-1.400**	-1.730**	
	(0.372)	(0.376)	(0.634)	
Observations	1,900	1,794	897	
R-squared	0.106	0.146	0.188	

Standard errors in parentheses

** $p<0.01$, * $p<0.05$, + $p<0.1$

Association between investment and development

VARIABLES	PPVT at 8	PPVT at 8	With Investments	Investments + Previous Period
Wealth	1.316**	0.801**	0.849**	0.818**
	(0.108)	(0.133)	(0.201)	(0.200)
Mom Education		0.028**	0.033**	0.020*
		(0.007)	(0.010)	(0.010)
Dad Education		0.021**	0.012	0.006
		(0.006)	(0.009)	(0.009)
PPVT Age 5				0.170**
				(0.029)
Gender	0.183**	0.209**	0.277**	0.272**
	(0.044)	(0.044)	(0.063)	(0.063)
Age in Months	0.017**	0.019**	0.020*	0.020*
	(0.006)	(0.006)	(0.009)	(0.009)
Number of Children	-0.104**	-0.086**	-0.064+	-0.042
	(0.021)	(0.021)	(0.034)	(0.033)
Constant	-1.222**	-1.400**	-1.730**	-1.760**
	(0.372)	(0.376)	(0.634)	(0.633)
Observations	1,900	1,794	897	860
R-squared	0.106	0.146	0.188	0.227

Standard errors in parentheses

** $p<0.01$, * $p<0.05$, + $p<0.1$

Association between investment and development

VARIABLES	Health at Age 5	Health at Age 5	With Investments
Wealth	1.273**		
	(0.122)		
Mom Education			
Dad Education			
Gender	-0.129**		
	(0.049)		
Age in Months	-0.004		
	(0.006)		
Number of Children	-0.091**		
	(0.023)		
Constant	-1.680**		
	(0.416)		
Observations	1,943		
R-squared	0.070		

Standard errors in parentheses

** $p<0.01$, * $p<0.05$, + $p<0.1$

Association between investment and development

VARIABLES	Health at Age 5	Health at Age 5	With Investments
Wealth	1.273**	0.941**	
	(0.122)	(0.154)	
Mom Education		0.007	
		(0.008)	
Dad Education		0.022**	
		(0.007)	
Gender	-0.129**	-0.106*	
	(0.049)	(0.051)	
Age in Months	-0.004	-0.004	
	(0.006)	(0.007)	
Number of Children	-0.091**	-0.081**	
	(0.023)	(0.024)	
Constant	-1.680**	-1.698**	
	(0.416)	(0.433)	
Observations	1,943	1,835	
R-squared	0.070	0.081	

Standard errors in parentheses

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Association between investment and development

VARIABLES	Health at Age 5	Health at Age 5	With Investments
Wealth	1.273**	0.941**	0.560*
	(0.122)	(0.154)	(0.229)
Mom Education		0.007	-0.016
		(0.008)	(0.011)
Dad Education		0.022**	0.016
		(0.007)	(0.010)
Gender	-0.129**	-0.106*	-0.184*
	(0.049)	(0.051)	(0.072)
Age in Months	-0.004	-0.004	-0.012
	(0.006)	(0.007)	(0.010)
Number of Children	-0.091**	-0.081**	-0.013
	(0.023)	(0.024)	(0.038)
Constant	-1.680**	-1.698**	-0.730
	(0.416)	(0.433)	(0.725)
Observations	1,943	1,835	911
R-squared	0.070	0.081	0.085

Standard errors in parentheses

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Latent factors and production functions

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  - They are all likely to be affected by measurement error.
  - Children's development in its many dimensions is likely to be affected by many factors:
    - Parental background
    - Lagged development
    - Investment
    - Shocks

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  - They are all likely to be affected by measurement error.
  - Children's development in its many dimensions is likely to be affected by many factors:
    - Parental background
    - Lagged development
    - Investment
    - Shocks
  - Some factors are chosen by parents (investment), possibly in reaction to shocks.

Latent factors and production functions

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  - We focus on cognitive and health factors.

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  - Some of these factors will have (measurement error ridden) signals associated with them.

Latent factors and production functions

- Following Heckman et al. (2010), we assume that children's development is driven by a certain number of latent factors:
  - We focus on cognitive and health factors.
- These factors are reflected in measurements.
- Analogously, there will be other latent factors that drive investment, parental background and shocks
  - Some of these factors will have (measurement error ridden) signals associated with them.
- We can then model (in a flexible fashion) the relationship between the distributions of these factors and give them a structural interpretation.
  - Investment functions
  - Production functions.

The production function

- We consider two production functions:
  - One for the production of cognitive skills

$$\theta_{ct+1} = A_{ct}[\delta_{ct}\theta_{ct}^{\rho} + \delta_{ht}\theta_{ht}^{\rho} + \delta_{cpt}\theta_{cp}^{\rho} + \delta_{hpt}\theta_{hp}^{\rho} + \delta_{It}\theta_{It}^{\rho}]^{\frac{1}{\rho}}$$

$$A_{ct} = exp(d_{0t} + d_{Xt}X_t + u_{ct})$$

  - One for the production of health

$$\theta_{ht+1} = A_{ct}[\alpha_{ct}\theta_{ct}^{\zeta} + \alpha_{ht}\theta_{ht}^{\zeta} + \alpha_{cpt}\theta_{cp}^{\zeta} + \alpha_{hpt}\theta_{hp}^{\zeta} + \alpha_{It}\theta_{It}^{\zeta}]^{\frac{1}{\zeta}}$$

$$A_{ht} = exp(a_{0t} + a_{Xt}X_t + u_{ht})$$

- The term θ_I reflects investments by parents.
- By allowing for a CES structure we allow for complementarities of inputs
  - Further generalizations are possible (will discuss later)

The model

- The factor structure we use is particularly useful:
  - It allows use of the huge amount of information in the data in a parsimonious fashion
  - In an experimental setting it offers a way of understanding how the experiment generated the outcomes
  - It provides a key element of an economic model for household behavior.
- We use a measurement system with at least two measures per factor and three measurements for at least one factor

  $$m_{jkt} = a_{jkt} + \lambda_{jkt} ln(\theta_{kt}) + \epsilon_{jkt}$$

  where m represents an observable measurement, ϵ a measurement error and λ a factor loading that takes care of the units.
- One of the central elements in the analysis is specifying the way measurements and factors relate.

A technical summary

- The approach draws from the Kotlarski theorem:
  - In a measurement error problem with two independent measurements per factor one can identify non-parametrically the distribution of the unobserved factor and the measurement error
  - This can be generalized to allow for correlated measurement error and for non-classical measurement error (e.g. discrete variables)

Identification and endogenous investments

- The basic premise of the model is that all relevant heterogeneity is captured by the included factors
- It is thus important to make sure the specification is complete
- Beyond the issue of permanent omitted variables there is the question of temporal shocks
- Investments may respond to shocks:
  - A positive shock to child cognition may lead to more or less investment depending on complementarities
- Thus we also control for the possible correlation between TFP shocks and investment

Controlling for endogenous investments

- We view investments as being chosen as a function of child background and the economic environment
- Hence we include all predetermined factors from the production function as well as prices and household income
- We also include the number of other children and the child's birth order, since they will be competing for resources
- Income may still be endogenous
- We thus also include a robustness exercise using only prices

Econometric approach to endogeneity

- We assume a semilog linear investment equation of the form

$$
\begin{aligned}
ln\theta_{It} = \gamma_0 + \gamma_{ct}\theta_{ct} + \gamma_{ht}\theta_{ht} + \gamma_{cpt}\theta_{cp} + \gamma_{hpt}\theta_{hp} \\
+ \gamma'_{Xt}X_t + \gamma'_{Pt} lnp_{It} + \gamma_Y ln\theta_{Yt} + v_t
\end{aligned}
$$

where Z are the instruments and the right hand side variables are in logs

- We assume the production function takes the form

$$
\begin{aligned}
\theta_{ct+1} &= A_{ct}[\delta_{ct}\theta_{ct}^{\rho} + \delta_{ht}\theta_{ht}^{\rho} + \delta_{cpt}\theta_{cp}^{\rho} + \delta_{hpt}\theta_{hp}^{\rho} + \delta_{It}\theta_{It}^{\rho}]^{\frac{1}{\rho}} \\
A_{ct} &= exp(d_{0t} + d_{Xt}X_t + \kappa_c v_t + u_{ct})
\end{aligned}
$$

- The measurements will now include the instruments as factors measured with no error.
- Once the investment equation is estimated we then include the residual in the production function as an extra regression, and if $\kappa_c = \kappa_h = 0$, investments are exogenous
- This is a control function approach.

The Econometric model

- So consider again the measurement system

$$m_{jkt} = a_{jkt} + \lambda_{jkt} ln(\theta_{kt}) + \epsilon_{jkt}$$

- We express the distribution of the factors θ as a mixture of normals

$$F_\theta = \tau \Phi(\mu_A, \Omega_A) + (1-\tau)\Phi(\mu_B, \Omega_B)$$

  where Φ is a normal distribution with mean μ_k and covariance matrix Ω_k.
- This and the structure of the measurement equations implies that the distribution of the measurements can also be expressed as a mixture of normals.
- We also assume that the measurement errors are normal although this is not necessary
- Measurement errors need only be independent of θ.

Estimating the Model

- The key idea is to estimate the joint distribution of the factors, by starting with the joint distribution of the measurements, with $M = \boldsymbol{A} + \Lambda ln\theta + \Sigma_\varepsilon$, and then the joint distribution of measurements can be written as

$$F_M = \tau \Phi(\Pi_A, \Psi_A) + (1 - \tau)\Phi(\Pi_B, \Psi_B)$$

  where $\Psi_K = \Lambda^T \Omega_K \Lambda + \Sigma$; and $\Pi_K = \boldsymbol{A} + \Lambda \mu_K$
- We also impose the standard mean zero assumption in the first period (but only first period)
- Then the production function can be seen as the conditional mean of the relevant factors given the rest.
- Allowing for non-normality is crucial: under normality the conditional mean has to be linear.

Estimating the Model: Three Steps

1. Use MLE to estimate τ,Π_K, Ψ_K from the data
2. Use minimum distance to impose the restrictions in equations in previous slide and the mean zero normalization, as well as age-invariant assumptions, initial period normalizations, and zero restrictions in Λ to recover Λ, $\boldsymbol{A}$,Σ, μ_K, Ω_K, from Π_K and Ψ_K
3. Draw a synthetic data set from this joint distribution to estimate the model using regression methods. The joint distribution includes the full amount of information in the data relevant to the model. The larger the data we draw the lower the simulation error.

Estimating the model: The first step

- E-step: Given a set of parameters and given the data calculate the probability P_k that an observation is drawn from each normal distribution.
- M-step: maximize the conditional likelihood and and update the parameter estimates
- Each part is the usual least squares problem so it has an analytical solution
- Iterate between the E and the M step.

Measures

- The first step in the model specification is to link measures to underlying latent factors (such as cognitive skill or investments)
- A measure may be driven by more than one factor
- For each factor we need an exclusive measure
- We need at least $2F + 1$ measures for F factors in general
- For now we assume that the measurement errors across factors are independent - this can be relaxed to an extent.

Signal to noise ratio

Table 4: Signal to Noise Ratios

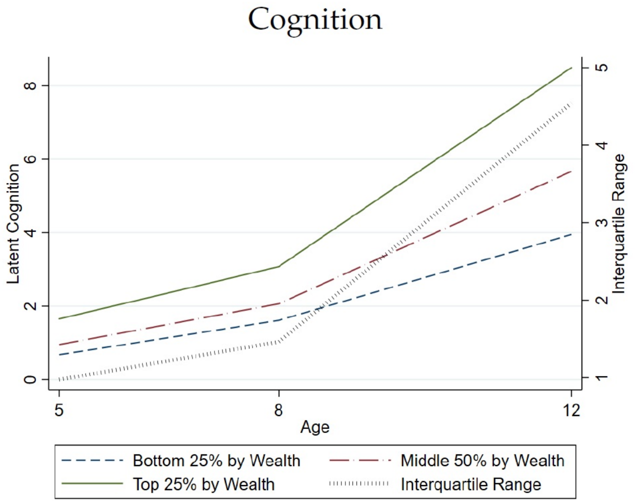
	Age 1	Age 5	Age 8	Age 12
		Child Cognition		
PPVT		74%	26%	35%
Math			35%	60%
English				70%
Language				39%
EGRA (rasch)			53%	
CDA (rasch)		43%		
		Child Health		
Height Z-Score	57%	77%	68%	77%
Weight Z-Score	78%	70%	73%	
Weight in kg				66%
Health Status	7%	1%	5%	
		Investments		
Books		36%	26%	34%
Clothing		51%	35%	44%
Shoes		58%	42%	37%
Uniform		20%	15%	22%
Meals/day		4%	8%	2%
Food groups/day		21%	10%	0%

Signal to noise ratio

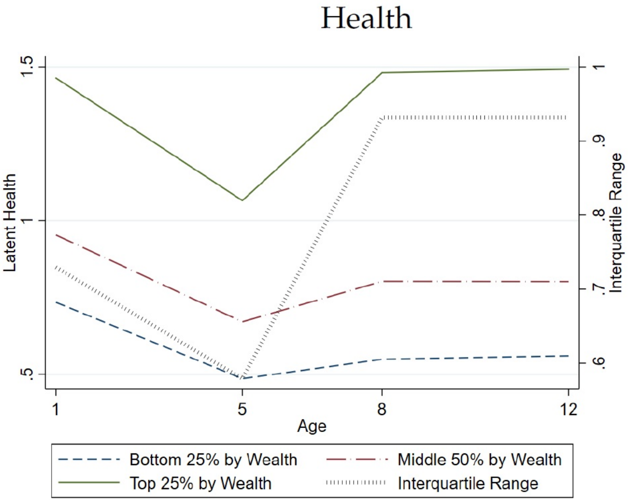
	Resources		
Income	30%	18%	20%
Wealth	63%	52%	49%
	Parental Cognition (fixed over age)		
Mother's education	79%		
Father's education	52%		
Literacy	45%		
	Parental Health (fixed over age)		
Mother's weight	62%		
Mother's height	13%		

PPVT: Peabody Picture Vocabulary Test, EGRA: Reading comprehension test, CDA: Cognitive Development Assessment. Books, clothing, shoes and uniform measured in monetary units.

Wealth gradients cognitive development



Wealth gradients in health capital



Estimates of the investment equation

	Age 5	Age 8	Age 12
		Child human capital	
Cognition		0.029 [−0.01,0.05]	0.436 [0.22,0.55]
Health	0.033 [0.02,0.04]	−0.001 [−0.03,0.03]	0.042 [−0.02,0.13]
Gender	−0.005 [−0.03,0.02]	−0.022 [−0.1,0.03]	0.029 [−0.09,0.16]
		Parental human capital	
Parental Cognition	0 [−0.02,0.03]	0.01 [−0.02,0.09]	−0.146 [−0.2,−0.03]
Parental Health	−0.014 [−0.04,0.01]	−0.021 [−0.06,0.04]	−0.073 [−0.23,−0.01]
		Prices	
Price Clothes	−0.022 [−0.05,0.01]	0.051 [−0.08,0.12]	0.189 [0.02,0.38]
Price Notebook	−0.11 [−0.16,−0.07]	−0.175 [−0.32,−0.05]	−0.414 [−0.56,−0.26]
Price Mebendazol	0.015 [0,0.03]	−0.117 [−0.2,−0.08]	0.032 [−0.06,0.09]
Price Food	−0.035 [−0.11,0.04]	−0.287 [−0.59,0.03]	−0.416 [−0.65,−0.17]

Estimates of the investment equation

	Household Characteristics		
Resources	0.163 [0.1,0.2]	0.628 [0.43,0.69]	0.797 [0.58,0.97]
Older Siblings	0.013 [−0.01,0.03]	0.052 [−0.01,0.1]	−0.026 [−0.11,0.07]
Number of Children	−0.03 [−0.05,−0.01]	−0.044 [−0.09,0]	−0.073 [−0.16,0]
Urban	0.119 [0.08,0.19]	0.088 [0,0.23]	0.117 [−0.06,0.34]
Hindu	−0.001 [−0.01,0]	−0.013 [−0.02,0]	0.001 [−0.01,0.02]
Muslim	−0.029 [−0.1,0.03]	−0.224 [−0.35,−0.04]	−0.009 [−0.31,0.23]
Mother's Age	−0.001 [−0.05,0.04]	−0.096 [−0.21,0.08]	−0.039 [−0.23,0.19]
Scheduled Caste	−0.023 [−0.06,0.02]	−0.028 [−0.16,0.12]	−0.375 [−0.6,−0.13]
Scheduled Tribe	0.035 [−0.02,0.07]	−0.002 [−0.12,0.1]	−0.313 [−0.52,−0.07]
BC Caste	−0.008 [−0.05,0.03]	0.093 [0,0.21]	−0.205 [−0.4,−0.03]
Prices and Income (P-values)	0	0	0
Prices (P-values)	0	.017	0

Note: 90% confidence intervals based on 100 replications in square brackets

Production of cognitive skills and health

	Cognition			Health		
Age	5	8	12	5	8	12
			Lagged Skills			
Cognition		0.15 [0.11,0.2]	0.77 [0.64,0.87]		0 [−0.04,0.02]	−0.01 [−0.05,0.14]
Health	0.05 [0.01,0.09]	0.14 [0.1,0.18]	0.03 [−0.01,0.09]	0.47 [0.44,0.52]	0.9 [0.84,0.93]	0.91 [0.85,0.97]
			Investment and Parental Skills			
Parental Cognition	0.34 [0.3,0.39]	0.11 [0.04,0.17]	0.04 [0,0.13]	0.02 [−0.04,0.05]	0.05 [0.03,0.09]	−0.05 [−0.09,0.01]
Parental Health	0.07 [0,0.18]	−0.07 [−0.1,0.01]	−0.02 [−0.06,0.04]	0.26 [0.18,0.38]	0.06 [0.02,0.1]	0.02 [−0.03,0.1]
Investment	0.53 [0.43,0.6]	0.66 [0.57,0.76]	0.19 [0.06,0.26]	0.25 [0.17,0.34]	0 [−0.05,0.08]	0.12 [−0.01,0.17]

Production of cognitive skills and health

TFP - Demographic Characteristics

Log TFP	−0.04 [−0.07,0.04]	0.57 [0.49,0.61]	1.08 [1.01,1.18]	−0.33 [−0.38,−0.27]	0.14 [0.08,0.2]	−0.09 [−0.14,−0.02]
Num Child	0 [−0.02,0.01]	−0.01 [−0.02,0.01]	−0.02 [−0.04,−0.01]	0.01 [−0.01,0.03]	0 [−0.01,0]	0 [−0.02,0.01]
Older Sibs	−0.01 [−0.03,0]	−0.01 [−0.03,0]	0.01 [−0.01,0.02]	−0.03 [−0.05,−0.01]	0 [−0.01,0.01]	0.01 [0,0.03]
Gender	0.01 [0,0.03]	0.03 [0.01,0.04]	−0.02 [−0.03,−0.01]	0 [−0.01,0.01]	0.01 [0,0.01]	0.01 [0,0.02]
Urban	0.01 [0,0.01]	−0.02 [−0.02,0]	−0.01 [−0.02,0]	0 [−0.01,0]	0.01 [0,0.01]	0 [−0.01,0]
Hindu	−0.01 [−0.02,0.01]	−0.01 [−0.02,0]	0.01 [0,0.03]	0.01 [0,0.02]	0 [−0.01,0.01]	−0.01 [−0.01,0.01]
Muslim	0 [0,0]	0 [0,0]	−0.01 [−0.01,0]	0 [−0.01,0]	0 [0,0]	0 [0,0]
Mother Age	0.01 [0,0.03]	0.02 [0,0.03]	−0.01 [−0.03,0]	0 [−0.01,0.02]	0 [−0.01,0.01]	−0.02 [−0.03,−0.01]
Sched Caste	−0.01 [−0.02,0]	0.02 [0.01,0.03]	0 [−0.01,0.01]	0 [−0.01,0.01]	0 [−0.01,0]	0 [−0.01,0.01]
Sched Tribe	0.03 [0.02,0.04]	0 [−0.01,0]	0 [−0.01,0.01]	0.01 [0,0.02]	−0.02 [−0.02,−0.01]	0.01 [0,0.01]
BC Caste	−0.01 [−0.03,0]	−0.01 [−0.02,0.01]	0.01 [0,0.02]	−0.02 [−0.03,−0.01]	0.01 [0,0.02]	−0.01 [−0.01,0.01]

Production of cognitive skills and health

Production function structure and test of exogeneity for investment

(ρ, ζ)	0.02 [−0.32,0.17]	0.04 [−0.06,0.15]	−0.09 [−0.33,0.11]	0 [−0.07,0.04]	0.36 [0.11,0.46]	−0.08 [−0.63,0.2]
Subst. Elast.	1.02 [0.76,1.21]	1.05 [0.94,1.18]	0.92 [0.75,1.12]	1 [0.93,1.04]	1.57 [1.12,1.84]	0.92 [0.61,1.24]
Inv. Res.	−0.84 [−1.26,−0.3]	−0.51 [−0.65,−0.37]	−0.28 [−0.39,−0.1]	−0.84 [−1.23,−0.51]	0.02 [−0.08,0.11]	−0.1 [−0.18,0.02]

Robustness

Table 7: Robustness to using resources as an excluded instrument

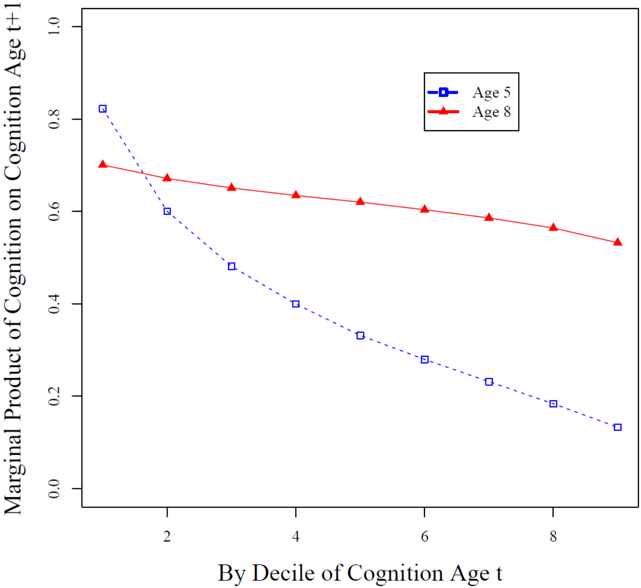
	Age 5		Age 8		Age 12	
			Child Cognition			
Coefficient on investment	0.53	0.55	0.66	0.62	0.19	0.18
	[0.43,0.6]	[0.45,0.64]	[0.57,0.76]	[0.53,0.71]	[0.06,0.26]	[0.06,0.27]
P-value equality	0.43		0.01		0.87	
P-value excluding income		0.40		0.02		0.88
			Child Health			
Coefficient on investment	0.25	0.28	0	0.01	0.12	0.12
	[0.17,0.34]	[0.17,0.38]	[−0.05,0.08]	[−0.03,0.08]	[−0.01,0.17]	[−0.02,0.18]
P-value equality	0.21		0.19		0.92	
P-value excluding income		0.22		0.05		0.93

Notes: P-values for the tests computed using the bootstrap. "P-value equality": p-value for the equality of the income coefficients across the two specifications (with and without income as an excluded instrument). 90% confidence intervals in square brackets.

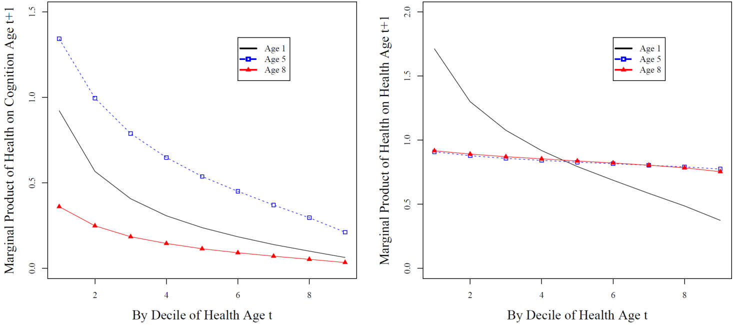
Some implications

- Both skills highly self productive, increasingly so with age
- Investments have a large influence but are also endogenous and compensate for shocks
- Health is cross productive, not so for cognition

Marginal Product of Cognition

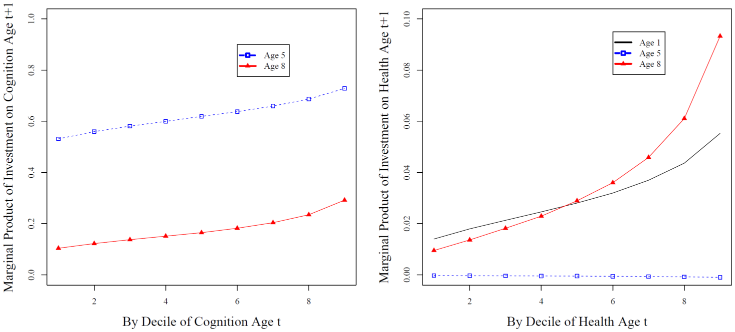


Marginal Product of Health



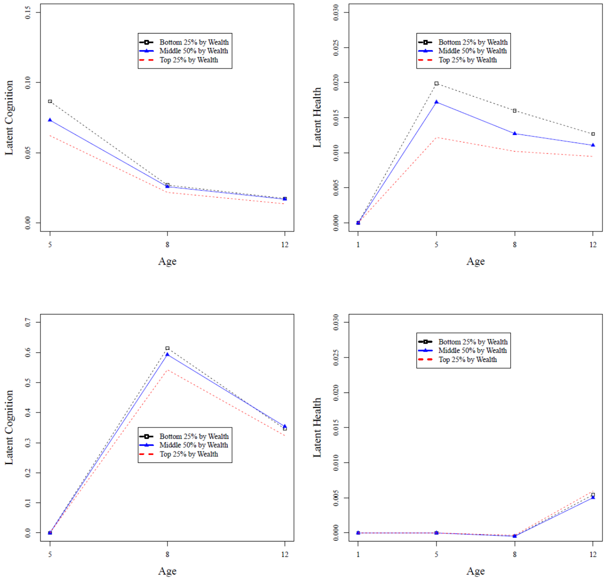
Note: The y-axis represents the impact on the outcome in question, in standard deviation units, of increasing cognition or health by one standard deviation. All other inputs are kept at their median value for the respective age group.

Marginal Product of Investments

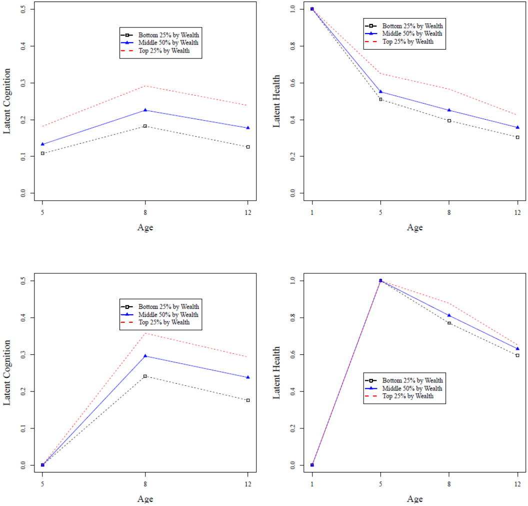


Note: The y-axis represents the impact on the outcome in question, in standard deviation units, of increasing investment by one standard deviation.

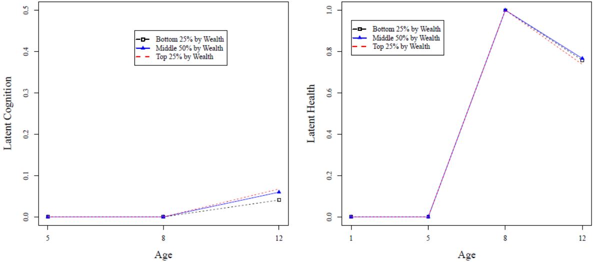
Impact of income transfer equal to 25% of mean income



Impact of health intervention increases health by 1 standard deviation at 1, 5, or 8



Impact of health intervention increases health by 1 standard deviation at 1, 5, or 8



Note: The y-axis represents the impact on cognition (left) and health (right) of artificially improving health by 1 standard deviation. In the top two graphs the increase in health takes place at age 1. In the middle two graphs it is made at age 5. In the lower two graphs it is made at age 8.

Optimal path of investments

Table 8: The optimal path of investment

Share of Cognition in Human Capital (α)	Age		
	5	8	12
0.25	0.405	0.281	0.314
0.50	0.265	0.452	0.283
0.75	0.175	0.563	0.262
1.00	0.112	0.640	0.248

Notes: The numbers show how the average amount of life time investment in children is optimally allocated across ages based on the production function estimates and on the weight that cognition versus health has on final human capital.

Conclusion

- Ill health at a young age causes permanent cognitive deficits
- Investments are important in improving cognition and to a lesser degree health,
- Investments are endogenous and compensate for negative shocks
- Important complementarities in the production of skills; marginal product of investments increases with cognition and health, accentuating inequalities

Second paper: Peru and Ethiopia

- In a follow up paper, we decided to explore the functional form assumptions, and expand the analysis to look at two additional but quite different developing countries
  - Ethiopia and Peru
  - Look at CES and nested CES production functions
- We find that wealthier and more able parents are invest more in their children, particularly in the formative early years
- These differences in investment patterns exacerbate existing inequality

Nested CES

$$\theta_{i,t+1}^{k} = [\gamma_{1t}^{k} P_i^{C\,\rho_{tk}} + \gamma_{2t}^{k} P_i^{H\,\rho_{tk}} + \gamma_{3t}^{k} I_{i,t}^{\ \rho_{tk}} + \gamma_{4t}^{k} (\delta_{1t}^{k} \theta_{i,t}^{C\ \rho_{skills,tk}} + (1-\delta_{1t}^{k}) \theta_{i,t}^{H\ \rho_{skills,tk}})^{\frac{\rho_{tk}}{\rho_{skills,tk}}}]^{\frac{1}{\rho_{tk}}} e^{\phi_{tk}' X_{i,t} + A_t^k + \varepsilon_{i,t}^k}, \quad k \in \{C, H\}$$

- Allows for greater flexibility
- Reverts to CES if $\rho_{skills,tk} = \rho_{tk}$
- We are able to reject the CES, but it turns out that even with that being the case, the simulations are similar with both CES and Nested CES

Nested CES

Table 11
Test of the nested CES.

	Cognition	
	Ethiopia	Peru
Age 8	1.496	0.57
	[0.346, 3.626]	[0.021, 1.384]
Age 12	0.853	0.644
	[0.133, 2.67]	[0.077, 2.225]
Age 15	0.445	0.249
	[0.044, 1.555]	[0.025, 1.279]

Notes: 95% confidence intervals based on 100 bootstrap replications in square brackets.

- We are able to reject the CES, but it turns out that even with that being the case, the simulations are similar with both CES and Nested CES

A Vibrant Literature

Since our paper, this literature has continued to expand, with many well published or on their way to being well published papers appearing regularly. Some recent papers I have liked:

- Agostinelli and Wiswall (2020) Estimating the Technology of Children's Skill Formation
- Agostinelli, Saharkhiz, and Wiswall (2020) Home and School in the Development of Children
- Del Bono, Kinsler and Pavan (2020) A Note on the Importance of Normalizations in Dynamic Latent Factor Models of Skill Formation
- And many more

Conclusion

- This is an exciting area of research
- This work can also complement more reduced form exercises: for example, if you run an RCT and find a 1 std deviation increase in health at age 1 versus at age 5, what does our model say the long run effect will be?
- We can learn a lot about optimal investments in children and how to improve child outcomes by carefully modeling and estimating the process