The Dynamics of Child Development in Early Childhood

The AEIOTU Evaluation

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Outline

Motivation

- Child development is dynamic and multidimensional.
- Current skills depend on:
  - past skills,
  - parental investments,
  - health and environment.
- A large literature estimates production functions of child development.
- However, most datasets observe children only at a few ages.

Main question:

How do persistence and the productivity of parental investments evolve during early childhood?

Two Main Contributions

Contribution 1: High-frequency measurement

- Children observed annually from roughly age 1 to age 7.
- Allows estimation of age-specific production functions.
- Makes it possible to study how persistence and investment effects evolve over time.

Contribution 2: Dynamic normalization

- Different tests are administered at different ages.
- The paper develops a normalization strategy that places latent factors on a common metric.
- Essential for studying growth and dynamics.

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The Dynamic Production Function

- For each developmental domain:

$$\theta_{t+1} = f_t\left(\theta_t, I_t, X_t, \varepsilon_{t+1}\right)$$

- The properties of this production function are key to determine the process of child development.
- The technology of skill formation is allowed to evolve.

$$f_1 \neq f_2 \neq f_3 \neq \cdots$$

- Persistence can vary with age.
- Investment productivity can vary with age.
- These features identify windows of opportunities.

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Why Existing Studies Are Limited

- Typical studies observe children at only a few points in time.
- One of the best existing studies, the Millennium Cohort Study in the UK:

Age 1 Age 3 Age 5 Age 7 Age 11 Age 14 Age 17

- Persistence estimated over long intervals.
- Investment effects averaged over several years.
- Difficult to identify sensitive periods.

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$$1 \rightarrow 2 \rightarrow 3 \rightarrow 4 \rightarrow 5 \rightarrow 6 \rightarrow 7$$

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The Data

Three latent dimensions of child development:

1. Cognitive and language skills
2. Socio-emotional skills
3. Health

Additional latent factor:

- Parental investments

Multiple noisy measures available for each dimension at each age.

The Normalization Problem

Different tests are administered at different ages.

Age 1–3	Bayley
Age 3–7	TVIP
Age 4–7	Woodcock-Muñoz
Age 4–7	ELSA

If factors are normalized separately at each age:

- Means cannot be compared.
- Variances cannot be compared.
- Growth is not identified.
- Persistence estimates become difficult to interpret.

The Key Idea

Use overlapping measures to create a common metric.

Age 1	Bayley
Age 2	Bayley + TVIP
Age 3	TVIP + Woodcock-Muñoz
Age 4	Woodcock-Muñoz

The overlap allows one test to be translated into the metric of another.

An Example

- Let's consider 3 time periods and 4 measures for a generic factor k:
  - $m_k^{a_1}$, available at $t = 1,\ t = 2$
  - $m_k^{a_2}$, available at $t = 1$
  - $m_k^{b_1}$, available at $t = 2,\ t = 3$
  - $m_k^{b_2}$, available at $t = 3$

An Example (cont.)

$$
\begin{aligned}
t = 1 \quad & \begin{cases} m_1^{a_1} = \alpha_1^{a_1} + \lambda_1^{a_1} \ln \theta_1 + \epsilon_1^{a_1} \\ m_1^{a_2} = \alpha_1^{a_2} + \lambda_1^{a_2} \ln \theta_1 + \epsilon_1^{a_2} \end{cases} \\
t = 2 \quad & \begin{cases} m_2^{a_1} = \alpha_2^{a_1} + \lambda_2^{a_1} \ln \theta_2 + \epsilon_2^{a_1} \\ m_2^{b_1} = \alpha_2^{b_1} + \lambda_2^{b_1} \ln \theta_2 + \epsilon_2^{b_1} \end{cases} \\
t = 3 \quad & \begin{cases} m_3^{b_1} = \alpha_3^{b_1} + \lambda_3^{b_1} \ln \theta_3 + \epsilon_3^{b_1} \\ m_3^{b_2} = \alpha_3^{b_2} + \lambda_3^{b_2} \ln \theta_3 + \epsilon_3^{b_2} \end{cases}
\end{aligned} \tag{1}
$$

- Normalization: $\alpha_1^{a_1} = \alpha_2^{a_1} = 0$ and $\lambda_1^{a_1} = \lambda_2^{a_1} = 1$.
- We can use the estimates of the intercept and factor loading of $m_2^{b_1}$ to express the location and scale of the latent factor at age 3 in the same metric.

An Example (cont.)

- Taking expectations of the first measure at $t = 1$ and $t = 2$ we get:

$$E(\ln \theta_1) = E(m_1^{a_1}) \qquad E(\ln \theta_2) = E(m_2^{a_1})$$

The factor mean in periods 1 and 2 is expressed in terms of the same measure.

- Using the measurement equation for $m_2^{b_1}$, we get: $\alpha_2^{b_1}$:

$$\alpha_2^{b_1} = E(m_2^{b_1}) - \lambda_2^{b_1} E(\ln \theta_2)$$

- Using the measurement equation for $m_3^{b_1}$:

$$E(\ln \theta_3) = \frac{E(m_3^{b_1}) - \alpha_3^{b_1}}{\lambda_3^{b_1}}$$

- Imposing $\alpha_2^{b_1} = \alpha_3^{b_1}$ and $\lambda_2^{b_1} = \lambda_3^{b_1}$ and substituting, we get:

$$E(\ln \theta_3) = E(\ln \theta_2) + \frac{E(m_3^{b_1}) - E(m_2^{b_1})}{\lambda_2^{b_1}}$$

- So that θ_3 is expressed in the same metric as θ_2 and θ_1.

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Identification Assumption

The crucial assumption is local:

> *A measure has the same factor loading and intercept across adjacent ages where it is administered.*

Not required:

- same informativeness across the entire childhood period;
- same factor loading from age 1 to age 7.

This is both flexible and empirically plausible.

Why the Normalization Matters

The procedure delivers:

- Comparable factor means over time.
- Comparable factor variances over time.
- Meaningful estimates of growth.
- Consistent estimates of persistence.
- Age-specific production functions.

Without a common metric, the main dynamic results would not be interpretable.

Outline

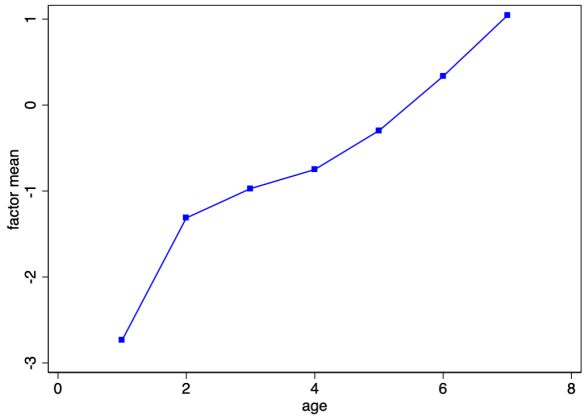
Latent Factor Moments

	Mean						
	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7
Cognitive factor	-2.73	-1.52	-0.10	-0.72	-0.25	0.33	1.04
Socio-emotional factor	0.048	-0.107	-0.319	-0.284	0.02	0.118	-
Health factor	-1.71	-1.113	-0.732	-0.339	0.079	0.496	1.039

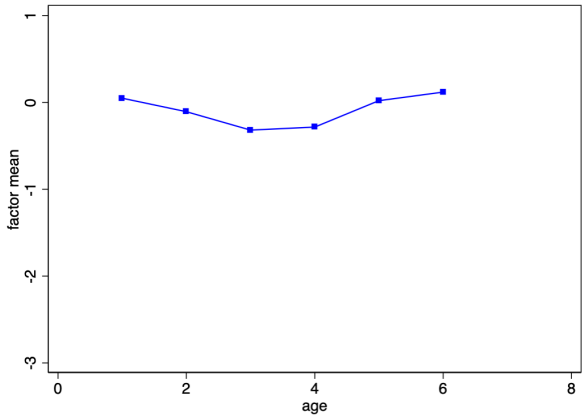
	St Dev.						
	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7
Cognitive factor	0.55	0.36	0.26	0.29	0.41	0.60	0.60
Socio-emotional factor	0.45	0.35	0.43	0.51	0.47	0.65	-
Health factor	0.39	0.29	0.32	0.34	0.39	0.58	0.73

Table: Evolution of the latent factors mean and standard deviations with age

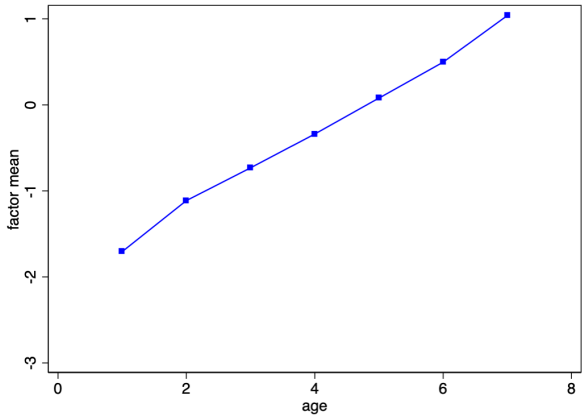
Latent Factor Means Over Time



(a) Cognitive factor



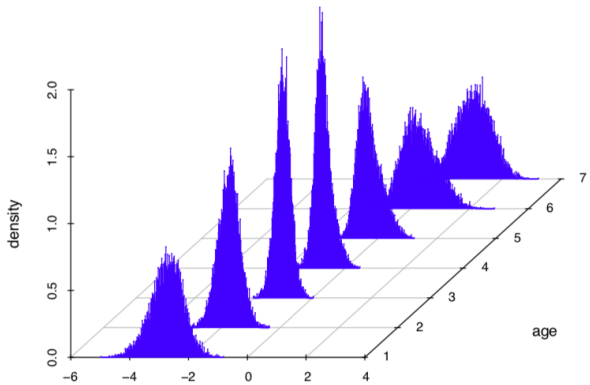
(b) Socio-emotional factor



(c) Health factor

Figure: Latent Factors' Means Over Time

Results: Latent Factor Distributions Over Time



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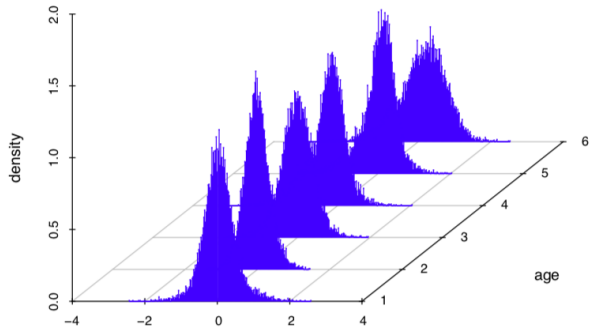

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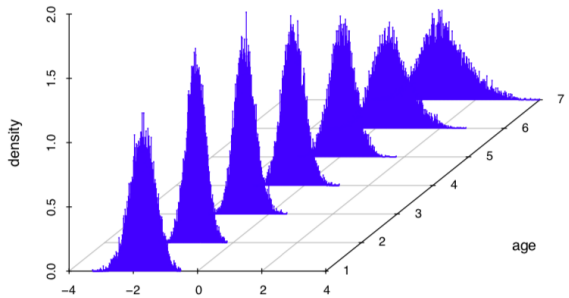

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(a) Cognitive factor

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Figure: Latent Factors' Distributions Over Time

Investment function

	Investment equations					
	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7
Cognition t	0.084	0.026	-0.099	0.115	0.147	0.093
	0.078	0.087	0.054	0.091	0.077	0.062
	[-0.045,0.205]	[-0.081,0.202]	[-0.198,-0.01]	[-0.014,0.268]	[0.035,0.279]	[-0.01,0.179]
Socio-emotional t	-0.231	-0.05	-0.027	-0.01	0.11	0.022
	0.29	0.114	0.036	0.051	0.07	0.049
	[-0.392,0.491]	[-0.163,0.199]	[-0.088,0.023]	[-0.071,0.088]	[0.027,0.25]	[-0.039,0.123]
Health t	0.045	0.201	0.085	0.118	0.018	0.043
	0.125	0.103	0.067	0.066	0.054	0.040
	[-0.155,0.248]	[-0.024,0.302]	[0,0.217]	[-0.001,0.216]	[-0.072,0.114]	[-0.016,0.118]
Parental Cognition	0.062	0.059	0.233	0.229	0.350	0.357
	0.125	0.114	0.067	0.064	0.092	0.095
	[0.011,0.405]	[0.007,0.377]	[0.144,0.345]	[0.140,0.341]	[0.191,0.489]	[0.192,0.493]
Number of Children	-0.259	-0.296	-0.314	-0.317	-0.329	-0.347
	0.115	0.083	0.058	0.059	0.072	0.071
	[-0.445,-0.057]	[-0.404,-0.143]	[-0.391,-0.197]	[-0.375,-0.177]	[-0.395,-0.157]	[-0.409,-0.176]
Income	0.185	0.197	0.233	0.232	0.175	0.179
	0.067	0.061	0.044	0.043	0.043	0.044
	[0.064,0.274]	[0.075,0.268]	[0.150,0.290]	[0.140,0.277]	[0.082,0.227]	[0.085,0.232]
Household size	-0.293	-0.295	-0.106	-0.091	-0.056	-0.063
	0.077	0.065	0.044	0.043	0.067	0.067
	[-0.414,-0.168]	[-0.390,-0.184]	[-0.166,-0.015]	[-0.146,-0.002]	[-0.156,0.057]	[-0.161,0.052]
Father present	0.149	0.145	0.126	0.135	0.104	0.120
	0.040	0.040	0.023	0.024	0.030	0.028
	[0.082,0.211]	[0.087,0.208]	[0.076,0.150]	[0.065,0.139]	[0.030,0.124]	[0.047,0.133]

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	[0.064,0.274]	[0.075,0.268]	[0.150,0.290]	[0.140,0.277]	[0.082,0.227]	[0.085,0.232]
Household size	-0.293	-0.295	-0.106	-0.091	-0.056	-0.063
	0.077	0.065	0.044	0.043	0.067	0.067
	[-0.414,-0.168]	[-0.390,-0.184]	[-0.166,-0.015]	[-0.146,-0.002]	[-0.156,0.057]	[-0.161,0.052]
Father present	0.149	0.145	0.126	0.135	0.104	0.120
	0.040	0.040	0.023	0.024	0.030	0.028
	[0.082,0.211]	[0.087,0.208]	[0.076,0.150]	[0.065,0.139]	[0.030,0.124]	[0.047,0.133]

Investment function

	Investment equations					
	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7
Cognition t	0.084	0.026	-0.099	0.115	0.147	0.093
	0.078	0.087	0.054	0.091	0.077	0.062
	[-0.045,0.205]	[-0.081,0.202]	[-0.198,-0.01]	[-0.014,0.268]	[0.035,0.279]	[-0.01,0.179]
Socio-emotional t	-0.231	-0.05	-0.027	-0.01	0.11	0.022
	0.29	0.114	0.036	0.051	0.07	0.049
	[-0.392,0.491]	[-0.163,0.199]	[-0.088,0.023]	[-0.071,0.088]	[0.027,0.25]	[-0.039,0.123]
Health t	0.045	0.201	0.085	0.118	0.018	0.043
	0.125	0.103	0.067	0.066	0.054	0.040
	[-0.155,0.248]	[-0.024,0.302]	[0,0.217]	[-0.001,0.216]	[-0.072,0.114]	[-0.016,0.118]
Parental Cognition	0.062	0.059	0.233	0.229	0.350	0.357
	0.125	0.114	0.067	0.064	0.092	0.095
	[0.011,0.405]	[0.007,0.377]	[0.144,0.345]	[0.140,0.341]	[0.191,0.489]	[0.192,0.493]
Number of Children	-0.259	-0.296	-0.314	-0.317	-0.329	-0.347
	0.115	0.083	0.058	0.059	0.072	0.071
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Household size	-0.293	-0.295	-0.106	-0.091	-0.056	-0.063
	0.077	0.065	0.044	0.043	0.067	0.067
	[-0.414,-0.168]	[-0.390,-0.184]	[-0.166,-0.015]	[-0.146,-0.002]	[-0.156,0.057]	[-0.161,0.052]
Father present	0.149	0.145	0.126	0.135	0.104	0.120
	0.040	0.040	0.023	0.024	0.030	0.028
	[0.082,0.211]	[0.087,0.208]	[0.076,0.150]	[0.065,0.139]	[0.030,0.124]	[0.047,0.133]

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Parental Cognition	0.062	0.059	0.233	0.229	0.350	0.357
	0.125	0.114	0.067	0.064	0.092	0.095
	[0.011,0.405]	[0.007,0.377]	[0.144,0.345]	[0.140,0.341]	[0.191,0.489]	[0.192,0.493]
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Production Function for Cognitive Skills
Exogenous Investments

	Cognitive $t+1$					
	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7
TFP	-0.19	0.155	-0.135	0.44	0.552	0.74
	0.16	0.11	0.03	0.054	0.043	0.05
AeioTu	-0.13	0.034	0.03	0.068	0.025	0.05
	0.081	0.056	0.013	0.018	0.045	0.042
Cognitive t	0.30	0.501	0.436	1.021	1.138	0.908
	0.067	0.081	0.039	0.085	0.059	0.048
Socio-emotional t	0.08	0.158	0.058	-0.06	0.007	0.058
	0.103	0.075	0.023	0.031	0.036	0.043
Health t	0.39	0.238	0.293	0.006	-0.065	-0.062
	0.12	0.103	0.048	0.063	0.044	0.034
Parental cognition	0.02	0.013	0.102	-0.011	-0.031	0.101
	0.089	0.054	0.031	0.036	0.045	0.045
Investments	0.20	0.091	0.111	0.043	-0.05	-0.005
	0.085	0.068	0.041	0.042	0.053	0.045

Production Function for Cognitive Skills
Endogenous Investments

	Cognitive $t+1$					
	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7
TFP	-0.29	0.027	-0.176	0.481	0.548	0.739
	0.154	0.114	0.044	0.07	0.05	0.05
Control function	-0.22	-0.268	-0.132	0.133	-0.028	-0.061
	0.145	0.102	0.098	0.113	0.161	0.12
AeioTu	-0.11	0.046	0.03	0.068	0.026	0.056
	0.078	0.051	0.013	0.018	0.046	0.045
Cognitive t	0.30	0.494	0.423	1.051	1.133	0.898
	0.067	0.082	0.042	0.10	0.072	0.054
Socio-emotional t	0.08	0.121	0.046	-0.043	0.002	0.053
	0.101	0.074	0.028	0.035	0.049	0.044
Health t	0.35	0.161	0.267	0.024	-0.066	-0.066
	0.116	0.097	0.055	0.063	0.045	0.035
Parental cognition	0.00	-0.008	0.061	0.025	-0.04	0.079
	0.089	0.061	0.044	0.046	0.068	0.064
Investments	0.27	0.231	0.203	-0.057	-0.03	0.036
	0.12	0.103	0.092	0.103	0.145	0.097

Cognitive Development: Key Parameters

Age	2	3	4	5	6	7
Persistence	0.300	0.494	0.423	1.051	1.133	0.898
	(0.067)	(0.082)	(0.042)	(0.10)	(0.072)	(0.054)
Investment	0.270	0.231	0.203	−0.057	−0.030	0.036
	(0.120)	(0.103)	(0.092)	(0.103)	(0.145)	(0.097)
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- Instrumenting (via income...) is key for the significance of parental investment.
- Persistence roughly triples between ages 2–4 and ages 5–7.
- Investment matters only up to about age 4.
- Parental cognition is not directly important, ... but it affects investment.

Implication:

Early interventions generate larger impacts on cognition.

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Implication:

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Socio-emotional Development: Key Parameters

Age	2	3	4	5	6
Persistence	0.260	0.707	0.361	0.345	0.316
	(0.148)	(0.229)	(0.089)	(0.075)	(0.109)
Investment	0.600	0.415	0.506	0.654	0.354
	(0.232)	(0.246)	(0.203)	(0.243)	(0.286)

- Persistence does not increase monotonically with age.
- Investment remains important through age 5.
- Unlike cognition, socio-emotional skills remain malleable at later ages.

Health: Key Parameters

Age	2	3	4	5	6	7
Persistence (H_t)	> 0.7	high	high	≈ 1	≈ 1	≈ 1
Investment (I_t)	0.37	0	0	0	0	0

- Health is highly persistent.
- Parental investment matters only at age 2.
- Early health investments have long-lasting effects because of persistence.

What Changes with Age?

Dimension	Persistence	Investment Productivity
Cognition	Rises sharply after age 4	Falls to zero after age 4
Socio-emotional	Roughly stable	Remains large through age 5
Health	Very high from early ages	Only important at age 2

Key message:
Different dimensions exhibit very different windows of opportunity.

Why Annual Data Matter

The annual frequency reveals patterns that would be hidden in lower-frequency datasets.

- Rapid changes in persistence.
- Changing productivity of parental investments.
- Different sensitive periods across developmental domains.

The technology of skill formation is not constant over childhood.

Outline

Identification of windows of opportunities

- The estimation results can be used to identify periods during which policy interventions may be more effective.
- We think of policies that can increase parental investment.
- The results can also quantify the effect of different interventions and their timings.

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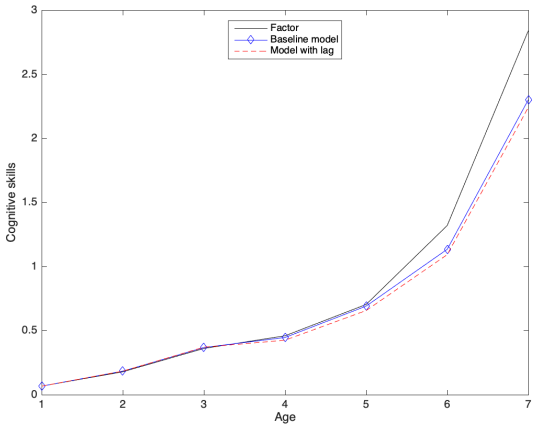
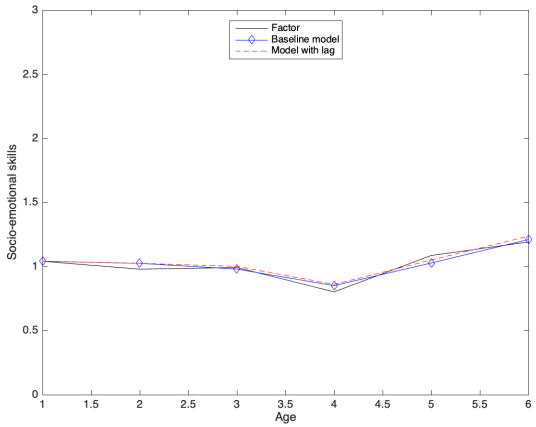
Model fit

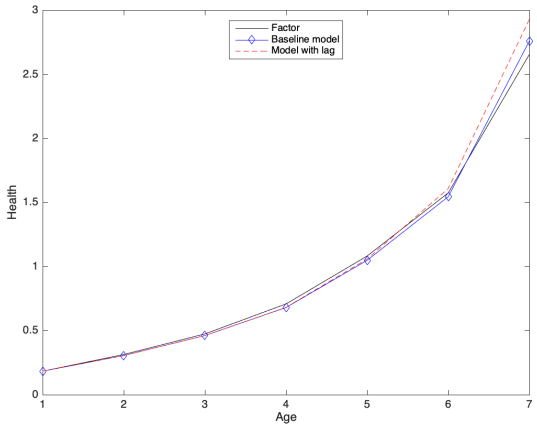
- We start by considering how well the model fits
- We report the results of additional models that include two lags of past development.



(a) Cognitive skills



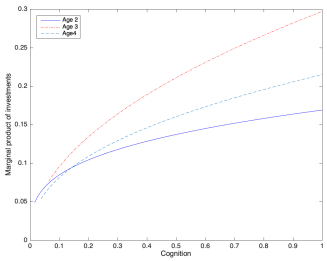
(b) Socio-emotional skills

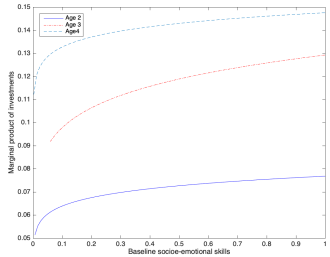


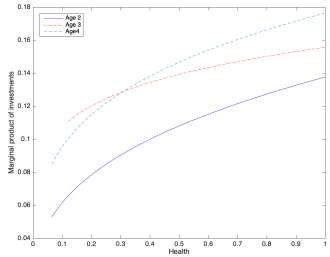
(c) Health

Figure: Evolution of Skills Over Time (Model Estimates)

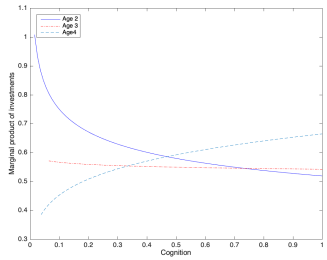
Marginal product of investment

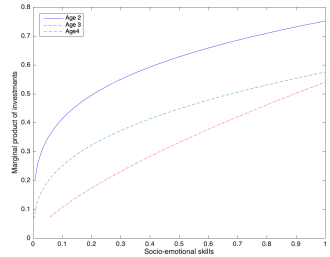


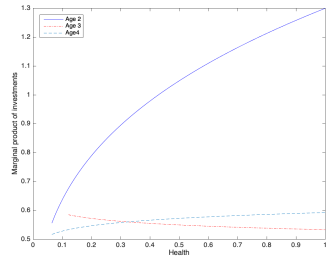




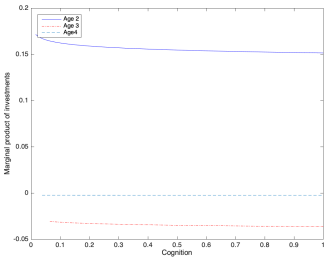
(a) Cognitive skills

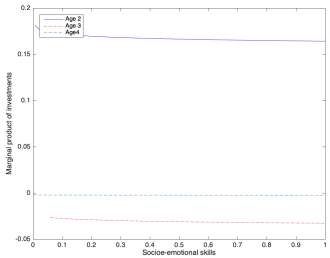


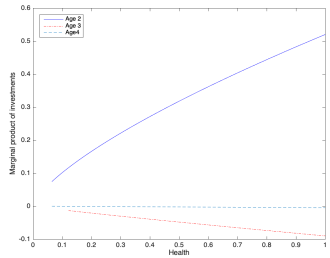




(b) Socio-emotional skills

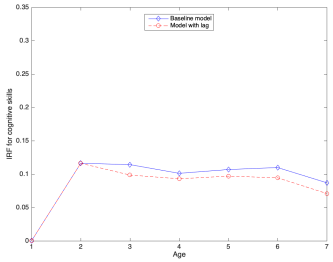




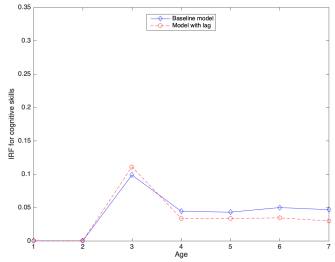


(c) Health

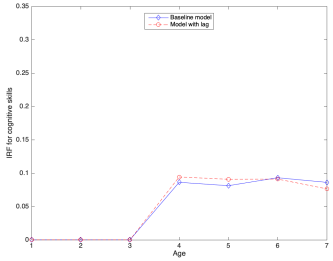
Impulse response functions: cognition



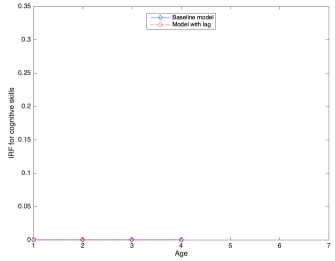
(a) Increase in investment at age 2



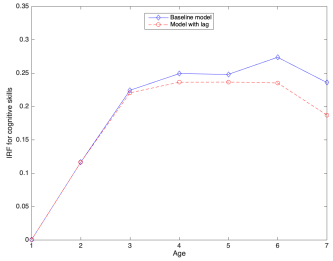
(b) Increase in investment at age 3



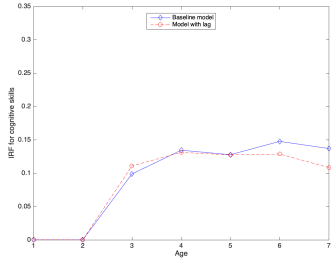
(c) Increase in investment at age 4



(d) Increase in investment at age 5

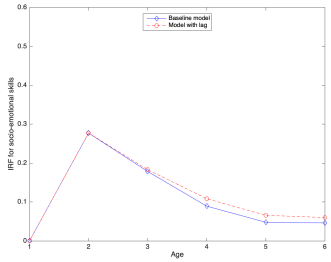


(e) Increase in investment at age 2, 3 and 4

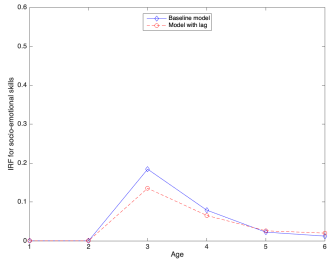


(f) Increase in investment at age 3 and 4

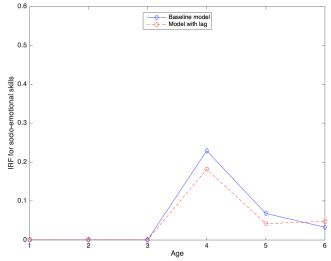
Impulse response functions: socio emotional



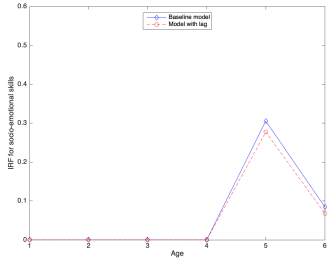
(a) Increase in investment at age 2



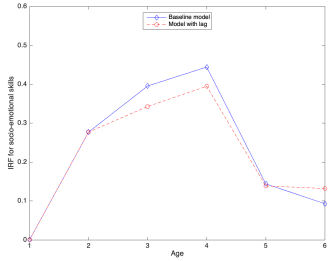
(b) Increase in investment at age 3



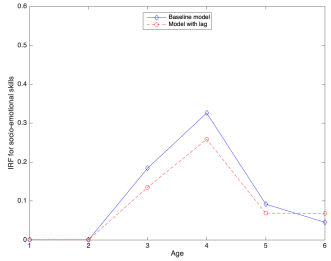
(c) Increase in investment at age 4



(d) Increase in investment at age 5

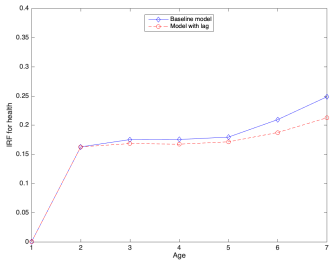


(e) Increase in investment at age 2, 3 and 4

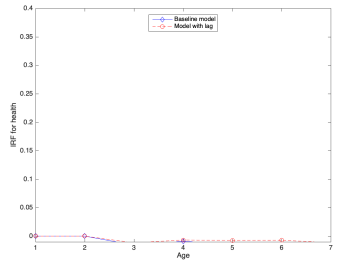


(f) Increase in investment at age 3 and 4

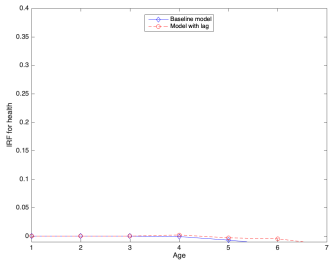
Impulse response functions: health



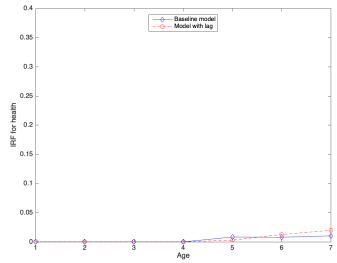
(a) Increase in investment at age 2



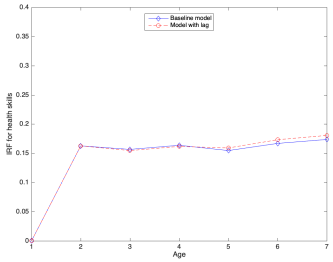
(b) Increase in investment at age 3



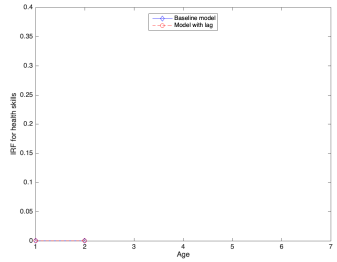
(c) Increase in investment at age 4



(d) Increase in investment at age 5



(e) Increase in investment at age 2, 3 and 4



(f) Increase in investment at age 3 and 4

Outline

Takeaways

1. This is the first paper to estimate child development dynamics at such high frequency.
2. Persistence and investment productivity evolve substantially with age.
3. The normalization strategy is a fundamental contribution:
   - creates a common metric,
   - permits growth comparisons,
   - allows meaningful estimation of dynamics.
4. The timing of investment matters:
   - For cognition early and persistent (ages 2 to 4) is the most effective;
   - For socioemotional: early and persistent is also important
   - For health: age 2 is key: driven by the increase in persistence.