Preschool developmental dynamics: Evidence from the Infant Health and Development Program

Aaron Sojourner

joint with Jeanne Brooks-Gunn, Flavio Cunha, Greg Duncan, James Heckman & Pamela Klebanov

University of Minnesota
Carlson School of Management

October 20, 2009

Best mix of earlier and later investment?

"There is no question that enriched inputs can lead to enhanced learning, at least on a short-term basis.... However, it is not clear what the longer-term implications of such inputs are, nor which skills are being transmitted. It is also not clear that early learning is any more efficient, enduring, or effective than later learning."

— Shonkoff et al (2000), *Neurons to Neighborhoods*, NAS/NRC

- Questions:
  - Given a fixed budget, what's the best way to spread investment across preschool ages?
  - How does the level of early (before 3) investment change the impact of later (3-5) investment?
  - What explains consistent pattern of large cognitive treatment effects and (partial) fade-out? (Karoly et al, 1998; Waldfogel, 2002; Ryan et al, 2006)
- Conclusions:
  - Depreciation of investments explains much of fade-out.
  - Masks moderate complementarity of early for late investments.
  - Best to balance investments over ages to some extent.

Ideal experiment to separate effect of level from effect of timing

Treatment	Level of investment Early	Late
Front loaded	1	0
Back loaded	0	1
Balanced	α	$(1-\alpha)$
Control	0	0

Which path of investment would produce the biggest effects on outcomes? Effects compared to control?

How is this study different than all other studies?

- **Experiments** have not separated timing of investment from level. Compare control to
  - Front-loaded: Early Head Start, IHDP
  - Back-loaded: Head Start, Perry, Chicago CPC
  - Balanced: Abecedarian
- **Model with observational data** can study timing but worry about causal inference.
- IHDP has randomly-assigned early investment, well-measured (but endogenous) late investment, and good long-term outcomes.

Early×Late interaction crucial for optimal investment timing

- More is better than less but, given any fixed amount, the best balance between early and late depends on:

Early×Late interaction crucial for optimal investment timing

- More is better than less but, given any fixed amount, the best balance between early and late depends on:
  - comparison of the direct effects of early versus late investment on outcomes, and

Early$\times$Late interaction crucial for optimal investment timing

- More is better than less but, given any fixed amount, the best balance between early and late depends on:
  - comparison of the direct effects of early versus late investment on outcomes, and
  - indirect effect of early through changing the productivity of later investments.

Early×Late interaction crucial for optimal investment timing

- More is better than less but, given any fixed amount, the best balance between early and late depends on:
  - comparison of the direct effects of early versus late investment on outcomes, and
  - indirect effect of early through changing the productivity of later investments.
- How do higher levels of early investment affect the productivity of later investment?

Early$\times$Late interaction crucial for optimal investment timing

- More is better than less but, given any fixed amount, the best balance between early and late depends on:
  - comparison of the direct effects of early versus late investment on outcomes, and
  - indirect effect of early through changing the productivity of later investments.
- How do higher levels of early investment affect the productivity of later investment?
  - Raise productivity: "skill-begets-skill." Positive interaction.

Early×Late interaction crucial for optimal investment timing

- More is better than less but, given any fixed amount, the best balance between early and late depends on:
  - comparison of the direct effects of early versus late investment on outcomes, and
  - indirect effect of early through changing the productivity of later investments.
- How do higher levels of early investment affect the productivity of later investment?
  - Raise productivity: "skill-begets-skill." Positive interaction.
  - No productivity effect: Zero interaction.

Early×Late interaction crucial for optimal investment timing

- More is better than less but, given any fixed amount, the best balance between early and late depends on:
  - comparison of the direct effects of early versus late investment on outcomes, and
  - indirect effect of early through changing the productivity of later investments.
- How do higher levels of early investment affect the productivity of later investment?
  - Raise productivity: "skill-begets-skill." Positive interaction.
  - No productivity effect: Zero interaction.
  - Lower productivity: diminishing-returns. Negative interaction.

IHDP Sample

Prospective random sample from

- Research hospitals in 8 cities

IHDP Sample

Prospective random sample from

- Research hospitals in 8 cities
- Enrolled 985 families delivering babies
  - Low birth weight: $\leq$ 2500 grams
  - Premature: $\leq$ 37 weeks

IHDP Sample

Prospective random sample from

- Research hospitals in 8 cities
- Enrolled 985 families delivering babies
  - Low birth weight: $\leq$ 2500 grams
  - Premature: $\leq$ 37 weeks
- We focus on the higher birth weight (2001 - 2500 g) HLBW subsample, $N = 362$.

IHDP Sample

Prospective random sample from

- Research hospitals in 8 cities
- Enrolled 985 families delivering babies
  - Low birth weight: $\leq$ 2500 grams
  - Premature: $\leq$ 37 weeks
- We focus on the higher birth weight (2001 - 2500 g) HLBW subsample, $N = 362$.
- Everyone got pediatric care from birth to age 3, feedback from battery of intensive testing, and referrals to social services

IHDP experimental treatment

Age 0 to 1

- Weekly home visits from clinically-trained staff to
    - develop parenting skills and child development knowledge
    - monitor and defuse issues and help family cope

IHDP experimental treatment

Age 0 to 1

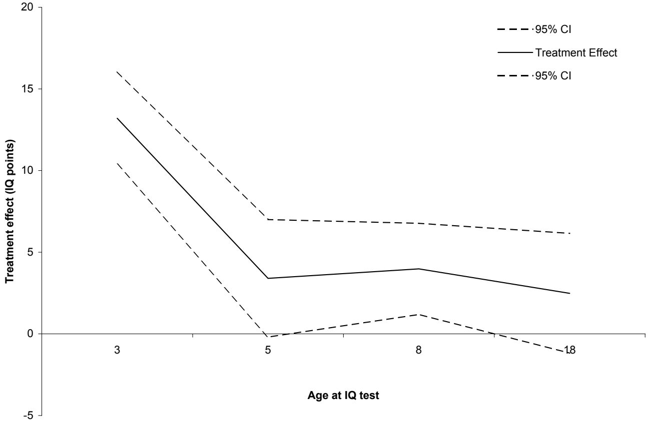
- Weekly home visits from clinically-trained staff to
  - develop parenting skills and child development knowledge
  - monitor and defuse issues and help family cope

Age 1 to 3

- Home visits bimonthly
- Childcare available
  - high-quality
  - full-day
  - free and free transportation

Variable	Mean	Std. Dev.	Obs. of 362	β_{Tr}
Age-1 IQ (θ_1)	111.6	15.5	330	2.5
Age-3 IQ (θ_3)	89.8	19.9	328	14.2***
Age-5 IQ (θ_5)	93.5	17.6	295	3.6**
Age-1 Home env. (H_1)	0.1	1.0	322	0.0
Age-3 Home env. (H_3)	0.0	1.0	298	0.4***
1(Treatment) (Tr)	0.39		362	
Maternal				
Maternal IQ (θ^c_M)	82.7	21.1	316	1.1
1(Ed $<$ High Sch Grad.)	0.41		362	0.12**
1(Ed $=$ HS grad)	0.26		362	0.02
1(Ed $=$ Some Coll)	0.19		362	-0.12***
1(Ed $=$ Coll Grad)	0.14		362	-0.02
1(Black)	0.48		362	-0.04
1(Hispanic)	0.12		362	-0.02
Age at child's birth	24.7	6.1	362	-0.9

Effect of IHDP's age 0-3 investments on cognitive skills from age 3 to 18

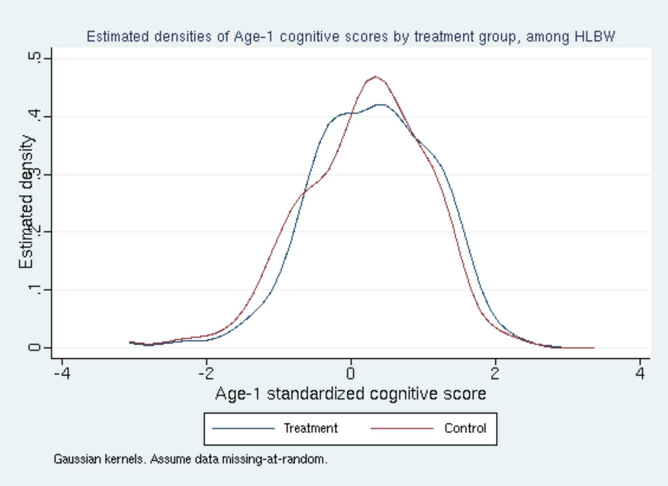


Note: Treatment effects estimated with linear controls for maternal IQ, race/ethnicity, age at birth, child birth weight, gest. age, neonatal health index, and site and within-site-corrected standard errors. HLBW is birthweight 2001-2500 g.

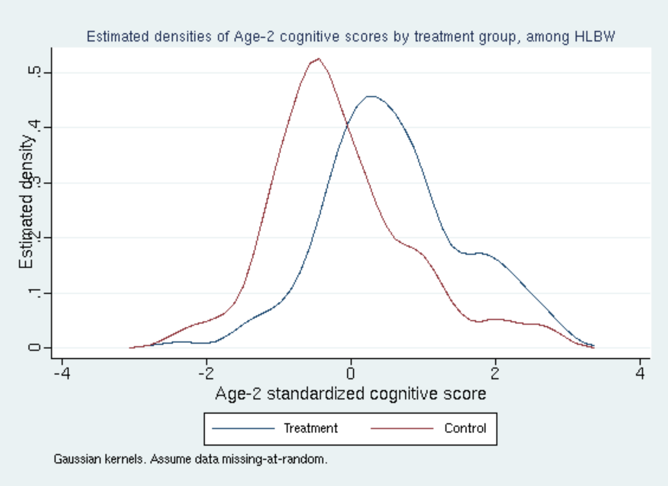
What happened?

What developmental process underlies this pattern?

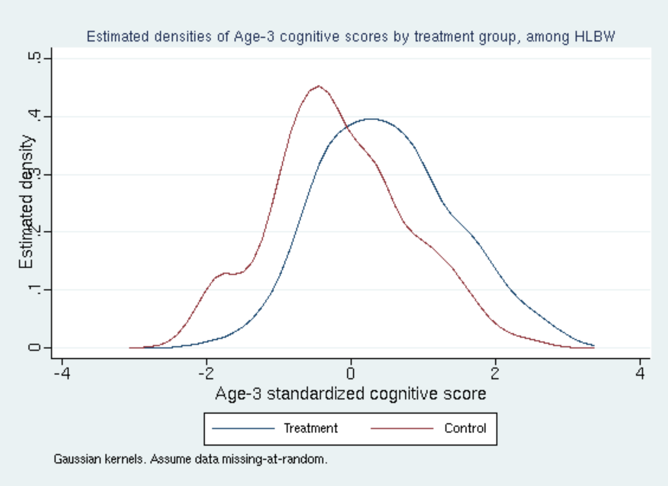
Age 1 IQ distributions by treatment group after a year of weekly home visits



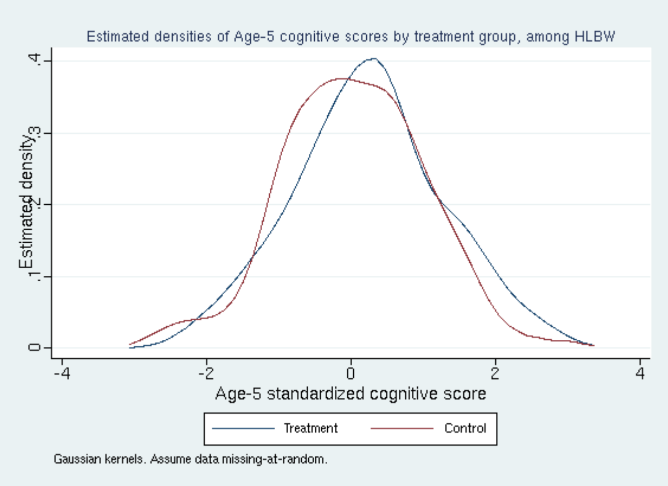
Age 2 IQ distributions by treatment group after a year of free high-quality childcare



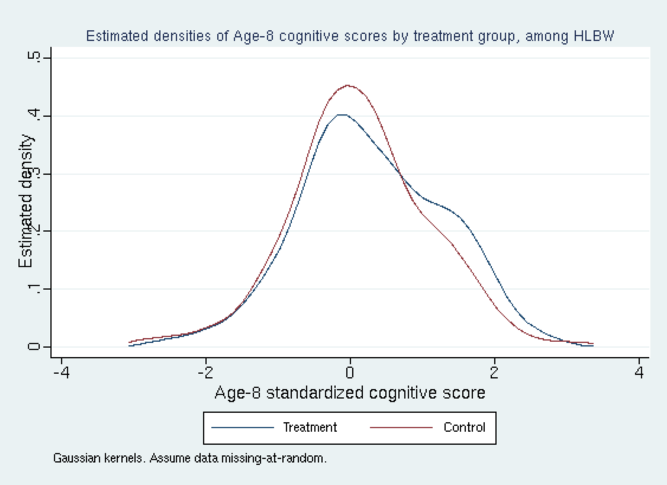
Age 3 IQ distributions by treatment group after 2 years of childcare



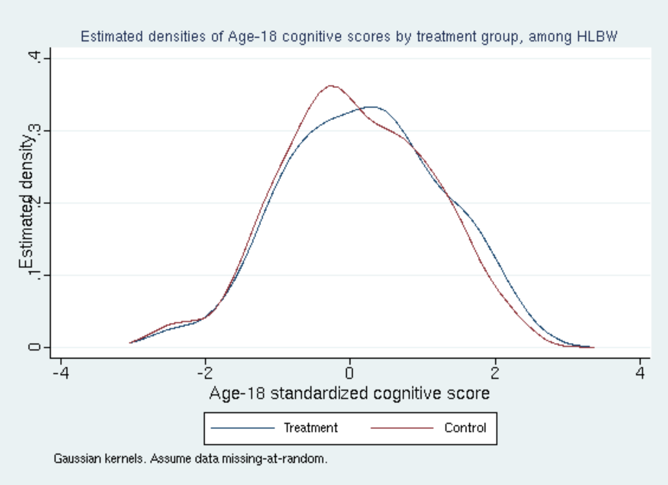
Age 5 IQ distributions by treatment group at school-entry, 2 years after treatment ends



Age 8 IQ distributions by treatment group 5 years after treatment ends



Age 18 IQ distributions by treatment group



Variables

- θ_a: age-a IQ

Variables

- θ_a: age-a IQ
- I_a: time-varying investments, e.g. quality of childcare, home environment, maternal interactions
  - I_1: **early** investment (treatment, Age-1 HOME)
  - I_3: **late** investment (HOME and parenting skills measured age 3-5)

Variables

- θ_a: age-a IQ
- I_a: time-varying investments, e.g. quality of childcare, home environment, maternal interactions
    - I_1: **early** investment (treatment, Age-1 HOME)
    - I_3: **late** investment (HOME and parenting skills measured age 3-5)
- X: fixed characteristics (birth weight, maternal IQ...)

Variables

- θ_a: age-a IQ
- I_a: time-varying investments, e.g. quality of childcare, home environment, maternal interactions
  - I_1: **early** investment (treatment, Age-1 HOME)
  - I_3: **late** investment (HOME and parenting skills measured age 3-5)
- X: fixed characteristics (birth weight, maternal IQ...)
- ϵ_a: unobserved influences on IQ

Path-of-influences production

$$\theta_3 = \alpha_0 + \alpha_{I_1} I_1 + \alpha_X X + \epsilon_1$$
$$\theta_5 = \beta_0 + \beta_{I_1} I_1 + \beta_{I_3} I_3 + \beta_{I_1 I_3} I_1 I_3 + \beta_X X + \epsilon_3$$

- *Compensation.* $\bar{I}_3^C > \bar{I}_3^T$ compensates for $\bar{I}_1^C < \bar{I}_1^T$.

Path-of-influences production

$$\theta_3 = \alpha_0 + \alpha_{I_1} I_1 + \alpha_X X + \epsilon_1$$

$$\theta_5 = \beta_0 + \beta_{I_1} I_1 + \beta_{I_3} I_3 + \beta_{I_1 I_3} I_1 I_3 + \beta_X X + \epsilon_3$$

- *Compensation*. $\bar{I}_3^C > \bar{I}_3^T$ compensates for $\bar{I}_1^C < \bar{I}_1^T$.
- *Diminishing-returns*: $\beta_{I_1 I_3} < 0$. Late investment more productive for controls due to less early investment.

Path-of-influences production

$$\theta_3 = \alpha_0 + \alpha_{I_1} I_1 + \alpha_X X + \epsilon_1$$
$$\theta_5 = \beta_0 + \beta_{I_1} I_1 + \beta_{I_3} I_3 + \beta_{I_1 I_3} I_1 I_3 + \beta_X X + \epsilon_3$$

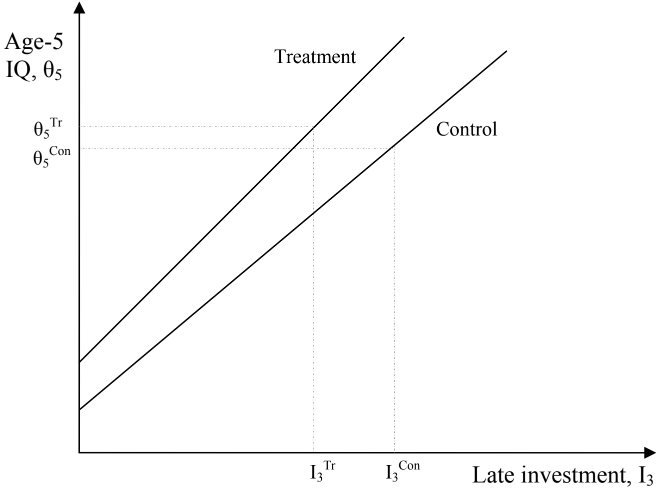
- *Compensation*. $\bar{I}_3^C > \bar{I}_3^T$ compensates for $\bar{I}_1^C < \bar{I}_1^T$.
- *Diminishing-returns*: $\beta_{I_1 I_3} < 0$. Late investment more productive for controls due to less early investment.
- *Depreciation*: $\alpha_{I_1} >> \beta_{I_1}$. Early investment matters less for age-5 than age-3 IQ.

Path-of-influences production

$$\theta_3 = \alpha_0 + \alpha_{I_1} I_1 + \alpha_X X + \epsilon_1$$
$$\theta_5 = \beta_0 + \beta_{I_1} I_1 + \beta_{I_3} I_3 + \beta_{I_1 I_3} I_1 I_3 + \beta_X X + \epsilon_3$$

- *Compensation*. $\bar{I}_3^C > \bar{I}_3^T$ compensates for $\bar{I}_1^C < \bar{I}_1^T$.
- *Diminishing-returns*: $\beta_{I_1 I_3} < 0$. Late investment more productive for controls due to less early investment.
- *Depreciation*: $\alpha_{I_1} >> \beta_{I_1}$. Early investment matters less for age-5 than age-3 IQ.
- *Perfect-complements*: $\theta_5 = \min\{I_1, I_3\} + \epsilon_3$. Failure to follow high early with high late causes fade-out.

Compensation, $I_3^T < I_3^C$

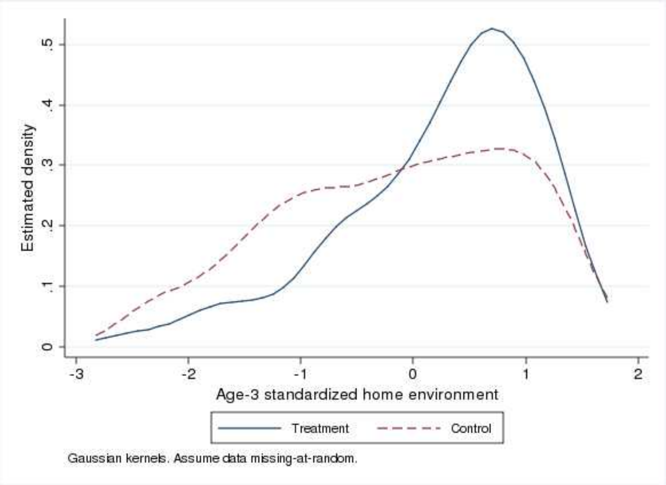


~~Compensation, $I_3^T < I_3^C$~~

Most "late" factors look equal between groups

- All fixed (observables and unobservables) of kids and families are balanced across groups by initial randomization
- Most observable time-varying characteristics look similar too
  - Maternal fertility: pregnancies, births, abortions, miscarriages
  - Changes in family structure
  - Maternal child development knowledge (KIDI) and beliefs (CODQ)
- Any differences (parenting quality and home environment) tends to favor treatment group

Compensation, $I_3^T < I_3^C$

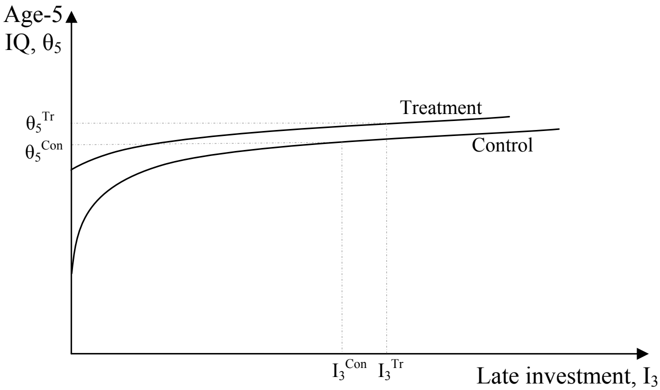


~~Compensation, $I_3^T < I_3^C$~~

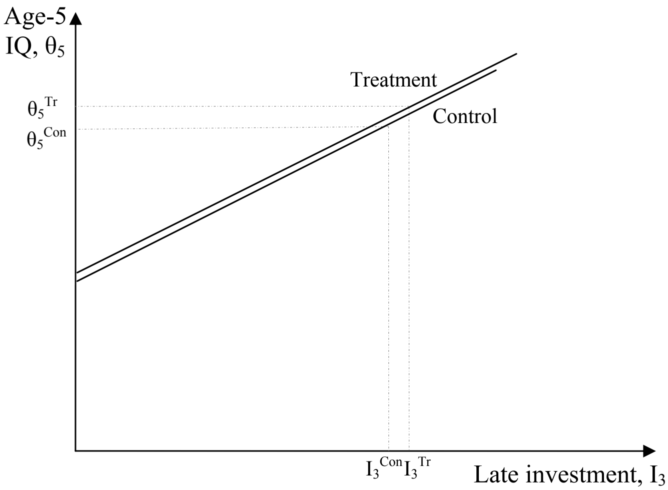
Variable, X	$\bar{X}_{Con}$	$\bar{X}_{Tr} - \bar{X}_{Con}$	β_{Tr}
Age-3 home environment			
1(child's toys teach color, size, shape)	0.52	0.19***	
1(child has at least 3 puzzles)	0.34	0.12**	
1(child has record player and 5 records)	0.28	-0.04	
1(child's toys permit free expression)	0.59	0.13**	
1(child's toys require refined movements)	0.53	0.07	
1(child's toys teach numbers)	0.59	0.02	
1(child encouraged to learn shapes)	0.53	0.27***	
1(child's toys teach names of animals)	0.88	0.03	
1(child encouraged to learn colors)	0.76	0.14***	
1(child encouraged learn patterned speech)	0.86	0.00	
1(child encouraged learn spatial relations)	0.74	0.08*	
1(child encouraged to learn numbers)	0.87	0.06*	
1(child encouraged to learn to read)	0.26	0.09	
1(child has musical instrument)	0.65	0.00	
Standardized first factor (H_3)	-0.13	0.38***	0.43***
Age-5 home environment			
I(3 or more TVs in house)	0.48	-0.12**	
I(Dictionary in house)	0.95	-0.08***	
I(Bought > 12 books for child in prev. year)	0.44	0.04	
Freq. 8 types of adult-child actvts.	4.6	0.19***	
Home Literacy index	2.0	0.02	

Significance levels: *: 10%, **: 5%, ***: 1%.

Diminishing returns, $\beta_{I_1 I_3} < 0$



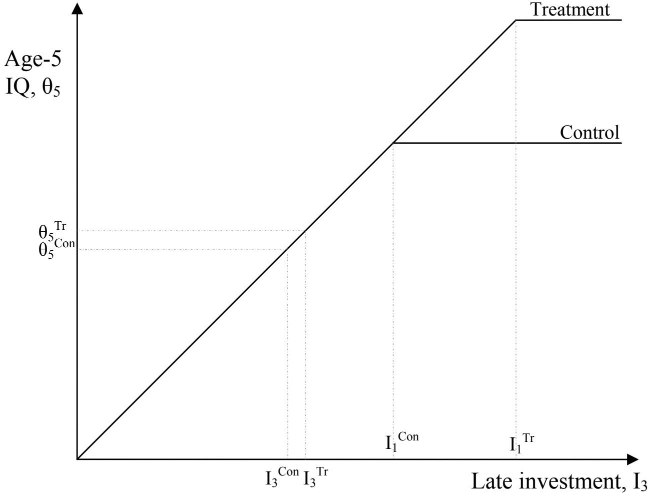
Depreciation $\alpha_{I_1} >> \beta_{I_1}$



Dependent variable	Age-3 IQ z-score (θ_3^c)	Age-5 IQ z-score (θ_5^c)
I(Treatment) (Tr)	0.93*** (0.12)	0.03 (0.11)
Age-3 Home env. (H_3)		0.18*** (0.06)
$H_3 \cdot Tr$		0.18* (0.11)
Maternal IQ (θ_M^c)	0.09 (0.06)	0.13** (0.05)
I(MatEd $<$ HS)	-0.14 (0.15)	-0.10 (0.13)
I(MatEd $=$ Some Coll)	0.59*** (0.18)	0.66*** (0.16)
I(MatEd $=$ Coll Grad)	1.13*** (0.24)	0.70*** (0.21)
I(Male)	-0.27** (0.12)	-0.19* (0.10)
I(Black)	-0.58*** (0.17)	-0.50*** (0.15)
I(Hispanic)	-0.97*** (0.26)	-0.66*** (0.23)
Adj. R^2	0.54	0.53
N	254	254

Coefficient (SE). Significance: $*$: 10% $**$: 5% $***$: 1%
Specifications also include a constant, birth weight, gestational age at birth, maternal age at birth, neonatal health index and site dummies.

Perfect complements, $\theta_5^c = \min\{I_1, I_3\}$



Constant Elasticity of Substitution production

$$\theta_5 = \beta[\Psi(\theta_3)^\nu + (1-\Psi)(I_3)^\nu]^{\frac{\rho}{\nu}} \epsilon_3$$

- Perfect-complements $\Leftrightarrow$ $(\nu = -\infty)$.
  95% confidence intervals of $\hat{\nu}$ above -2.5.
- Diminishing-returns $\Leftrightarrow$ $(\rho - \nu < 0)$.
  Estimates usually positive. Never significantly different than zero.

Limitations

- Endogenous late investment
  - Instrument late investment with birth order | family size
  - Instrument late investment with birthday
  - Model parental choice
- Generalizability from HLBW sample
- Low power/small sample: bring in CNLSY comparison group
- Include effect of health services using CNLSY kids outside recruitment window

Conclusions

- Strong evidence against two potential explanations of fade-out: compensation and diminishing-returns.
- Weak evidence against perfect complements.
- Low self-productivity of age-3 skills (large depreciation of early investment) drives fade-out.
- May mask moderate complementarity between early and late investment.
- Future: Include other human capital stocks and anchor in more concrete outcomes.

Time-varying measures by age

Age	Cognitive (θ_a^c)	Noncognitive Attention (θ_a^n)	Home investment (H_a)
1	age-1 Bayley IQ, mental subscale	Factor from 3 items in age-1 Bayley IQ examiner rating	Factor from the 10 age-1 HOME Learning items
3	age-3 Stanford-Binet IQ, mental subscale	Factor from 8 items in age-3 Stanford-Binet IQ examiner rating	Factor from the 14 age-3 HOME Literacy items
5	age-5 WPPSI Full scale IQ		

Variable (X)	Mean ($\bar{X}$)	Std. Dev.	Min.	Max.	Obs. of 362	$\bar{X}_{Tr} - \bar{X}_{Con}$	β_{Tr}
Age-1 IQ (θ_1^c)	111.6	15.5	50	147	330	2.0	2.5
Age-2 IQ	99.4	20.4	50	150	322	14.4***	14.7***
Age-3 IQ (θ_3^c)	89.8	19.9	43	144	328	13.2***	14.2***
Age-5 IQ (θ_5^c)	93.5	17.6	45	144	295	3.5*	3.6**
Age-8 IQ	94.3	17.4	40	147	311	2.9	4.5***
Age-18 IQ	93.3	17.1	50	131	224	1.9	3.1*
Age-1 Attention (θ_1^n)	0.1	0.9	-3.0	2.4	330	0.2**	0.2*
Age-3 Attention (θ_3^n)	0.0	1	-2.5	1.9	329	0.2	0.2
Age-1 Home env. (H_1)	0.1	1.0	-2.6	1.5	322	-0.0	0.0
Age-3 Home env. (H_3)	0.0	1.0	-2.6	1.4	298	0.4***	0.4***
1(Treatment) (Tr)	0.39				362		
1(Male)	0.52				362	-0.05	
Birth weight	2256	139	2001	2500	362	1.6	
Gest. age at birth	34.9	1.5	30	38	362	0.8	
Neonatal health index	99	15	32	137	362	0.8	
Maternal							
Maternal IQ (θ_M^c)	82.7	21.1	46	144	316	-0.1	1.1
1(Ed $<$ High Sch Grad.)	0.41				362	0.12**	
1(Ed $=$ HS grad)	0.26				362	0.02	
1(Ed $=$ Some Coll)	0.19				362	-0.12***	
1(Ed $=$ Coll Grad)	0.14				362	-0.02	
1(Black)	0.48				362	-0.04	
1(Hispanic)	0.12				362	-0.02	
Age at child's birth	24.7	6.1	14	42	362	-0.9	

Spearman rank correlations

	θ_1^c	θ_3^c	θ_5^c	θ_1^n	θ_3^n	H_1	H_3	θ_M^c
Age-1 IQ, θ_1^c	1.00							
Age-3 IQ, θ_3^c	0.38*	1.00						
Age-5 IQ, θ_5^c	0.31*	0.72*	1.00					
Age-1 Attention, θ_1^n	0.47*	0.19*	0.18*	1.00				
Age-3 Attention, θ_3^n	0.16*	0.43*	0.44*	0.17*	1.00			
Age-1 Home Env., H_1	0.19*	0.48*	0.55*	0.12*	0.20*	1.00		
Age-3 Home Env., H_3	0.21*	0.57*	0.61*	0.12*	0.32*	0.58*	1.00	
Maternal IQ, θ_M^c	0.16*	0.46*	0.53*	0.03	0.26*	0.54*	0.47*	1.00
1(Treatment), Tr	0.06	0.32*	0.09	0.11	0.09	-0.00	0.18*	0.00

*: significantly different than zero at 5 percent level.