Marshall Lectures:
The Economics and Psychology of Human Development and Inequality
Lecture II:
Understanding the Origins of Inequality and Understanding Effective Interventions and the Channels Through Which They Work.

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The Marshall Lectures 2010-2011
Lady Mitchell Hall
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1. Multiple Abilities Generate Life Outcomes Through Multiple Channels
Human Capabilities Predict Outcomes

- Cognitive capacities at age $t$: $\theta^C_t$
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- Cognitive capacities at age $t$: $\theta_t^C$
- Personal and social skills ("noncognitive"): $\theta_t^N$
Human Capabilities Predict Outcomes

- Cognitive capacities at age $t$: $\theta_t^C$
- Personal and social skills ("noncognitive"): $\theta_t^N$
- Health: $\theta_t^H$
Outcomes for task $j$ at age $t$: 

\[ \text{Outcomes: } Y_{jt} = \phi_{jt}(\theta_C^t, \theta_N^t, \theta_H^t, e_{jt}, A_{jt}), \quad j = 1, \ldots, J, \quad t = 1, \ldots, T \]

\[ e_{jt} = \eta_{jt}(R_{jt}, A_{jt}), \]

where $R_{jt}$ are rewards to effort, and $A_{jt}$ are other background and situational factors.
Outcomes for task $j$ at age $t$:

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\[ e_t^j: \text{ effort applied to task } j \text{ at time } t. \]
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A Life Cycle Framework for Organizing Studies and Integrating the Evidence on Life Cycle Skill Formation

\[
\theta_t = (\theta_C, \theta_N, \theta_H) \text{ capacities at } t
\]

\[l_t: \text{ investment at } t\]

\[
\theta_{t+1} = f_t(\theta_t, l_t, \theta_{t,p})
\]

\[\theta_{t,p} \text{ is parental home environment.}\]
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2. Ability gaps among individuals and across socioeconomic groups open up at early ages and persist for both cognitive and noncognitive traits.
Trend in mean cognitive score by maternal education

Each score standardized within observed sample. Using all observations and assuming data missing at random. Source: Brooks-Gunn et al. (2006).
PEABODY standardized scores of vocabulary by household wealth and child’s age, by area in Colombia

Source: Longitudinal Colombian Survey, Universidad de los Andes (2010), prepared by Raquel Bernal
Average percentile rank on anti-social behavior score, by income quartile

(The higher the score, the worse are behavioral problems)
Gaps emerge in health. They *diverge* with age. A higher score is a worse health outcome.
Origins of Gaps

- Genes?
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- Genes?
- Family environments and family investment?
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- Schools?
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- Evidence from a variety of intervention studies suggests an important role for investments and family environments in determining adult capacities above and beyond genes, and also in interactions with the genes.
- Exact mechanisms are still being explored. This lecture is a progress report on what is known about these mechanisms.
- All of the evidence points to an important role for the family environments in shaping capabilities.
3. Child Rearing Environments Are Deteriorating in Many Countries Around the World
This is a source of concern because, as Marshall wrote, the family and especially the mother plays an important role in shaping the capabilities of children.
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Family Environments in the UK
Lone mother families with dependent children: 
by marital status, Great Britain

Comment: Children aged under 16, or aged 16 to 18 and in full-time education, in the family unit, and living in the household. Source: Office for National Statistics

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Comment: Children aged under 16 and those aged 16 to 18 who have never married and are in full-time education. Source: Office for National Statistics
Percentage of families with dependent children: by family type, UK

Married couple family: 65% (2001), 60% (2010)
Opposite sex cohabiting couple family: 11% (2001), 14% (2010)
Lone parent family: 24% (2001), 26% (2010)

Source: Office for National Statistics
Percentage of children in non traditional families by race, UK 2008

Comment: Children aged under 16 and those aged 16 to 18 who have never married and are in full-time education. Source: Office for National Statistics
Investment by Family Type
Cognitive Stimulation: Age 0-2, White, By Family Type

(a) Girls: Material Resource
(b) Boys: Material Resource
(c) Girls: Cognitive Stimulation
(d) Boys: Cognitive Stimulation
(e) Girls: Emotional Support
(f) Boys: Emotional Support

Source: Seong Hyeok Moon (2008) analysis of CNLSY data
Cognitive Stimulation: Age 0-2, White, By Family Income Quartile

Source: Seong Hyeok Moon (2008) analysis of CNLSY data
Cognitive Stimulation: Age 10-11, White, By Family Type


Females

Source: Seong Hyeok Moon (2008) analysis of CNLSY data
There Are Substantial Differences in Family Investment and Parenting Practices Across Ethnic Groups in the U.S.
Hispanic and Black PI in White Distribution: intact family, adjusted for mother’s education, age 0-3

Material Goods

Source: Moon (2010)
Hispanic and Black PI in White Distribution: intact family, adjusted for mother’s education, age 0-3

Cognitive Stimulation

Source: Moon (2010)
Hispanic and Black PI in White Distribution: intact family, adjusted for mother’s education, age 0-3

Emotional Support

Source: Moon (2010)
4. Epigenetics and the Role of Genes
Experience gets embodied in the biology of the organism.
Evidence on gene-environment interactions: experience gets under and stays under the skin.
Gene expression patterns in young and old identical twins

Source: Fraga, Ballestar et al. (2005)
Gene Expression is Triggered by Environments
CHILDHOOD MALTREATMENT
AGE 3-11 in Dunedin cohort

Maternal rejection (14%)
Harsh discipline (10%)
Caregiver changes (6%)
Physical abuse (4%)
Sexual abuse (12%)

Caspi, McClay et al. (2002).
IL6 GENOTYPE x MALTREATMENT > ADULT INFLAMMATION:
Gene x Environment interaction

Danese et al. (in preparation)

Source: Danese, Moffitt et al. (2008)
Open Question

- The quantitative importance of these epigenetic interactions on economic and social outcomes remains to be determined — what % of variance in outcomes explained by them?
5. Evidence on Critical and Sensitive Periods in Skill Development
A Life Cycle Framework for Organizing Studies and Integrating Evidence

\[ \theta_t = (\theta_C, \theta_N, \theta_H) \] capacities at \( t \)

\( I_t \): investment at \( t \)

\[ \theta_{t+1} = f_t(\theta_t, I_t, \theta_t, p) \]

\( \theta_{t, p} \) is parental home environment.
6. **Enriched Early Environments Compensate In Part For Risk Features of Disadvantaged Environments**
The Perry Preschool Program is the best studied of all early childhood intervention programs.
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The evidence from it and other programs shows that supplementing early family life can permanently boost life outcomes.
Early Intervention Programs for Disadvantaged Children

- The Perry Preschool Program is the best studied of all early childhood intervention programs.
- It operated primarily by boosting social and emotional skills.
- The evidence from it and other programs shows that supplementing early family life can permanently boost life outcomes.
- Family and environment matters.
Perry preschool program: IQ, by age and treatment group

Source: Perry Preschool Program. IQ measured on the Stanford-Binet Intelligence Scale (Terman & Merrill, 1960). Test was administered at program entry and each of the ages indicated.
Perry preschool program: IQ, by age and treatment group

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Figure 1: Personal Behavior Index by Treatment Group

(1 is bad; 5 is good)
Figure 2: Socio-Emotional Index by Treatment Group

(1 is bad; 5 is good)
Decomposing Treatment Effects of the Perry Program
<table>
<thead>
<tr>
<th>Category</th>
<th>Cognitive Factor</th>
<th>Externalizing Behavior</th>
<th>Academic Motivation</th>
<th>Other Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAT total (1), age 14 (+)</td>
<td>0.145</td>
<td>0.042</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>No tobacco use, age 27 (-)</td>
<td>0.158</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># of misdemeanor arrests, age 27 (-)</td>
<td>0.109</td>
<td>0.086</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td># of felony violent crimes, age 27 (-)</td>
<td>0.145</td>
<td>0.073</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Total # of arrests, age 27 (-)</td>
<td>0.088</td>
<td>0.073</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td># of misdemeanor arrests, up to age 40 (-)</td>
<td>0.268</td>
<td>0.082</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td># of felony violent crimes, age 40 (-)</td>
<td>0.222</td>
<td>0.100</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Total # of arrests up to age 40 (-)</td>
<td>0.287</td>
<td>0.100</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Ever sentenced to prison, age 40 (-)</td>
<td>0.287</td>
<td>0.100</td>
<td>0.002</td>
<td></td>
</tr>
</tbody>
</table>
Evidence on the Effectiveness of Early Childhood Interventions in LDCs
LDCs

- Less public infrastructure
LDCs

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- Extreme disadvantage (ex. hygienic conditions: no access to safe water, sanitation etc).
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- Prevalence of diseases and malnutrition.
LDCs

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- Extreme disadvantage (ex. hygienic conditions: no access to safe water, sanitation etc).
- Prevalence of diseases and malnutrition.
- Nutrition and health are important aspects
Guatemalan intervention

1. 8 year-long nutrition intervention
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2. 4 villages randomized into two groups: one given Atole the other one Fresco
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3. Atole a high protein, high calories and micronutrients complete beverage
4. Fresco as placebo: Kool-Aid like drink, just sugar
5. Total of 2400 children
Outcomes 25 years later: Long lasting impacts on

1. Raven’s IQ (9% improvement over the average score)
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1. Raven’s IQ (9% improvement over the average score)
2. Reading scores (14% improvement in reading comprehension test)
3. 30 to 40% higher earnings, for men
4. Grade attained, ↑ for women only (0.11 grades per year more, and less likely to drop out)
Jamaican intervention program
Program description

Initial Study

- **Long term follow-up** of cognitive stimulation program through home visits
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- **Long term follow-up** of cognitive stimulation program through home visits
- Intervention **very early in life**: started between 9 and 24 months of age, and lasted 2 years
- 129 stunted kids living in Kingston, Jamaica.
- Randomized trial
- Sample of non-stunted kids also followed for comparison purposes
The cognitive intervention

- The stimulation comprised weekly play sessions at home with a community health aid, for 2 years, 1 hr per week
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- The stimulation also actively involved mothers.
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- The stimulation also **actively involved mothers**
- Very similar to home visits in Perry program
Previous follow-up showed long lasting impact on cognitive outcomes

Impact of treatment on cognitive skills

Note: bright green and bright red markers signify a mean significantly larger than the one below

Adapted from Lancet (2005)
Labor market impacts at 22 years old

- Impact on earnings >30%

Statistically significant impact on education, especially for girls
- 0.7 years more of school
- 12% more likely to go to college
- 40% more likely to have passed at least at 'O' levels.

Impact on education and earnings may be a consequence of impact on cognitive, verbal and socioemotional skills

Did not fully catch up with non-stunted kids
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7. Later Remediation is Costly and Often Ineffective

- As **currently implemented**, most adolescent remediation efforts targeted towards disadvantaged adolescents have low returns. For example:
  
  - Active labor market programs (Martin and Grubb)
  - Class size reductions (reducing class size by five pupils per classroom)
  - Adult literacy programs
  - Public job training programs
  - Tuition reduction policy

Returns are the highest for adolescents with the greatest abilities.

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Returns to a unit dollar invested.

Programs targeted towards the earliest years

Source Heckman (2008).
Returns to a unit dollar invested.

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8. Constraints Operating on the Family and the Child
Inability of children to buy good parents and good environments.
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- Inability of parents to borrow against child’s future income.
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A large body of evidence (e.g., Carneiro and Heckman, 2003; Dahl and Lochner, 2010) points to the important role of family income in the child’s early years in shaping adult capabilities.
9. A Model of Family Skill Formation Consistent with the Evidence and Lessons for Policy

- Build on and extend Cunha and Heckman (2007)
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Recent research in the economics of the family (Cunha et al. 2006, 2007, 2008, 2009, 2010; Moon, 2008; Bernal and Keane, 2009; Del Boca, Flinn and Wiswall, 2010; Tartari, 2010; Conti et al., 2010; Akabayashi, 1995, 2000; Weinberg, 2006; Cosconati, 2009; Caucutt and Lochner, 2011) and research under way improves on earlier work by Becker and Tomes (1986) in the following ways:

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f. Child preference formation
Recent research in the economics of the family (Cunha et al. 2006, 2007, 2008, 2009, 2010; Moon, 2008; Bernal and Keane, 2009; Del Boca, Flinn and Wiswall, 2010; Tartari, 2010; Conti et al., 2010; Akabayashi, 1995, 2000; Weinberg, 2006; Cosconati, 2009; Caucutt and Lochner, 2011) and research under way improves on earlier work by Becker and Tomes (1986) in the following ways:

- **Multiple periods of childhood and the adult life cycle** — to address timing questions and the role of credit constraints.
- **The early work assumes one period of childhood.**
- **Specifies and estimates economic models of preferences and technology of skill formation**
- **Adds fertility**
- **Multiple children**
- **Child preference formation**
- **Interaction between child and parents in shaping investment. (principle-agent problems)**
Overlapping generations model of a one-child family (Cunha and Heckman, 2007)

- Individual lives $2T$ years.
Overlapping generations model of a one-child family (Cunha and Heckman, 2007)

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- From age $T + 1$ to $2T$ the individual lives as an adult and is the parent of a child.
Overlapping generations model of a one-child family (Cunha and Heckman, 2007)

- Individual lives $2T$ years.
- The first $T$ years the individual is a child of an adult parent.
- From age $T + 1$ to $2T$ the individual lives as an adult and is the parent of a child.
- The individual dies at the end of the period in which he is $2T$ years-old, just before his child’s child is born.
A household consists of an adult parent and his child.
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Parents invest in their children because of altruism.
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Parents invest in their children because of altruism.

$l_t$: parental investments in child skill when the child is $t$ years-old, where $t = 1, 2, \ldots, T$. 
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Parents invest in their children because of altruism.

$L_t$: parental investments in child skill when the child is $t$ years-old, where $t = 1, 2, \ldots, T$.

The output of the investment process is a skill vector.
Agent born with initial conditions: $\theta_0$. 

$\theta_t$ is the vector of skill stocks.

The technology of production of skill when the child is $t$ years-old:

$$\theta_{t+1} = f_t(h, \theta_t, I_t), \quad (1)$$

for $t = 1, 2, ..., T$.

$f_t$ is neoclassical: strictly increasing, strictly concave, and twice continuously differentiable in $I_t$. 

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Agent born with initial conditions: $\theta_0$.
This can be influenced by family investment.
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$h$ is parental characteristics (e.g., their IQ, education, etc.).
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Agent born with initial conditions: $\theta_0$.
This can be influenced by family investment.
$h$ is parental characteristics (e.g., their IQ, education, etc.).
$\theta_t$ is the vector of skill stocks.
The technology of production of skill when the child is $t$ years-old:

$$\theta_{t+1} = f_t(h, \theta_t, l_t) , \quad (1)$$

for $t = 1, 2, \ldots, T$.

$f_t$ is neoclassical: strictly increasing, strictly concave, and twice continuously differentiable in $l_t$. 
Solve recursively to obtain:

\[
\theta_{t+1} = m_t (h, \theta_1, l_1, \ldots, l_t).
\]
Dynamic complementarity arises when

$$\frac{\partial^2 f_t(h, \theta_t, l_t)}{\partial \theta_t \partial l_t'} > 0.$$
Dynamic complementarity arises when

$$\frac{\partial^2 f_t (h, \theta_t, I_t)}{\partial \theta_t \partial I'_t} > 0.$$  

Two distinct ideas:
Dynamic complementarity arises when

\[ \frac{\partial^2 f_t(h, \theta_t, I_t)}{\partial \theta_t \partial I'_t} > 0. \]

Two distinct ideas:
1. Higher stocks of capabilities at age \( t \) promote the productivity of investment at that age;
• Dynamic complementarity arises when

\[
\frac{\partial^2 f_t(h, \theta_t, I_t)}{\partial \theta_t \partial I_t'} > 0.
\]

• Two distinct ideas:
  1. Higher stocks of capabilities at age \( t \) promote the productivity of investment at that age;
  2. Investment today raises the stock of skills in future periods and raises the productivity of future investment.
**Self-productivity:**

\[
\frac{\partial f_t (h, \theta_t, l_t)}{\partial \theta_t} > 0.
\]
Critical and sensitive periods for investment:

\[ \frac{\partial f_t(h, \theta_t, I_t)}{\partial I_t} = 0 \text{ for } t \neq t^* \]

\[ t^* \] is the critical period for that investment.

\[ \frac{\partial f_t}{\partial I_t} (\cdot) > \frac{\partial f_t}{\partial I_t} (\cdot) t \neq t' \]

then \( t \) is a sensitive period, where “\( \cdot \)” is a common point of evaluation.
Critical and sensitive periods for investment:

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Critical and sensitive periods for investment:

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\frac{\partial f_t(h, \theta_t, l_t)}{\partial l_t} = 0 \quad \text{for } t \neq t^*
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$t^*$ is the critical period for that investment.

2. If

\[
\frac{\partial f_t(\cdot)}{\partial l_t} > \frac{\partial f_{t'}(\cdot)}{\partial l_{t'}} \quad t \neq t'
\]

then $t$ is a sensitive period, where "\(\cdot\)" is a common point of evaluation.
Parental preferences for child outcomes
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$V^P(V^C)$: valuation by parents of child value function.
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Parental preferences for child outcomes

- $V^P(V^C)$: valuation by parents of child value function.
- $V^P = $ Parental Preference.
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- Models of Preference Formation.
Parental preferences for child outcomes

- $V^P(V^C)$: valuation by parents of child value function.
- $V^P = \text{Parental Preference}$. 
- $V^C = \text{Child Preference}$. 
- Models of Preference Formation. 
- Models of Parent-Child Interactions (Akabayashi; Weinberg; Cosconati; Conti et al.)
Preferences and the Optimal Lifecycle Profile of Investments

- Assume $T = 2$: Stationary environment.
Preferences and the Optimal Lifecycle Profile of Investments

- Assume $T = 2$: Stationary environment.
- $w$: wage rate
Preferences and the Optimal Lifecycle Profile of Investments

- Assume $T = 2$: Stationary environment.
- $w$: wage rate
- $r$: interest rate
Preferences and the Optimal Lifecycle Profile of Investments

- Assume $T = 2$: Stationary environment.
- $w$: wage rate
- $r$: interest rate
- At the beginning of adulthood, the parents draw the initial level of skill of the child, $\theta_1$, from $J(\theta_1)$. 
On reaching adulthood, the parents receive bequest $b$. 

Let variables for the parent: parental skills, $h$, the parental financial resources, $b$, and the initial skill level of the child, $\theta_1$. $c_1$ and $c_2$ denote the consumption of the household in the first and second period of the lifecycle of the child.

The budget constraint is:

$$c_1 + I_1 + c_2 + I_2 (1 + r) + b' (1 + r)^2 = wh + wh (1 + r) + b.$$ 

(3)
On reaching adulthood, the parents receive bequest $b$.

State variables for the parent: parental skills, $h$, the parental financial resources, $b$, and the initial skill level of the child, $\theta_1$. 
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c_1$ and $c_2$ denote the consumption of the household in the first and second period of the lifecycle of the child.

The budget constraint is:

$$c_1 + I_1 + \frac{c_2 + I_2}{(1 + r)} + \frac{b'}{(1 + r)^2} = wh + \frac{wh}{(1 + r)} + b. \quad (3)$$
\( \beta \): discount factor
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\( \delta \): measure of parental altruism toward the child.
• $\beta$: discount factor
• $\delta$: measure of parental altruism toward the child.
• $u(\cdot)$ is the utility function.
\( \beta \): discount factor
\( \delta \): measure of parental altruism toward the child.
\( u(\cdot) \) is the utility function.
Problem of the parent:

\[
V(h, b, \theta_1) = \max \left\{ u(c_1) + \beta u(c_2) + \beta^2 \delta E \left[ V(h', b', \theta'_1) \right] \right\}. \tag{4}
\]
Assume $\theta_1, I_1, I_2$ are scalars.
Assume $\theta_1, I_1, I_2$ are scalars.

The child’s adult stock of skills, $h'$:

$$h' = m_2(h, \theta_1, I_1, I_2). \tag{5}$$
Conventional specification of technology (5):

\[ h' = m_2(h, \theta_1, \gamma l_1 + (1 - \gamma) l_2) \]  
\[ \gamma = 1/2. \]
Conventional specification of technology (5):

\[ h' = m_2 (h, \theta_1, \gamma l_1 + (1 - \gamma) l_2) \]  \hspace{1cm} (6)

\[ \gamma = 1/2. \]

Polar opposite:

\[ h' = m_2 (h, \theta_1, \min \{l_1, l_2\}) . \]  \hspace{1cm} (7)
More general technology:

\[ h' = m_2 \left( h, \theta_1, \left[ \gamma (l_1)^\phi + (1 - \gamma) (l_2)^\phi \right]^{\frac{1}{\phi}} \right), \quad (8) \]

for \( \phi \leq 1 \) and \( 0 \leq \gamma \leq 1 \).
More general technology:

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for \( \phi \leq 1 \) and \( 0 \leq \gamma \leq 1 \).

The CES share parameter \( \gamma \) is a *skill multiplier*. 

James Heckman

Marshall Lecture II
Optimal Investment Strategy for $\phi = 1$ (Perfect Substitutes)

- When $\phi = 1$, early and late investments are perfect CES substitutes, the optimal investment strategy is straightforward.

The price of early investment is $1$. The price of late investment is $1 / (1 + r)$. Productivity of early investment: $\gamma$; later investment $(1 - \gamma)$. Invest early if $\gamma > (1 - \gamma)(1 + r)$. 
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Optimal Investment Strategy for $\phi = 1$ (Perfect Substitutes)

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- The price of late investment is $1/(1 + r)$.
- Productivity of early investment: $\gamma$; later investment $(1 - \gamma)$.
- Invest early if $\gamma > (1 - \gamma)(1 + r)$. 
$\phi \to -\infty$ (perfect complementarity), the optimal investment strategy is to set $l_1 = l_2$. 
$-\infty < \phi < 1$: 

$$\frac{l_1}{l_2} = \left[ \frac{\gamma}{(1 - \gamma)(1 + r)} \right]^{\frac{1}{1 - \phi}}.$$  

(9)
The Ratio of Early to Late Investment in Human Capital As a Function of the Skill Multiplier for Different Values of Complementarity

( Assumes $r = 0$)

Source: Cunha et al. (2007).
Alternative Market Environments
Suppose parents cannot borrow against child’s future earnings.

\[ b' \geq 0. \] \hspace{1cm} (10)
If binding, realized investment $\hat{I}_j$ less than optimal $I_j^*$

$\hat{I}_1 \leq I_1^*$ (unconstrained)

$\hat{I}_2 \leq I_2^*$ (unconstrained).
If binding, realized investment $\hat{I}_j$ less than optimal $I_j^*$

$$\hat{I}_1 \leq I_1^* \text{ (unconstrained)}$$
$$\hat{I}_2 \leq I_2^* \text{ (unconstrained)}.$$

Lower investment in both periods does not affect ratio of investments ($I_1/I_2$).
Parents Face Lifetime Liquidity Constraints

- Cunha and Heckman (2007).
Parents Face Lifetime Liquidity Constraints

- Cunha and Heckman (2007).
- Assume that parents’ productivity grows exogenously at rate $\alpha$. 
s: parental savings.
- $s$: parental savings.
- Parents face a sequence of constraints at each stage of the life cycle of the child:

\[
c_1 + l_1 + \frac{s}{1 + r} = wh + b
\]

\[
c_2 + l_2 + \frac{b'}{(1 + r)} = w(1 + \alpha)h + s,
\]

$s \geq 0$ and $b' \geq 0$. 
Suppose \( u(c) = (c^\lambda - 1)/\lambda \):

\[
\frac{l_1}{l_2} = \left[ \frac{\gamma}{(1 - \gamma)(1 + r)} \right]^{\frac{1}{1 - \phi}} \left[ \frac{(wh + b - l_1)}{\beta \left( (1 + \alpha)wh - l_2 \right)} \right]^{\frac{1 - \lambda}{1 - \phi}} \leq 1 .
\]
Suppose $u(c) = \left( c^\lambda - 1 \right) / \lambda$:

$$\frac{l_1}{l_2} = \left[ \frac{\gamma}{(1 - \gamma)(1 + r)} \right]^{\frac{1}{1 - \phi}} \left[ \frac{(wh + b - l_1)}{\beta ((1 + \alpha)wh - l_2)} \right]^{\frac{1 - \lambda}{1 - \phi}} \leq 1$$

Tug of war between $\lambda$ and $\phi$. 

Evidence of credit constraints at early years that affect child outcomes.
Suppose $u(c) = (c^\lambda - 1)/\lambda$:

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With sufficiently high $\lambda$ (e.g., $\lambda = 1$), parental deferred consumption can compensate for binding early credit constraints. ($\lambda = 1$ no effect of constraint)
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Estimates of Cunha, Heckman and Schennach (2010) suggests $\frac{1}{1 - \phi} = 0.3$ ($\phi = -2$) and Attanasio and Browning (1995) estimate $\lambda \in [-3, -1.5]$. 

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Evidence of credit constraints at early years that affect child outcomes.

James Heckman
Marshall Lecture II
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\]

Tug of war between \( \lambda \) and \( \phi \).

With sufficiently high \( \lambda \) (e.g., \( \lambda = 1 \)), parental deferred consumption can compensate for binding early credit constraints. \( (\lambda = 1 \text{ no effect of constraint}) \)

Estimates of Cunha, Heckman and Schennach (2010) suggests \( \frac{1}{1 - \phi} = .3 \) (\( \phi = -2 \)) and Attanasio and Browning (1995) estimate \( \lambda \in [-3, -1.5] \).

\( \therefore \frac{1 - \lambda}{1 - \phi} \in [.83, 1.33] \).

Evidence of credit constraints at early years that affect child outcomes.
10. Estimating and Interpreting the Estimates of the Technology of Skill Formation
A Life Cycle Framework for Organizing Studies and Integrating Evidence

$$\theta_t = (\theta_C, \theta_N, \theta_H)$$ capacities at \(t\)

$$\theta_{t,h}$$: parental traits at \(t\)

$$I_t$$: investment at \(t\)

$$\theta_{t+1} = f_t(\theta_t, I_t, \theta_{t,h})$$: Technology of Skill Formation
Econometric Challenges

- Multiplicity of measured inputs and measured outputs
- Measurement error in inputs and outputs (we only have proxies)
- Endogeneity of Investment and hence stocks of skills
- Omitted inputs
- Need to go beyond linear technologies for skill formation to capture the notion of substitution between early and late.
- Output as measured by test scores is meaningless—any monotonic function of a test score is a test score. Need to set the scale by anchoring in cardinal outcomes of interest e.g. earning, schooling.
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Strategy: Dynamic Factor Models (State Space models).
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  - Multiple measurements on $\theta_t, l_t, h_t, \theta_t, h$:

\[ M^j_{\theta_t}, j \in J_t \quad M^k_{l_t}, k \in K_t \quad M^\ell_{h_t}, \ell \in L_t \]  

Skills \quad Investments \quad Parental Background 

(\star)
Strategy: Dynamic Factor Models (State Space models).

a) Multiple measurements on $\theta_t, I_t, h_t, \theta_{t,h}$:

\[
\begin{align*}
M^j_{\theta_t}, & j \in J_t & \text{Skills} \\
M^k_{I_t}, & k \in K_t & \text{Investments} \\
M^\ell_{h_t}, & \ell \in L_t & \text{Parental Background}
\end{align*}
\] (*

b) Equation of motion (technology of skill formation)

\[
\theta_{t+1} = f_t(\theta_t, I_t, h_t) \\
\uparrow \text{skills in } t \\
\uparrow \text{investment in } t \\
\uparrow \text{parental inputs in } t
\] (**

Anchor scales of $\theta$ using observed outcomes ($Y$), not test scores.
Strategy: Dynamic Factor Models (State Space models).

- Multiple measurements on $\theta_t$, $l_t$, $h_t$, $\theta_{t,h}$:

$$M^j_{\theta_t}, j \in J_t \quad M^k_{l_t}, k \in K_t \quad M^\ell_{h_t}, \ell \in L_t$$

Skills Investments Parental Background

- Equation of motion (technology of skill formation)

$$\theta_{t+1} = f_t(\theta_t, l_t, h_t)$$

- Anchor scales of $\theta$ using observed outcomes ($Y$), not test scores.
Estimates of the Technology of Skill Formation
Linear specification: Stage-specific technology as in Todd-Wolpin (2003, 2007),

\[
\theta_{t+1} = A_t \theta_t + B_t l_t + \eta_t.
\]
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Todd-Wolpin — Cognitive output only and test scores as output.
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Estimated technology is not invariant to monotonic transformations of test scores.
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Cunha and Heckman (\( \theta_{t+1} \) is vector of outputs).
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Cunha et al. identify technology of skill formation nonparametrically (use CES specification to obtain estimates).
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Anchor the scale of the factors in outputs.
Sources of Identification

- Nonparametric factor structure and nonlinear generalizations of covariance restrictions.
Sources of Identification

- Nonparametric factor structure and nonlinear generalizations of covariance restrictions.
- Innovations in family income and other shocks to family resources.
Estimates from Nonlinear Model (Cunha et al., 2010)

- Age-specific CES models

Self-productivity becomes stronger as children become older, for both cognitive and noncognitive skill formation (i.e., $\partial \theta_{t+1} \theta_t^{t+1}$).

Complementarity between cognitive skills and investment becomes stronger as children become older. The elasticity of substitution for cognition is smaller in second stage production. Implies that at older ages, compensation for adverse early environments by cognitive interventions becomes more difficult.

$\sigma_C = 0.3$

Complementarity between noncognitive skills and investments becomes slightly weaker as children become older. Slightly easier to compensate using interventions in the adolescent years for adversity in the early years using investments in noncognitive skills.
Estimates from Nonlinear Model (Cunha et al., 2010)

a. Age-specific CES models

b. Self-productivity becomes stronger as children become older, for both cognitive and noncognitive skill formation (i.e., $\frac{\partial \theta_{t+1}}{\partial \theta_t} \uparrow t$).
Estimates from Nonlinear Model (Cunha et al., 2010)

- **a** Age-specific CES models

- **b** Self-productivity becomes stronger as children become older, for both cognitive and noncognitive skill formation (i.e., $\frac{\partial \theta_{t+1}}{\partial \theta_t} \uparrow t$).

- **c** Complementarity between cognitive skills and investment becomes stronger as children become older. The elasticity of substitution for cognition is *smaller* in second stage production. Implies that at older ages, compensation for adverse early environments by cognitive interventions becomes more difficult.
Estimates from Nonlinear Model (Cunha et al., 2010)

a. Age-specific CES models

b. Self-productivity becomes stronger as children become older, for both cognitive and noncognitive skill formation (i.e., $\frac{\partial \theta_{t+1}}{\partial \theta_t} \uparrow t$).

c. Complementarity between cognitive skills and investment becomes stronger as children become older. The elasticity of substitution for cognition is smaller in second stage production. Implies that at older ages, compensation for adverse early environments by cognitive interventions becomes more difficult.

d. $\sigma_C \doteq 0.3$
Estimates from Nonlinear Model (Cunha et al., 2010)

a. Age-specific CES models

b. Self-productivity becomes stronger as children become older, for both cognitive and noncognitive skill formation (i.e., $\frac{\partial \theta_{t+1}}{\partial \theta_t} \uparrow t$).

c. Complementarity between cognitive skills and investment becomes stronger as children become older. The elasticity of substitution for cognition is smaller in second stage production. Implies that at older ages, compensation for adverse early environments by cognitive interventions becomes more difficult.

d. $\sigma_C \approx .3$

e. Complementarity between noncognitive skills and investments becomes slightly weaker as children become older. Slightly easier to compensate using interventions in the adolescent years for adversity in the early years using investments in noncognitive skills.
34% of the variation in educational attainment in the sample is explained by cognitive and noncognitive capabilities.
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- 34% of the variation in educational attainment in the sample is explained by cognitive and noncognitive capabilities.
- 16% is due to adolescent cognitive capabilities.
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- Measured parental investments account for 15% of the variation in educational attainment.
34% of the variation in educational attainment in the sample is explained by cognitive and noncognitive capabilities.

16% is due to adolescent cognitive capabilities.

12% is due to adolescent noncognitive capabilities.

Measured parental investments account for 15% of the variation in educational attainment.

These estimates suggest that the measures of cognitive and noncognitive capabilities are powerful, but not exclusive, determinants of educational attainment and that other factors, besides the measures of family investment that we use, are at work in explaining variation in educational attainment.
Interpreting the Estimates

Consider a social planner’s problem.
Interpreting the Estimates

- Consider a social planner’s problem.
- Ignore parental feedback.
Let \( \theta^C, 1, q, \theta^N, 1, q, \theta^C, P, q, \theta^N, P, q \): initial cognitive and noncognitive skills of child \( q \). Parental cognitive and noncognitive skills denoted by \( \theta^C, P, q \) and \( \theta^N, P, q \), respectively. Let \( \pi^q \) denote additional unobserved determinants of outcomes.

Denote \( \theta^1, q = (\theta^C, 1, q, \theta^N, 1, q, \theta^C, P, q, \theta^N, P, q, \pi^q) \). \( F(\theta^1, q) \) denotes its distribution.

- \( Q \) children indexed by \( q \in \{1, \ldots, Q\} \).
Q children indexed by $q \in \{1, \ldots, Q\}$.

Let $(\theta_{C,1,q}, \theta_{N,1,q})$: initial cognitive and noncognitive skills of child $q$. 

$\theta_{1,q} = (\theta_{C,1,q}, \theta_{N,1,q}, \theta_{C,1,P,q}, \theta_{N,1,P,q}, \pi_q)$. 

$F(\theta_{1,q})$ denotes its distribution.
- Q children indexed by $q \in \{1, \ldots, Q\}$.
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• Parental cognitive and noncognitive skills denoted by $\theta_{C,P,q}$ and $\theta_{N,P,q}$, respectively.

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• Denote $\theta_{1,q} = (\theta_{C,1,q}, \theta_{N,1,q}, \theta_{C,P,q}, \theta_{N,P,q}, \pi_q)$.

• $F(\theta_{1,q})$ denotes its distribution.
Draw $Q$ people from the estimated initial distribution $F(\theta_{1,q})$. 
• Draw $Q$ people from the estimated initial distribution $F(\theta_1, q)$.
• The price of investment the same in each period.
Social planner maximizes per capita aggregate schooling:

\[
\max \bar{S} = \frac{1}{Q} \sum_{q=1}^{Q} S(\theta_{C,3,q}, \theta_{N,3,q}, \pi_q).
\]

schooling attained as a function of end of childhood endowment.
Social planner maximizes per capita aggregate schooling:

$$\max \bar{S} = \frac{1}{Q} \sum_{q=1}^{Q} S(\theta_{C,3,q}, \theta_{N,3,q}, \pi_q).$$

Aggregate budget constraint:

$$\sum_{q=1}^{Q} (l_{1,q} + l_{2,q}) = 2Q.$$
Technology constraint,

$$\theta_{k,t+1,q} = f_{k,t}(\theta_{C,t,q}, \theta_{N,t,q}, \theta_{C,P,q}, \theta_{N,P,q}, \pi_q)$$

for $k \in \{C,N\}$ and $t \in \{1,2\}$, and the initial endowments of the child and her family.
Technology constraint,

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for $k \in \{C, N\}$ and $t \in \{1, 2\}$, and the initial endowments of the child and her family.

Abstract from child and parental feedback from investment — principle-agent problems at the level of the parent-child and government-parent interactions.
Figure 3 (for the child’s personal endowments) shows the profiles of early (left hand side graph) and late (right hand side graph) investment as a function of child endowments.
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For the most disadvantaged, the optimal policy is to invest a lot in the early years.
Figure 3 (for the child’s personal endowments) shows the profiles of early (left hand side graph) and late (right hand side graph) investment as a function of child endowments.

For the most disadvantaged, the optimal policy is to invest a lot in the early years.

Moon (2010) shows that, in actuality, society and family together invest much more in the early years of the advantaged compared to the disadvantaged.
Figure 3: Optimal early (left) and late (right) investments by child initial conditions of cognitive and noncognitive skills maximizing aggregate education.
The decline in investment by level of advantage is dramatic for early investment.
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Second period investment profiles are much flatter and slightly favor more advantaged children.
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Second period investment profiles are much flatter and slightly favor more advantaged children.

A similar profile emerges for investments to reduce aggregate crime, which for the sake of brevity, we do not display.
Figures 4 and 5 reveal that the ratio of optimal early-to-late investment as a function of the child’s personal endowments declines with advantage whether the social planner seeks to maximize educational attainment (4) or to minimize aggregate crime (5).
Figure 4: Ratio of Early to Late Investments by Child Initial Conditions of Cognitive and Noncognitive Skills Maximizing Aggregate Education
Figure 5: Ratio of Early to Late Investments by Child Initial Conditions of Cognitive and Noncognitive Skills Minimizing Aggregate Crime
The optimal ratio of early-to-late investment depends on the desired outcome, the endowments of children and the budget.
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Figure 6 plots the density of the ratio of early-to-late investment for education and crime.
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Figure 6 plots the density of the ratio of early-to-late investment for education and crime.

Crime is more intensive in noncognitive skill than educational attainment, which depends much more strongly on cognitive skills.
Figure 6: Densities of Ratio of Early to Late Investments Maximizing Aggregate Education Versus Minimizing Aggregate Crime
Because compensation for adversity in noncognitive skills is somewhat less costly in the second period, and because of discounting of costs and concavity of the technology, it is efficient to invest relatively more in noncognitive traits in the second period.
Because compensation for adversity in noncognitive skills is somewhat less costly in the second period, and because of discounting of costs and concavity of the technology, it is efficient to invest relatively more in noncognitive traits in the second period.

The opposite is true for cognitive skills.
These simulations suggest that the timing and level of optimal interventions for disadvantaged children depend on the conditions of disadvantage and the nature of desired outcomes.
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Targeted strategies are likely to be effective especially for different targets that weight cognitive and noncognitive traits differently.
Note that even though there is static complementarity in the estimated technology for each period

$$\frac{\partial^2 f_j(\theta_j, I_j, h)}{\partial I_j \partial \theta_j} > 0,$$

the optimal policy is to invest in the less advantaged in early years.
• Note that even though there is static complementarity in the estimated technology for each period

\[ \frac{\partial^2 f_j(\theta_j, l_j, h)}{\partial l_j \partial \theta_j} > 0, \]

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• Not a theorem, but an implication of the empirical estimates.
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the optimal policy is to invest in the less advantaged in early years.

Not a theorem, but an implication of the empirical estimates.

Consistent with a large body of empirical research.
Some Economic Intuition for the Simulations

- Given the estimated (weak) complementarity in the production technology within each period, how is it possible to obtain the result that it is optimal to invest relatively more in the early years of the most disadvantaged?
Some Economic Intuition for the Simulations

Given the estimated (weak) complementarity in the production technology within each period, how is it possible to obtain the result that it is optimal to invest relatively more in the early years of the most disadvantaged?

The answer hinges on the interaction between different aspects of disadvantage (parental endowments and initial child endowments) and helps to illuminate the operation of dynamic complementarity.
Example:

- A single capability, $\theta$. 
Example:

- A single capability, $\theta$.
- Two children, $A$ and $B$. 
Example:

- A single capability, $\theta$.
- Two children, $A$ and $B$.
- Born with initial skills $\theta_1^A$ and $\theta_1^B$. 
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- Suppose that there are two periods for investment, which we denote by periods 1 (early) and 2 (late).
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- Born with initial skills $\theta^A_1$ and $\theta^B_1$.
- $\theta^A_P$ and $\theta^B_P$ denote the skills of the parents $A$ and $B$.
- Suppose that there are two periods for investment, which we denote by periods 1 (early) and 2 (late).
- For each period, there is a different technology that produces skills.
The technology for period one is:

$$\theta_2 = \gamma_1 \theta_1 + \gamma_2 l_1 + \gamma_3 \theta_P.$$
The technology for period one is:

\[ \theta_2 = \gamma_1 \theta_1 + \gamma_2 I_1 + \gamma_3 \theta_P. \]

For period two it is:

\[ \theta_3 = \min \{ \theta_2, I_2, \theta_P \} . \]
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These patterns of complementarity are polar cases that represent, in extreme form, the empirical pattern found for cognitive skill accumulation: that substitution possibilities are greater early in life compared to later in life.
The problem of society is to choose how much to invest in child A and child B in periods 1 and 2 to maximize total aggregate skills, $\theta^A_3 + \theta^B_3$, subject to the resource constraint $I^A_1 + I^A_2 + I^B_1 + I^B_2 \leq M$, where $M$ is total resources available to the family.
The problem of society is to choose how much to invest in child A and child B in periods 1 and 2 to maximize total aggregate skills, $\theta_3^A + \theta_3^B$, subject to the resource constraint $I_1^A + I_2^A + I_1^B + I_2^B \leq M$, where $M$ is total resources available to the family.

Formally,

$$\max \left[ \min \left\{ \gamma_1 \theta_1^A + \gamma_2 I_1^A + \gamma_3 \theta_P^A, I_2^A, \theta_P^A \right\} + \right.$$ 

$$\min \left\{ \gamma_1 \theta_1^B + \gamma_2 I_1^B + \gamma_3 \theta_P^B, I_2^B, \theta_P^B \right\} \right]$$

subject to: $I_1^A + I_2^A + I_1^B + I_2^B \leq M$  \hspace{1cm} (13)
When the resource constraint (13) does not bind, as it does not if $M$ is above a certain threshold (determined by $\theta_P$), optimal investments are

\[
I_1^A = \frac{(1 - \gamma_3) \theta_P - \gamma_1 \theta_1^A}{\gamma_2} \\
I_2^A = \theta_P \\
I_1^B = \frac{(1 - \gamma_3) \theta_P - \gamma_1 \theta_1^B}{\gamma_2} \\
I_2^B = \theta_P
\]
Notice that if child A is disadvantaged compared to B on both measures of disadvantage, \((\theta_A^1 < \theta_B^1 \text{ and } \theta_A^p < \theta_B^p)\), it can happen that

\[ I_A^1 > I_B^1, \text{ but } I_A^2 < I_B^2 \]

if

\[ \theta_A^p - \theta_B^p > \frac{\gamma_1}{(1 - \gamma_3)} (\theta_A^1 - \theta_B^1), \gamma_3 \neq 1. \]
Notice that if child A is disadvantaged compared to B on both measures of disadvantage, \((\theta_A^1 < \theta_B^1 \text{ and } \theta_A^P < \theta_B^P)\), it can happen that 

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Thus, if parental endowments are less negative than the childhood endowments (scaled by \(\frac{\gamma_1}{(1 - \gamma_3)}\)), it is optimal to invest more in the early years for the disadvantaged and less in the later years.
The higher the self-productivity ($\gamma_1$) and the higher the parental environment productivity, $\gamma_3$, the more likely will this inequality be satisfied for any fixed level of disparity. So the optimal policy is to invest more in the disadvantaged in the early years.
11. How Does This Research Cause Us to Rethink the Role of Education and Our Education and Human Capital Policies?

- Schools play an important role in creating capabilities.
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- Human capital policy, broadly defined, has important implications for social policy about health, crime, wage inequality, teenage pregnancy.
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- Human capital policy, broadly defined, has important implications for social policy about health, crime, wage inequality, teenage pregnancy.
- Schooling also creates the traits that promote successful lives.
The Causal Effects of Schooling on Cognitive and Personality Traits

- Use the methodology of Hansen, Heckman and Mullen [2004].
Use the methodology of Hansen, Heckman and Mullen [2004].

Two econometric strategies that produce estimates in close agreement.
**Figure 7: Causal Effect of Schooling on ASVAB Measures of Cognition**

Notes: Effect of schooling on components of the ASVAB. The first four components are averaged to create male’s with average ability. We standardize the test scores to have within-sample mean zero, variance one. The model is estimated using the NLSY79 sample. Solid lines depict average test scores, and dashed lines, confidence intervals.

Source: Heckman, Stixrud and Urzua [2006, Figure 4].
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Figure 8: Causal Effect of Schooling on Two Measures of Personality

Source: Heckman, Stixrud and Urzua [2006].
Revisiting the Signalling Debate.

- Is schooling an effective strategy for alleviating poverty or does its effect arise from pre-existing factors present before schooling begins? (The old signalling debate)
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- Is schooling an effective strategy for alleviating poverty or does its effect arise from pre-existing factors present before schooling begins? (The old signalling debate)
- The signalling debate was silent on where the ability came from.
Revisiting the Signalling Debate.

- Is schooling an effective strategy for alleviating poverty or does its effect arise from pre-existing factors present before schooling begins? (The old signalling debate)
- The signalling debate was silent on where the ability came from.
- Our analyses show the importance of the family and early environments in creating capabilities.
Consider the Causal Effects of Boosting Education Above Current Minimal Schooling Learning Levels as a Strategy for Reducing Inequality and Promoting Productivity
Note: Authors' calculations using BCS70. Conti, Heckman, Urzua (2010)
Decomposition of the Disparities

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Who benefits? 
(conditional on $\theta$)
Education compensates for low early noncognitive endowments and reinforces high early cognitive endowments.
Education compensates for low early noncognitive endowments and reinforces high early cognitive endowments.
Education compensates for low noncognitive endowments.
- Education compensates for low noncognitive endowments.
- Reinforces high cognitive endowments.
Effects of Education at Higher Levels of Education: UK
The Causal Effect of Education

Decomposition of Observed Disparities, Males; UK Data

Log Hourly Wage

Obesity

Poor Health

Daily Smoking

The Causal Effect of Education

Decomposition of Observed Disparities, Females; UK Data

Related Evidence from the U.S.
Like for U.K., the % of the observed disparities in log wages due to education is comparable across educational levels (70%).
Like for U.K., the % of the observed disparities in physical health due to education is comparable across educational levels (70%).
Like for U.K., the % of the observed disparities in daily smoking due to education is comparable across educational levels (70%).
Like for U.K., the % of the observed disparities in Labor Force Participation due to education is comparable across educational levels (70%).
Like for U.K., the % of the observed disparities in white collar due to education is comparable across educational levels (70%).
Cognitive and Socioemotional Factors

Adolescent cognitive and socioemotional factors affect the probability of graduating from high school.
Cognitive and Socioemotional Factors

Probability of College Degree, Males

...and from college.
Note: For each outcome we present three figures. The first figure (top) displays the levels of the outcome as a function of cognitive and socio-emotional endowments. In particular, we present the average level of outcomes for different deciles of cognitive and socio-emotional endowments. Notice that we define as “decile 1” the decile with the lowest values of endowments and “decile 10” as the decile with the highest levels of endowments. The second figure (bottom left) displays the average levels of endowment across deciles of cognitive endowments. The bars in this figure indicates the fraction of individuals reporting the respective schooling level for each decile of cognitive endowment. The last figure (bottom right) mimics the structure of the second one but now for the socio-emotional endowment.
Cognitive and Socioemotional Factors

Physical Health, Males: not conditioning on education

- Cognitive and socioemotional adolescent factors in U.S. affect the probability of being in good health.
Summary of the Lectures

- Inequality has many dimensions.
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- Not all inequality is produced by the inequality in skills.
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- But inequality in skills — broadly defined — plays an important role in creating inequality in society.
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- Skills are multidimensional.
Summary of the Lectures

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- Not all inequality is produced by the inequality in skills.
- Important role for markets, institutions, and government policies in determining the prices of skills.
- But inequality in skills — broadly defined — plays an important role in creating inequality in society.
- Skills are multidimensional.
- They produce inequality in education, wages, health, crime, and determine a host of important outcomes.
Understanding the origins of skills is essential in understanding inequality and effective policies to combat it, as measured in many ways.
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Skill gaps between advantaged and disadvantaged children open up early and persist before children start school.
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Economic and educational policy should recognize the dynamics of skill formation.
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• Progress in the economics of the family and in understanding the mechanisms of family influence is essential in shaping understanding of the origins of inequality.
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Family life plays an important role in shaping skills.

Progress in the economics of the family and in understanding the mechanisms of family influence is essential in shaping understanding of the origins of inequality.

Much recent work shows the importance of the early years in shaping skills.
Dynamics of skill formation has been formalized in models of dynamic complementarity.
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Schools matter, but what schools can do depends on the investments made by the parents.
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Redirects and broadens our thinking about policy.

Goes beyond equating education with skill.

Schools matter, but what schools can do depends on the investments made by the parents.

The true measure of child poverty is the quality of parenting, not income per se, although the former is correlated with the latter.
A Life Cycle Framework for Organizing Studies and Integrating Evidence

\[ \theta_t = (\theta_C, \theta_N, \theta_H) \] capacities at \( t \)

\( I_t \): investment at \( t \)

\[ \theta_{t+1} = f_t(\theta_t, I_t, \theta_{t,P}) \]

\( \theta_{t,P} \) is parental home environment.

\( \theta_{-1}, P \)

\( \theta_{0}, P \)

\( \theta_{1}, P \)

\( \theta_{2}, P \)

\( \theta_{T}, P \)

\( \theta_{-1}, C, \theta_{-1}, N, \theta_{-1}, H \)

\( \theta_{0}, C, \theta_{0}, N, \theta_{0}, H \)

\( \theta_{1}, C, \theta_{1}, N, \theta_{1}, H \)

\( \theta_{2}, C, \theta_{2}, N, \theta_{2}, H \)

\( \theta_{T}, C, \theta_{T}, N, \theta_{T}, H \)

\( \theta_{T+1}, C, \theta_{T+1}, N, \theta_{T+1}, H \)

PRENATAL

BIRTH

EARLY CHILDHOOD 0-3

LATE CHILDHOOD 3-6

ADULTHOOD