Schools, Skills and Synapses

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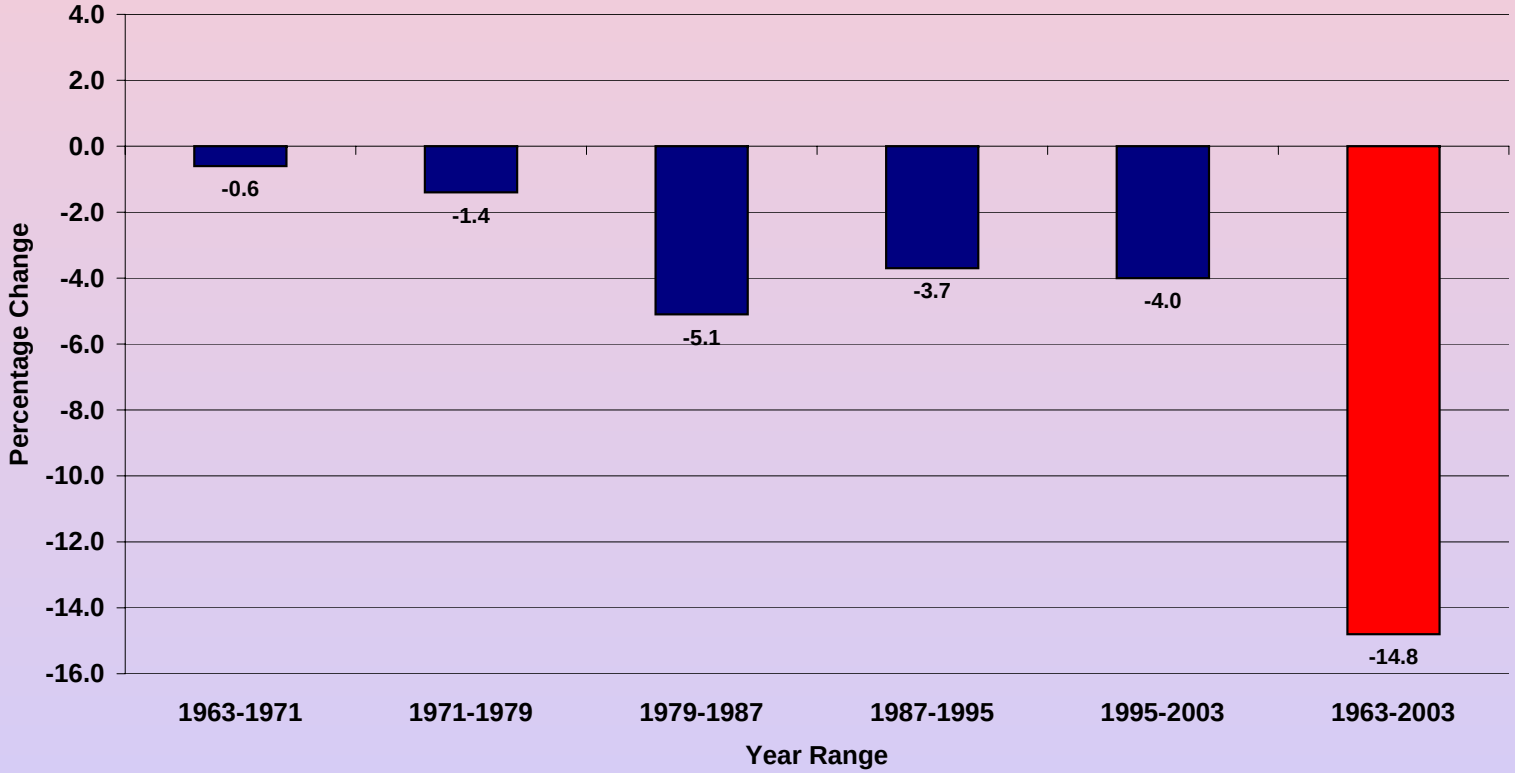
- **American society is becoming more polarized; not just by income but by education.**
- **At a time when skills are at a premium, the growth rate of the supply of high skilled workers is decreasing and an underclass high school dropouts is emerging.**

Percent change in the relative weekly wages of high school dropouts to high school graduates, CPS March 1963–2003



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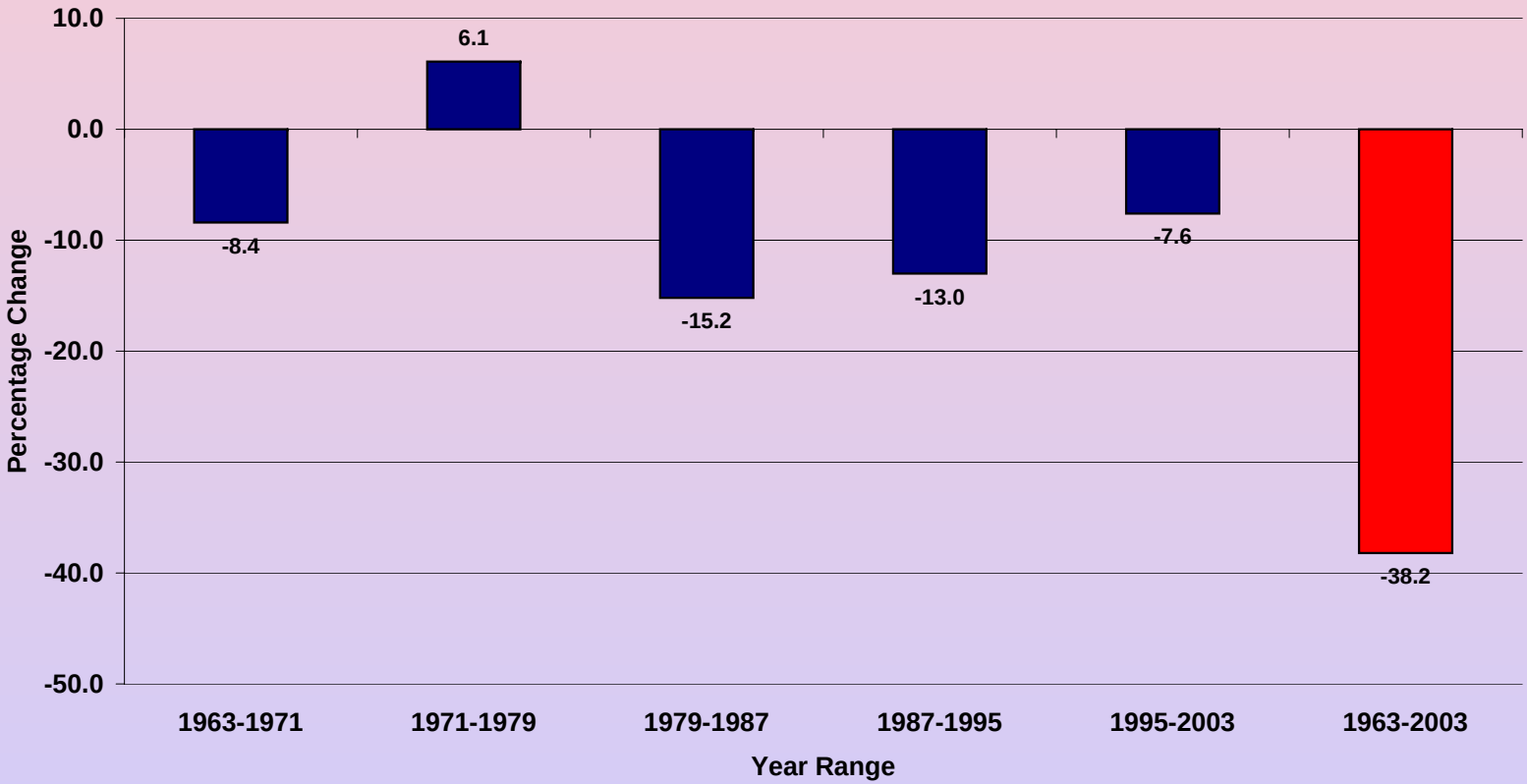

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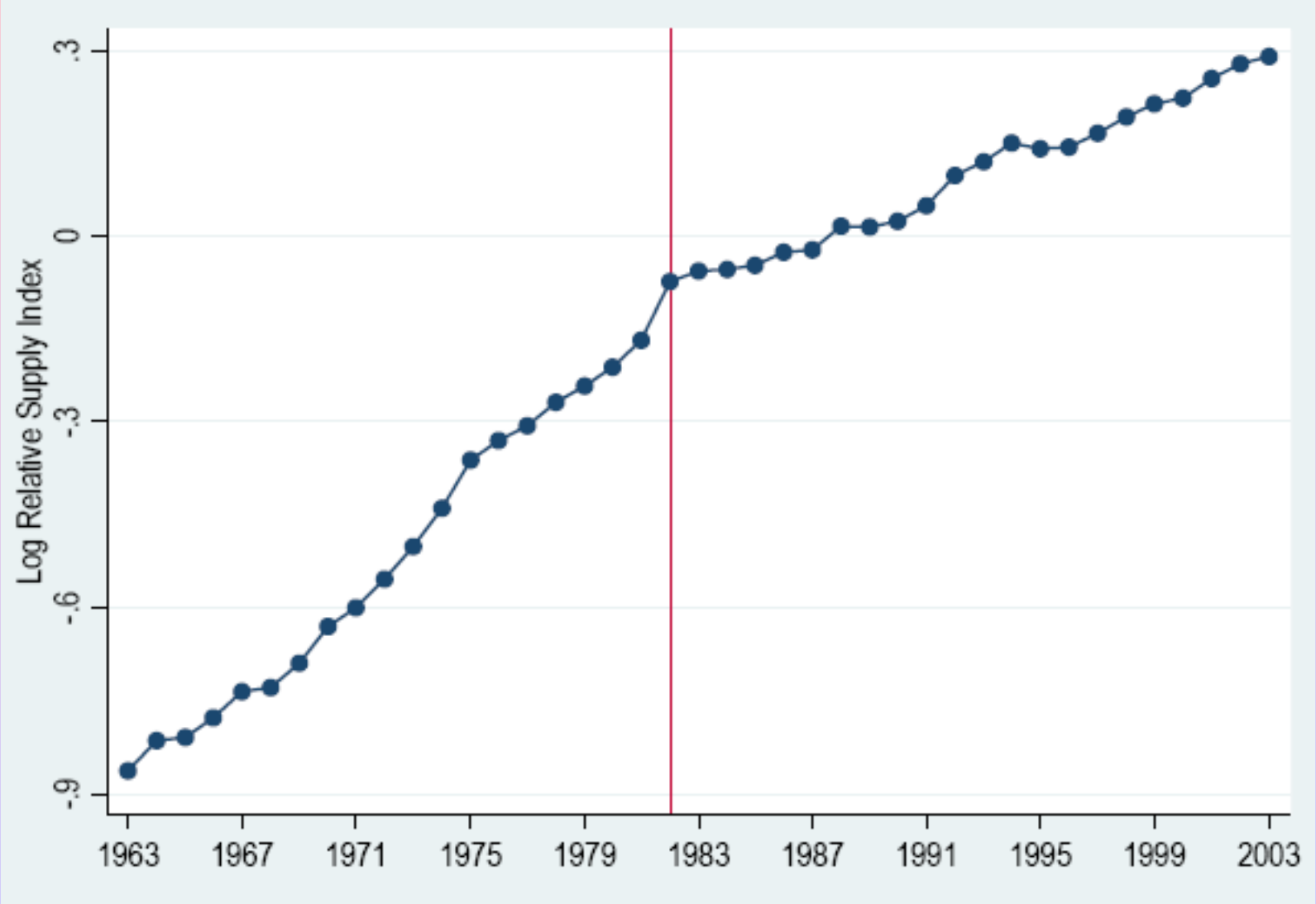
- Despite the growth in the "return" to skill, there is a slowdown in the growth of the supply of skill.

Relative supply of college equivalent labor, 1963–2003 (March CPS)



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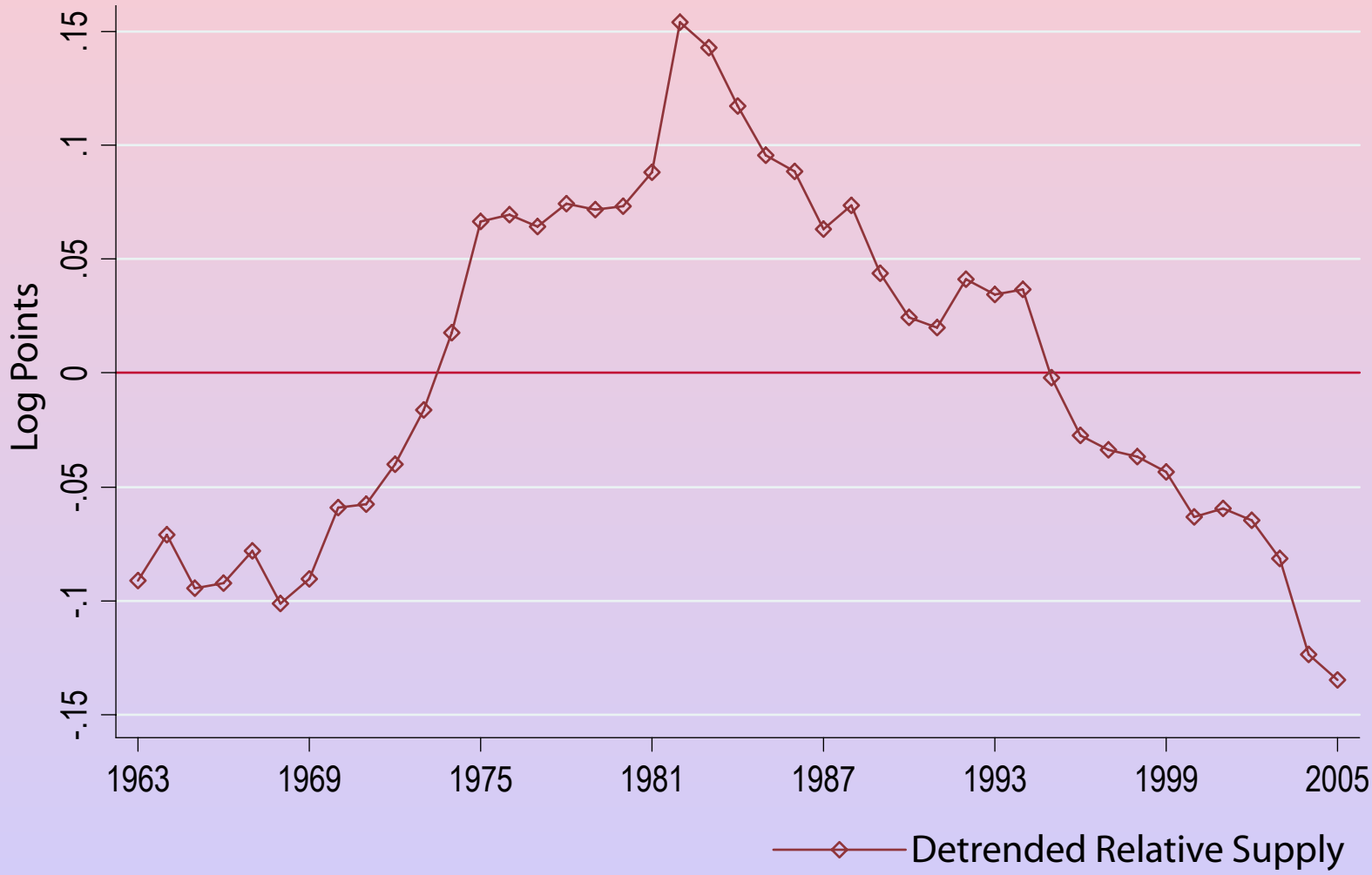
Detrended college/hs wage differential and relative supply, 1963–2003



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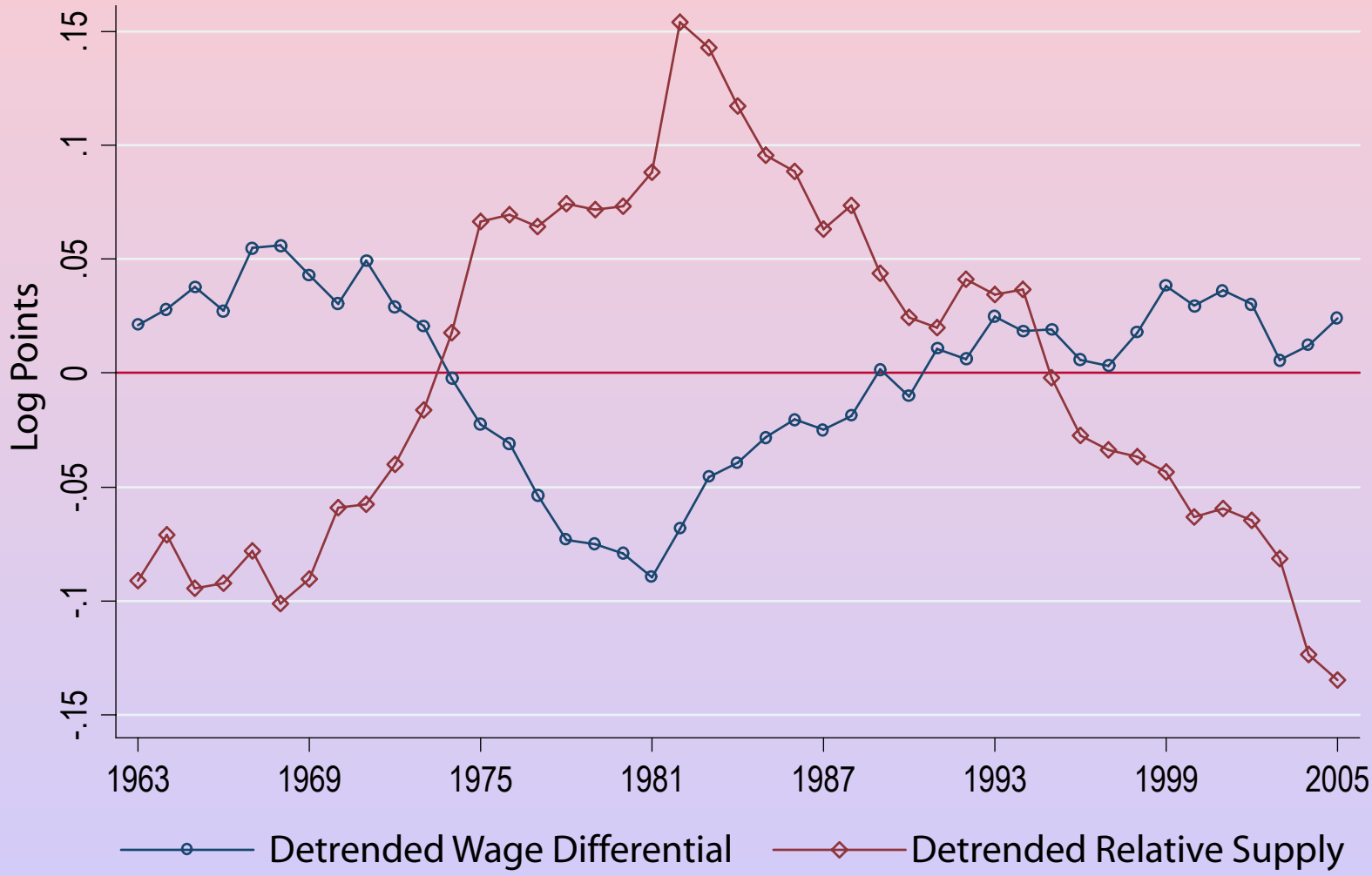

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- Why the slowdown in supply?

- The slowdown in the rate of growth of college attendance is not due to a slowdown in the rate of growth of college attendance among graduates.

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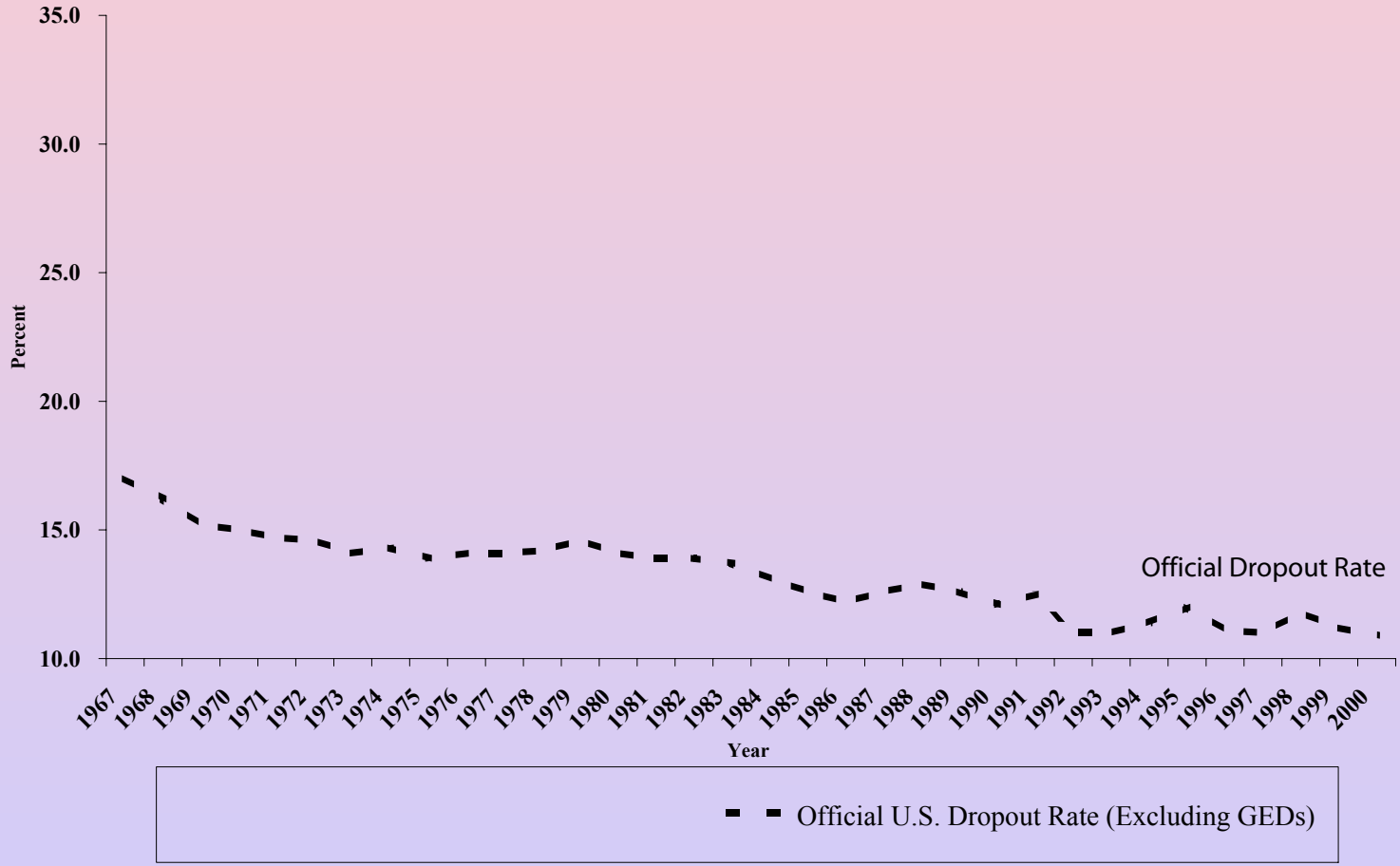
- It is due to the growth in high school dropouts.

The American High School Dropout Rate is Increasing



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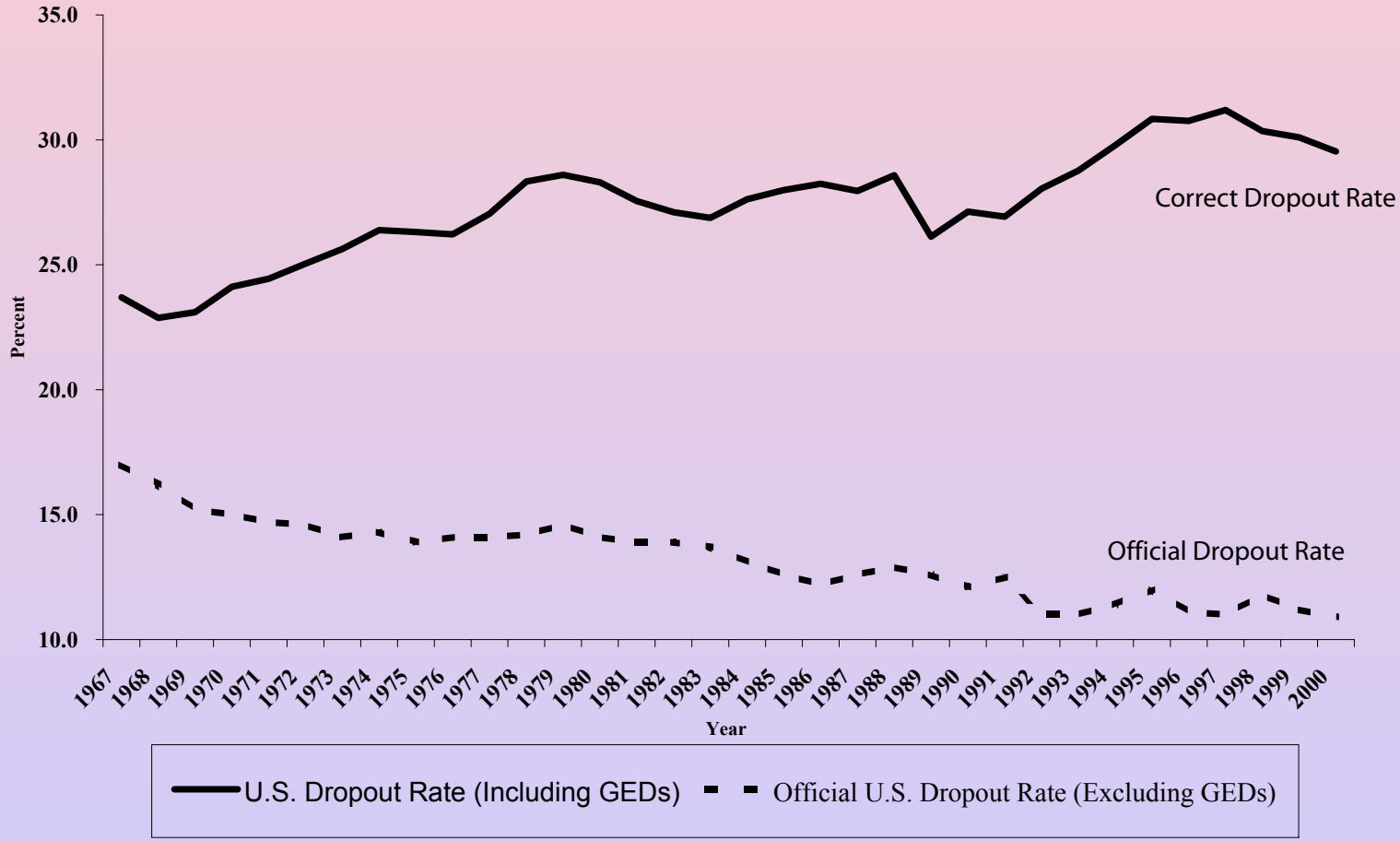

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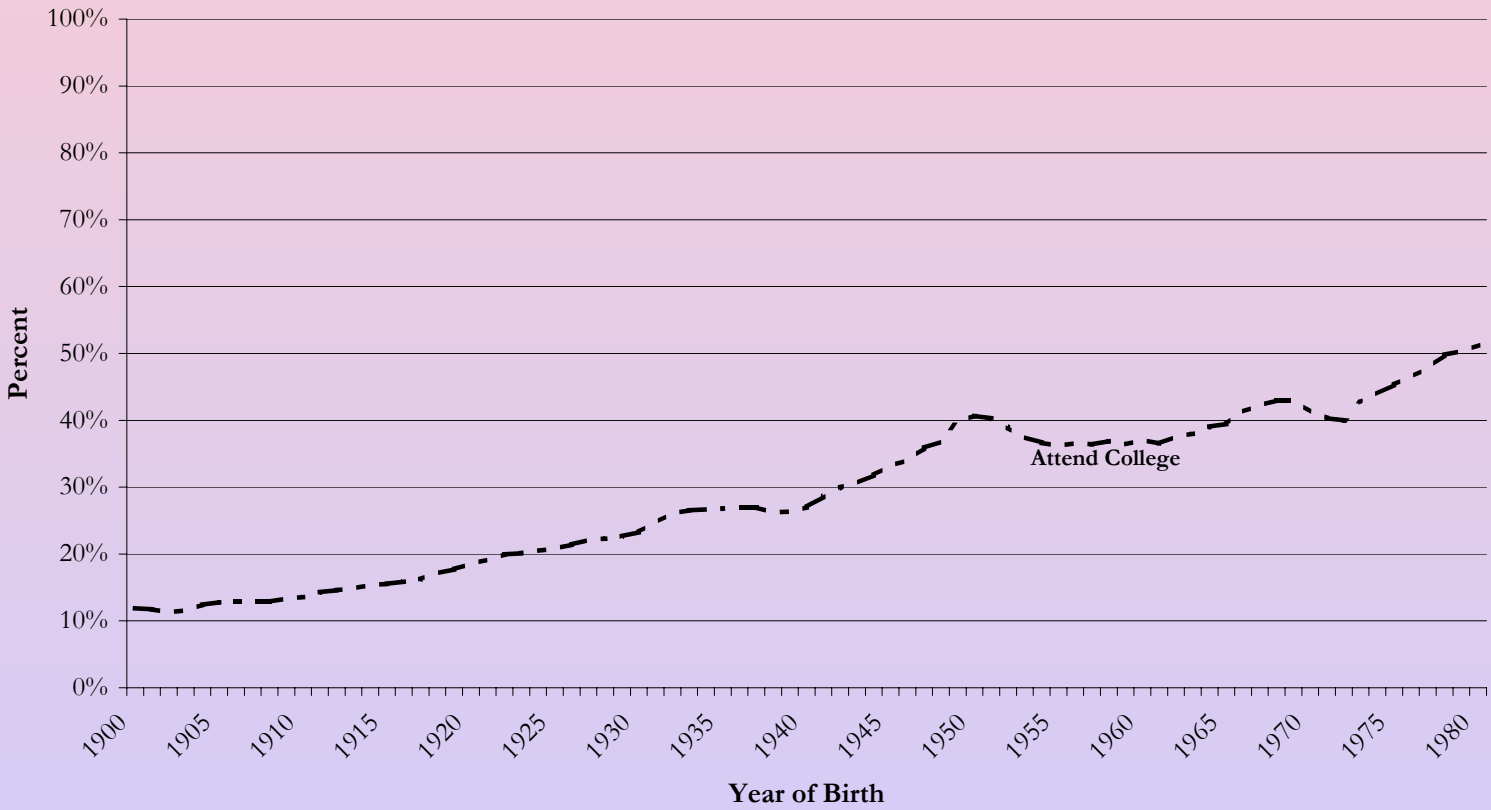
The Slowdown in the Growth of College Attendance is Due to the Growing High School Dropout Rate



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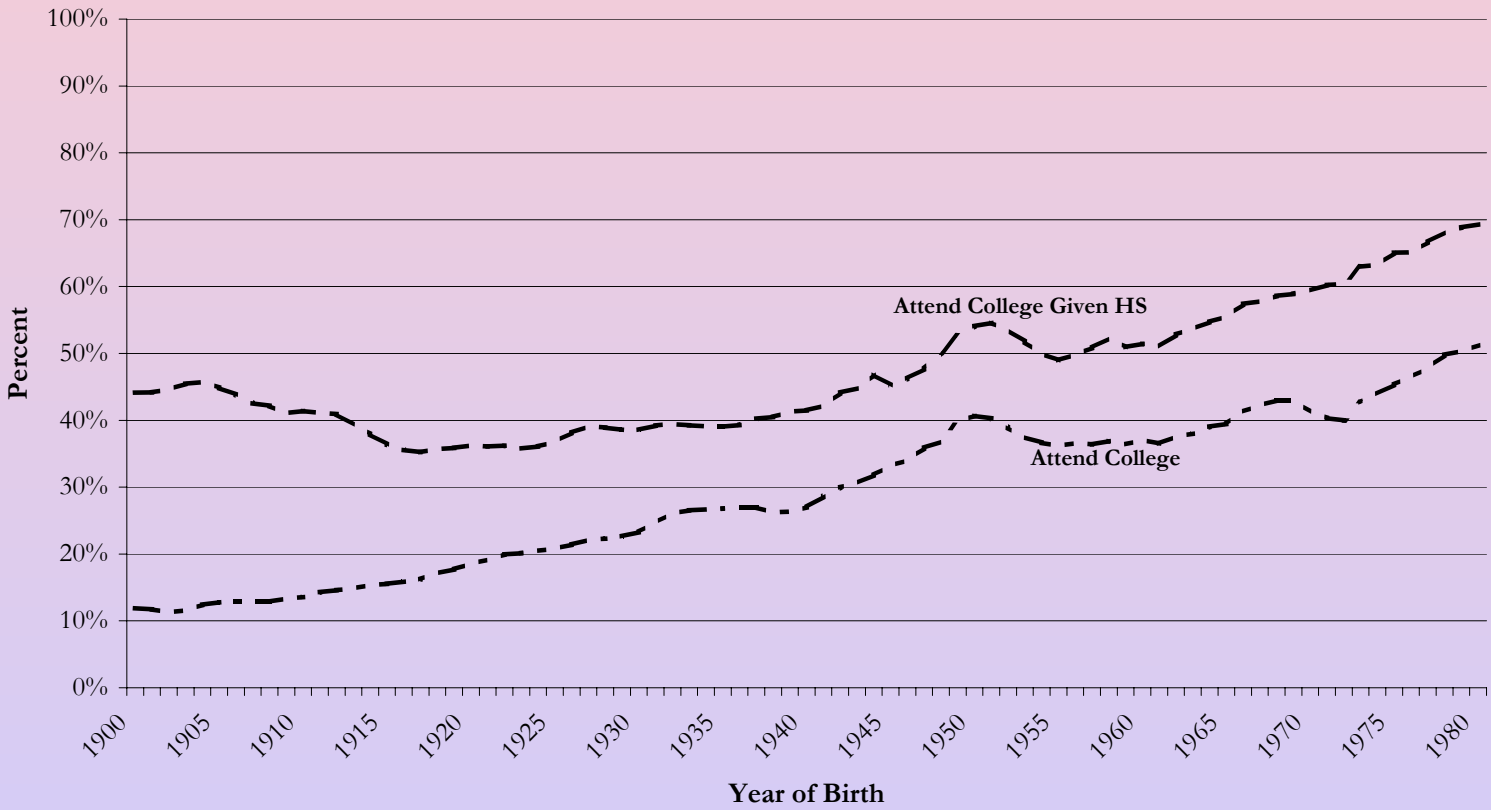

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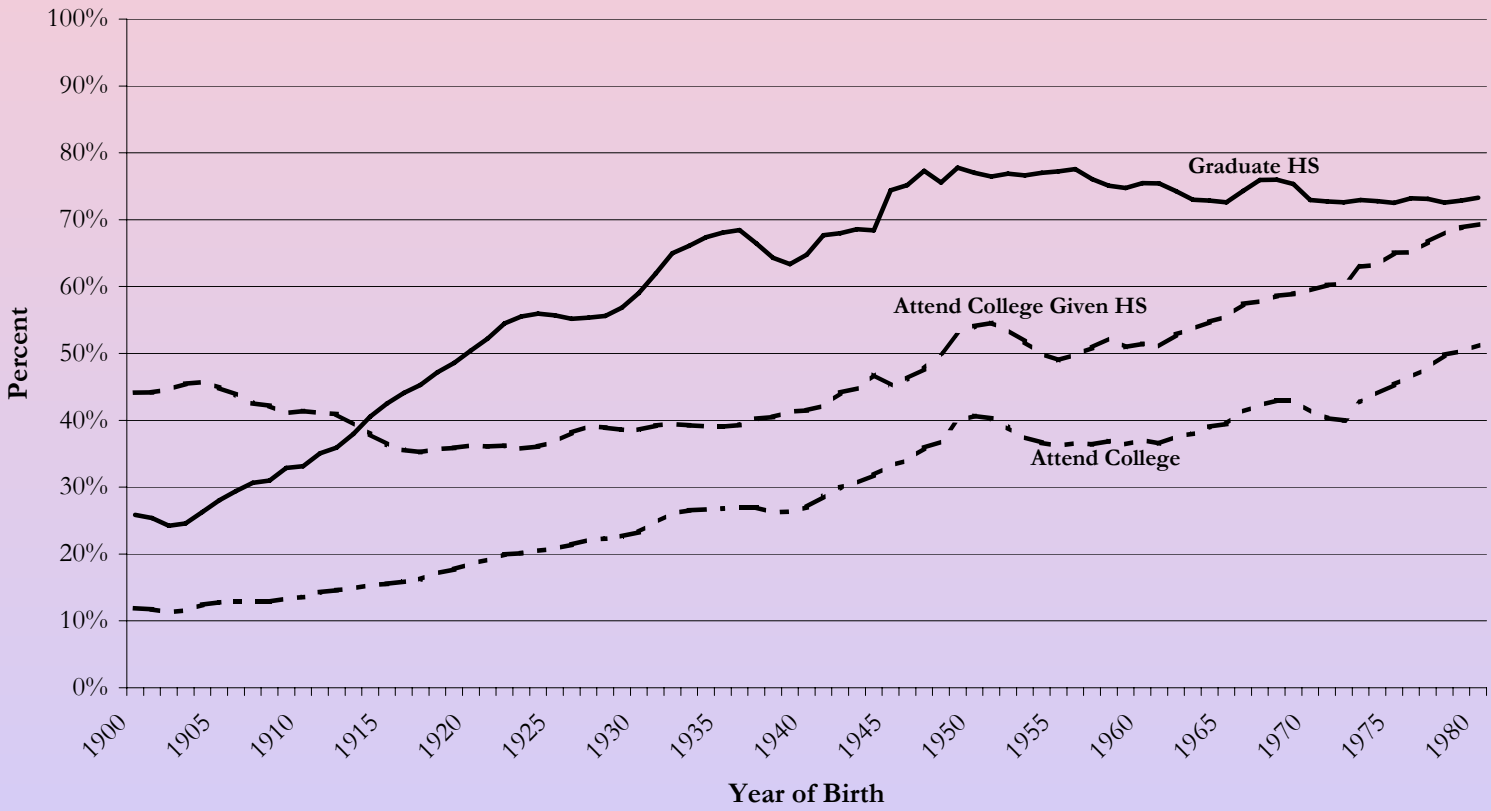

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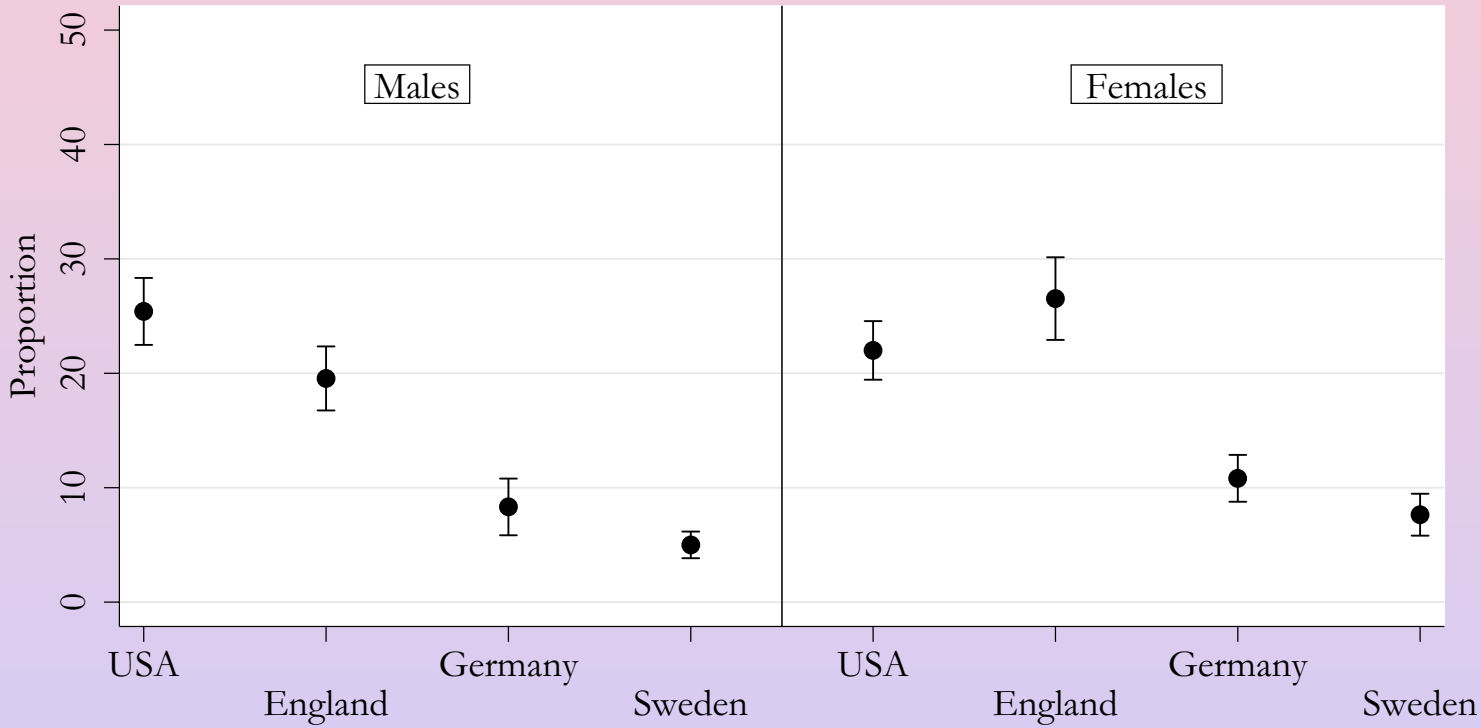
- Gaps in educational attainment have increased between majority and minority youth.

- High secondary school dropout rate leads to more people with low skills in U.S. and high level of unskilled people.

Percentage of each gender who perform at Level 1 on the IALS Document Literacy Scale



Note: The scale scores were grouped into five levels of increasing difficulty, with Level 1 representing functional illiteracy. Levels 4 and 5 were combined. The sample is restricted to adults who are between 16−65 years of age at the time of the survey (1994 for the US and Germany, 1996 for the UK, and 1994−1995 for Sweden). Standard errors are calculated using the methodology described in IALS (2002).

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- The answer is "No" to all of these questions.
- Controlling for the ability of the child, tuition costs explain a trivial fraction of the gaps by child's socieconomic status.

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- Controlling for ability at the age college decisions are made, minorities are *more* likely to enroll in college.
- Tuition costs cannot explain the dramatic gaps in high school dropping out.

Ability Explains Schooling Gaps

	White-Black Gap	White-Hispanic Gap
Complete Grade 9 or More by Age 15		
Actual White-Minority Gap	.16 (.02)	.21 (.02)
Ability Adjusted Gap	-.10 (.03)	-.02 (.07)
High School Completion Gap		
Actual White-Minority Gap	.06 (.01)	.14 (.02)
Ability Adjusted Gap	-.14 (.03)	-.12 (.04)

Source: Cameron and Heckman (2001)

Ability Explains Schooling Gaps

	White-Black Gap	White-Hispanic Gap
College Entry Probabilities given High School Completion		
Actual White-Minority Gap	.11 (.02)	.07 (.02)
Ability Adjusted Gap	-.14 (.02)	-.14 (.04)
Population College Entry Gap (Unconditional on HS Completion)		
Actual White-Minority Gap	.12 (.02)	.14 (.02)
Ability Adjusted Gap	-.16 (.03)	-.15 (.04)

Source: Cameron and Heckman (2001)

- How to explain these facts?

The Argument in a Nutshell

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1. Many major economic and social problems such as crime, teenage pregnancy, dropping out of high school and adverse health conditions can be traced to low levels of skill and ability in the population.
2. Ability gaps between the advantaged and disadvantaged open up early in the life of the child.
3. Life cycle skill formation is dynamic in nature. Skill begets skill; motivation begets motivation. If a child is not motivated and stimulated to learn and engage early on in life, the more likely it is that when the child becomes an adult, it will fail in social and economic life. The longer we wait to intervene in the life cycle of the child the more costly it is to remediate.

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5. Much public policy discussion focuses on promoting and measuring cognitive ability through IQ and achievement tests. No Child Left Behind focuses on achievement test scores in the 4th grade, not looking at a range of other factors that promote success in school and life.

6. Cognitive abilities are important for socioeconomic success.

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7. But socioemotional skills, physical and mental health, perseverance, attention, motivation, self confidence are also important for success in life.

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7. But socioemotional skills, physical and mental health, perseverance, attention, motivation, self confidence are also important for success in life.
8. Motivation, perseverance and tenacity feed into performance in society at large and even affect scores on achievement tests.

9. Early family environments are major predictors of cognitive and socioemotional abilities, as well as crime, health and obesity.

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11. Experiments support a large body of non-experimental evidence that adverse family environments promote adult failure.

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13. Early interventions promote schooling, reduce crime, promote workforce productivity and reduce teenage pregnancy.
14. These interventions are estimated to have high benefit-cost ratios and rates of return.

15. Early interventions have much higher returns than other later interventions such as reduced pupil-teacher ratios, public job training, convict rehabilitation programs, tuition subsidies or expenditure on police.

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16. A major refocus of policy is required to understand the life cycle of skill and health formation and the importance of the early years.

The Importance of Cognitive and Noncognitive Skills

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- Recent research has shown that earnings, employment, labor force experience, college attendance, teenage pregnancy, participation in risky activities, compliance with health protocols and participation in crime strongly depend on cognitive and noncognitive abilities.
- Noncognitive abilities mean socioemotional regulation, time preference, personality factors and ability to work with others.

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- Evidence from the GED program (Heckman and Rubinstein, 2001).

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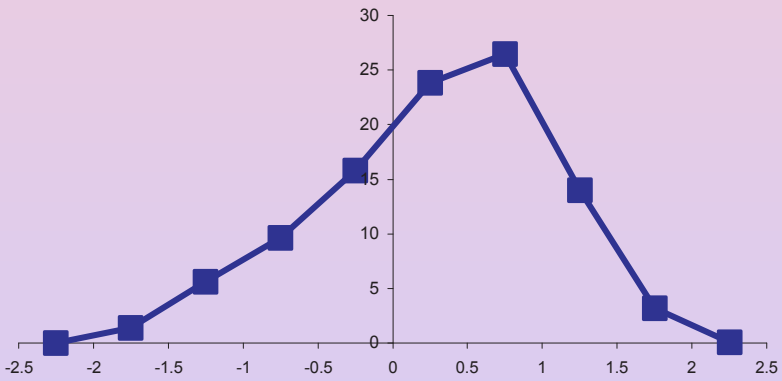
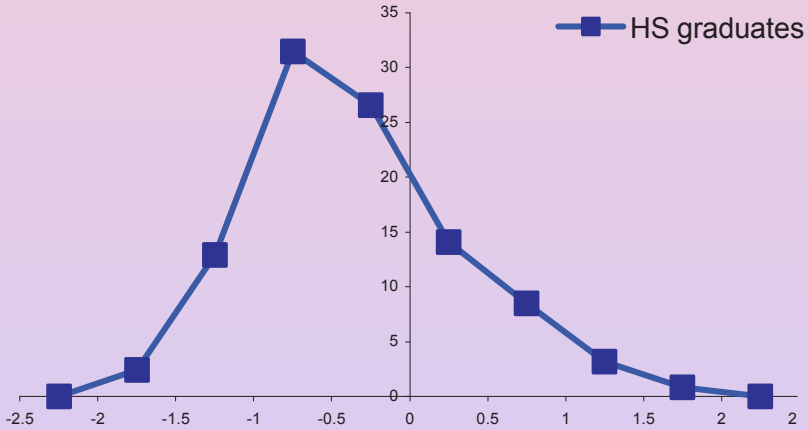
- Level relatively low–at the grade 8 to grade 10 level.
- Test is successful in its own terms.

Density of age adjusted AFQT scores, GED recipients and high school graduates with twelve years of schooling

White Males



White Females



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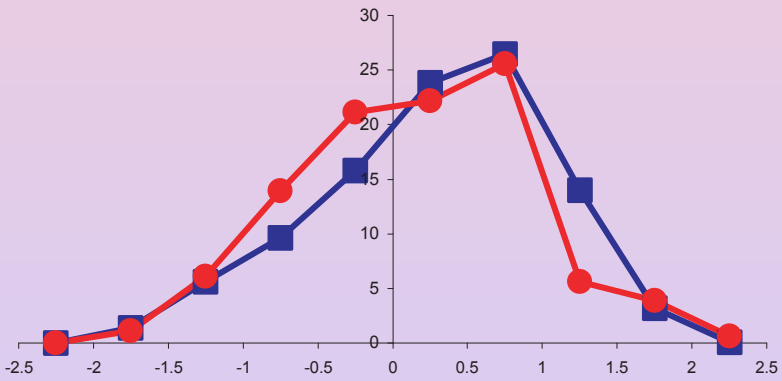

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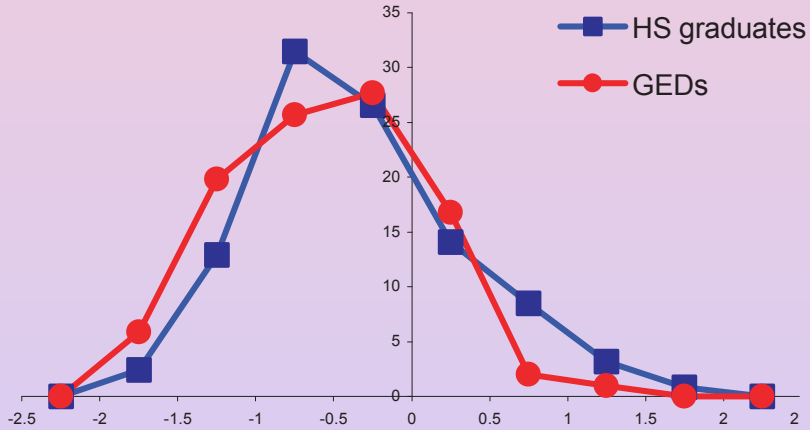

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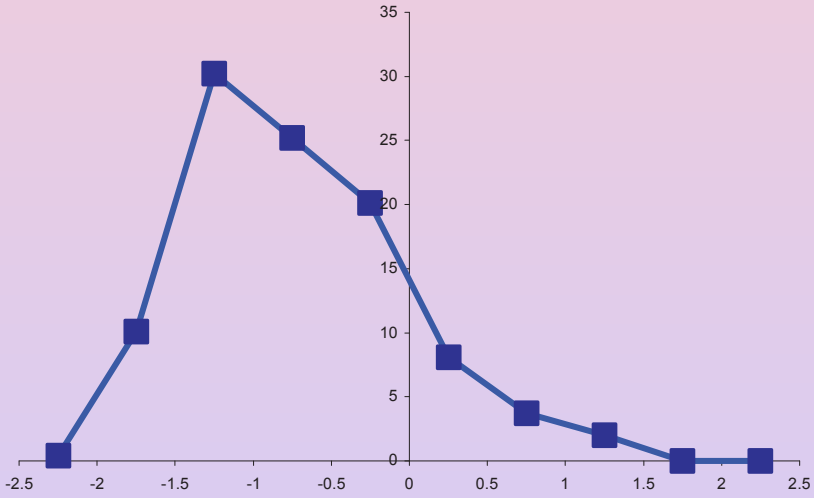

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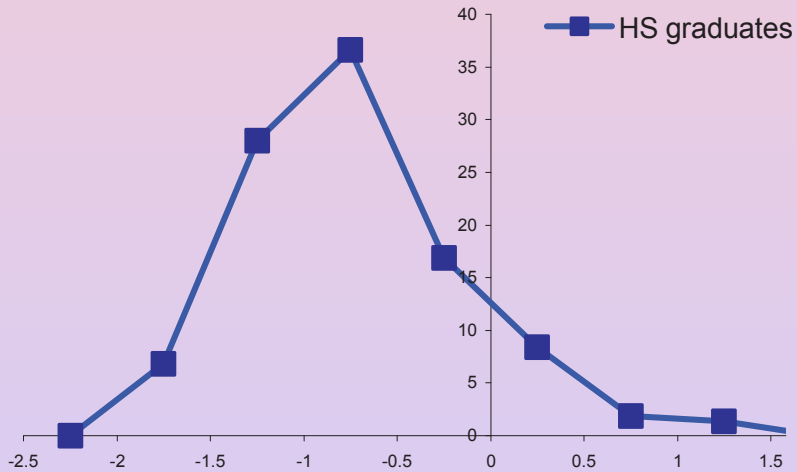

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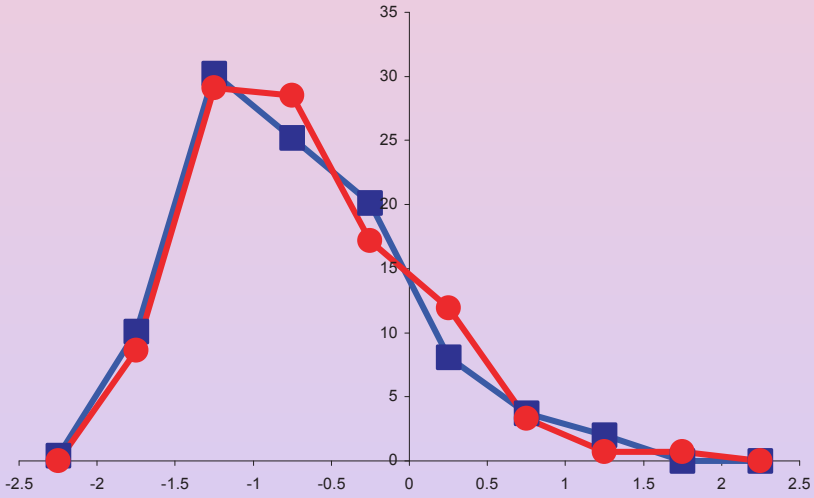

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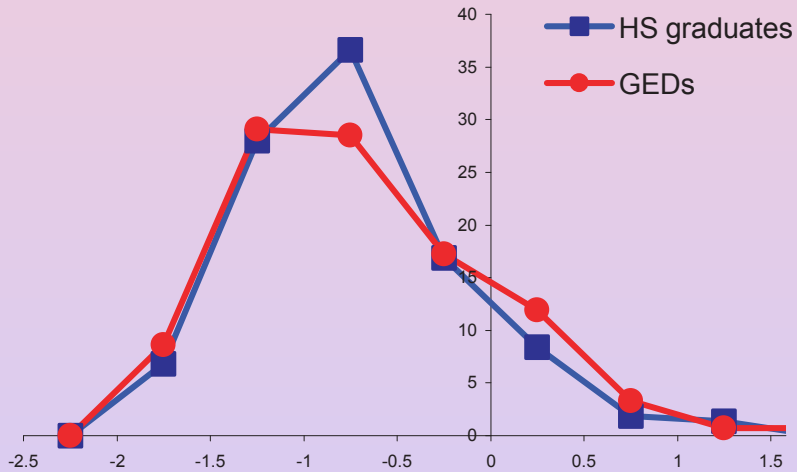

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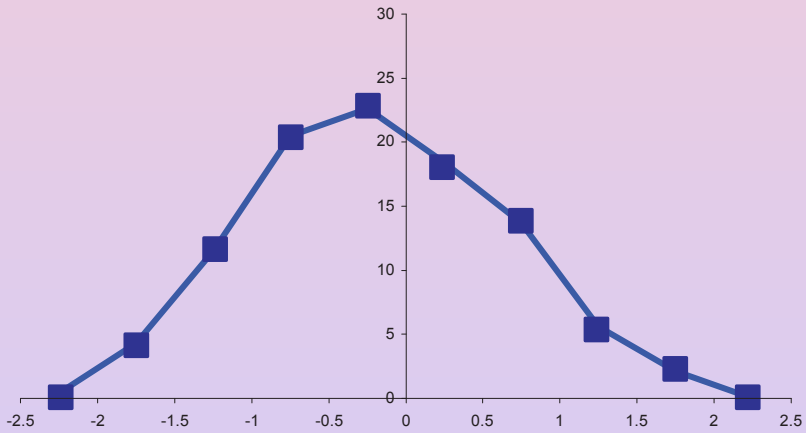

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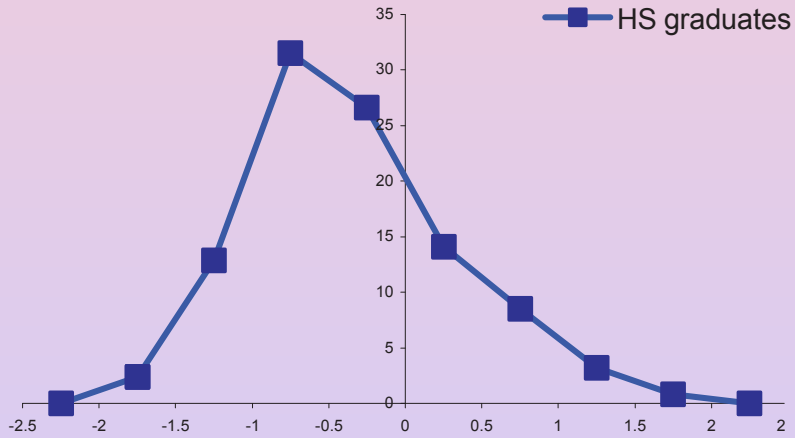

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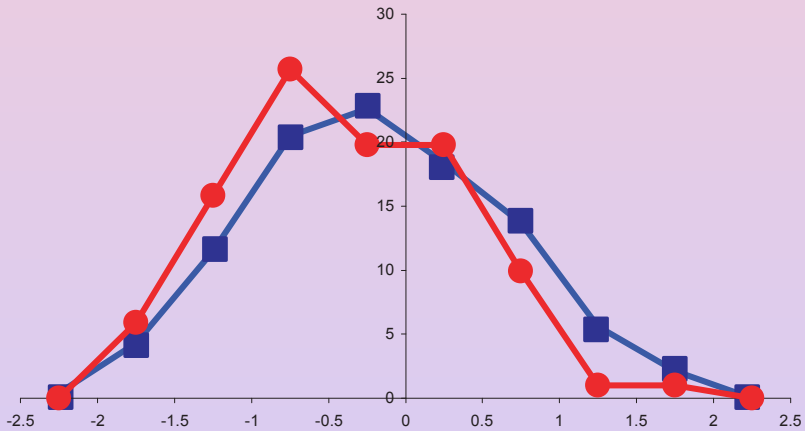

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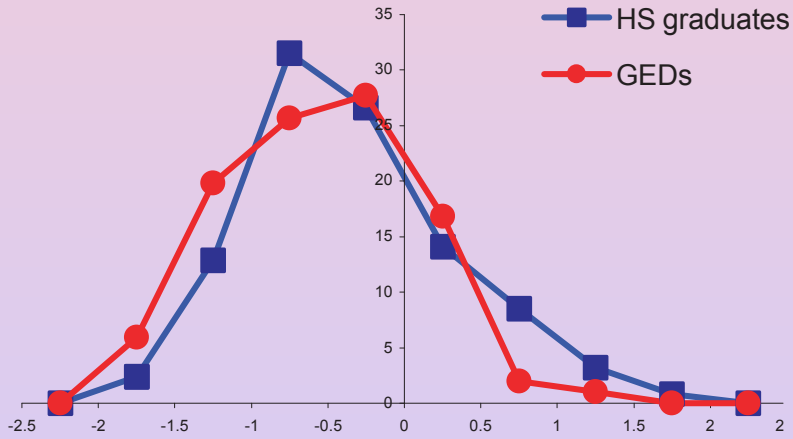

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- The GEDs are the wise guys who can't finish anything.
- Most branches of the U.S. military recognize this in their recruiting strategies.

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- Both cognitive and noncognitive skills matter in a variety of aspects of life.

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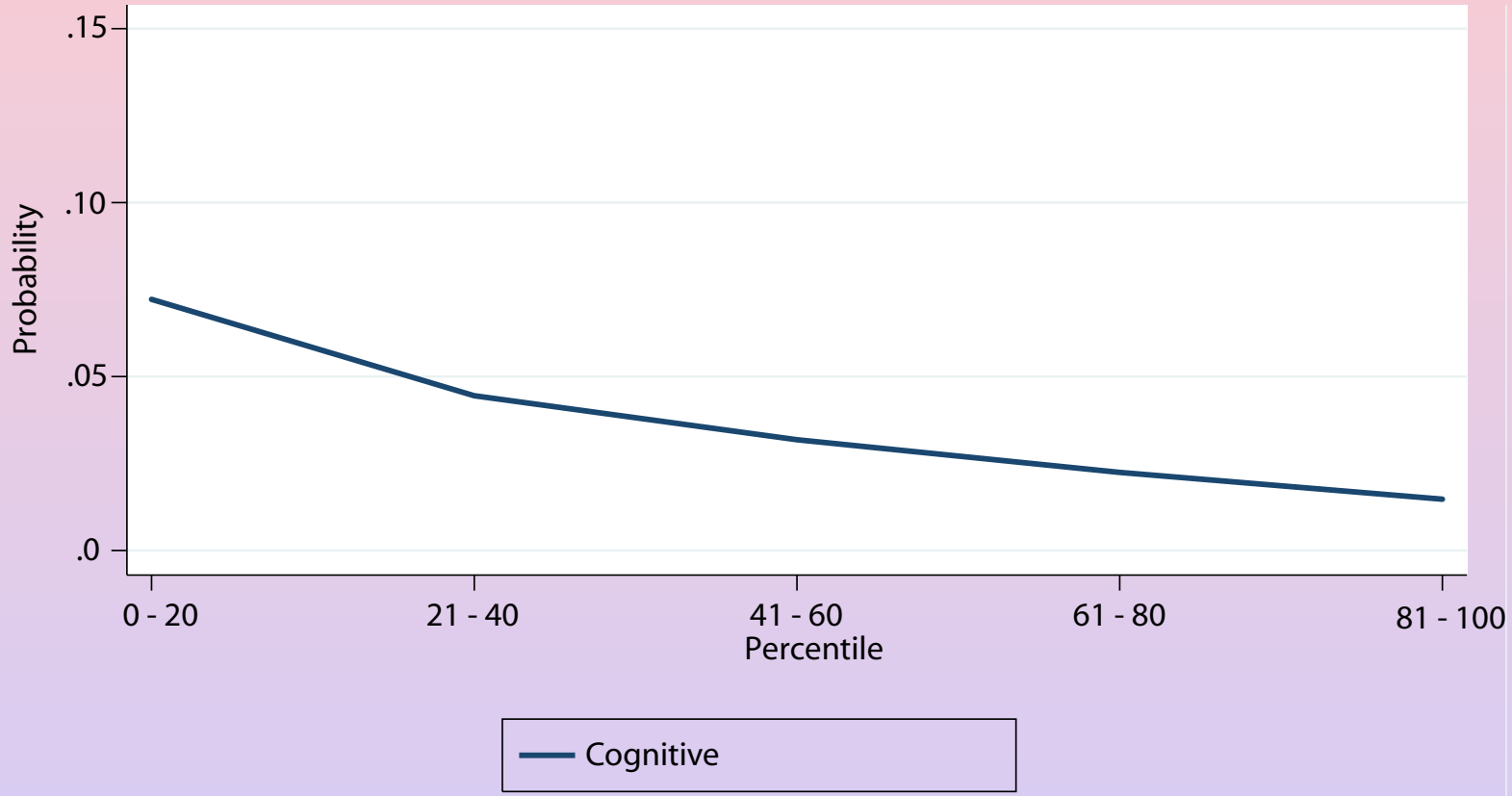
- Look at effects of both cognitive and noncognitive skills on many measures of social performance.

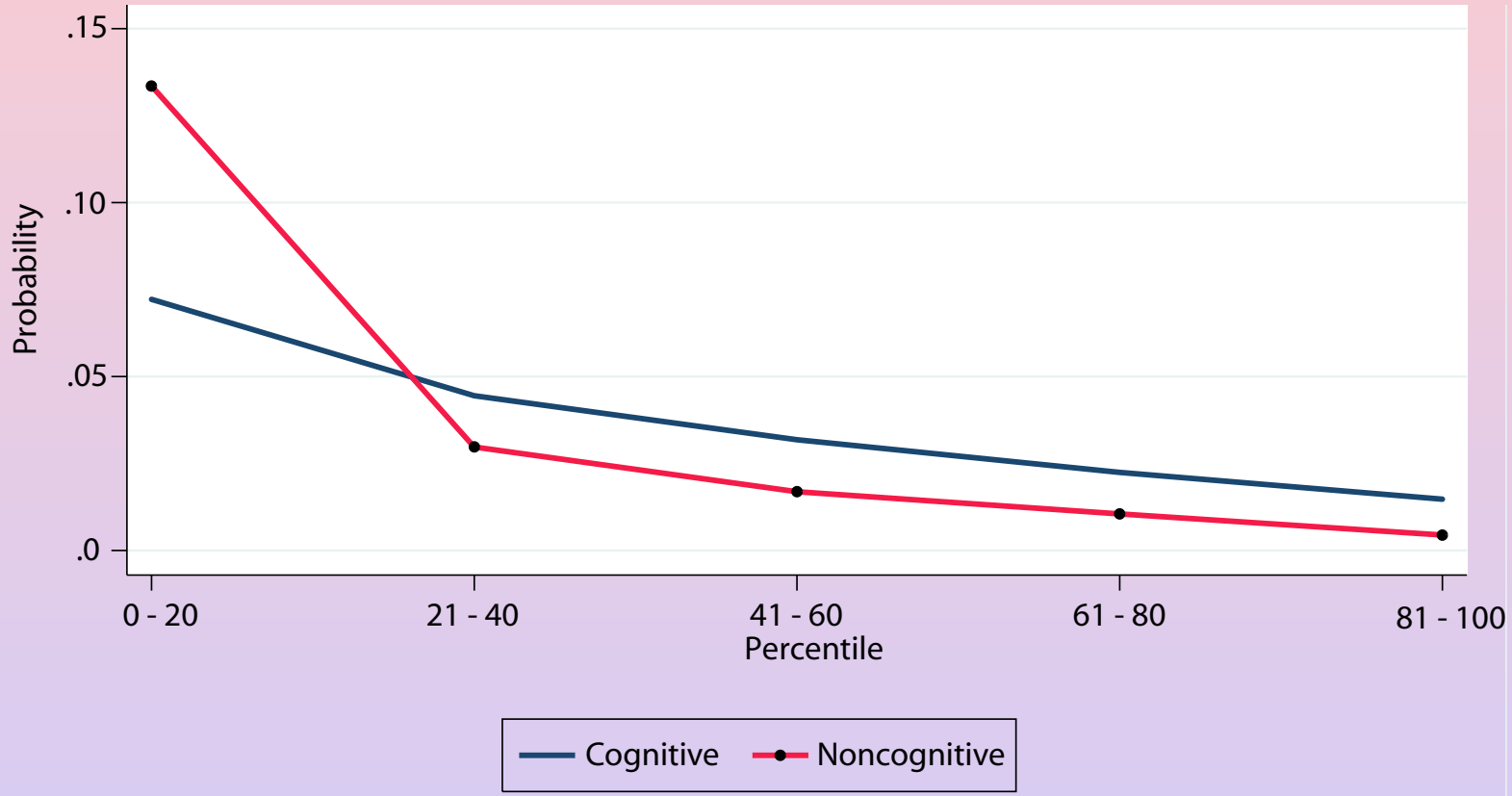
Ever been in jail by age 30, by ability (males)



Note: This figure plots the probability of a given behavior associated with moving up in one ability distribution for someone after integrating out the other distribution. For example, the lines with markers show the effect of increasing noncognitive ability after integrating the cognitive ability.

Source: Heckman, Stixrud, and Urzua (2006).

Ever been in jail by age 30, by ability (males)



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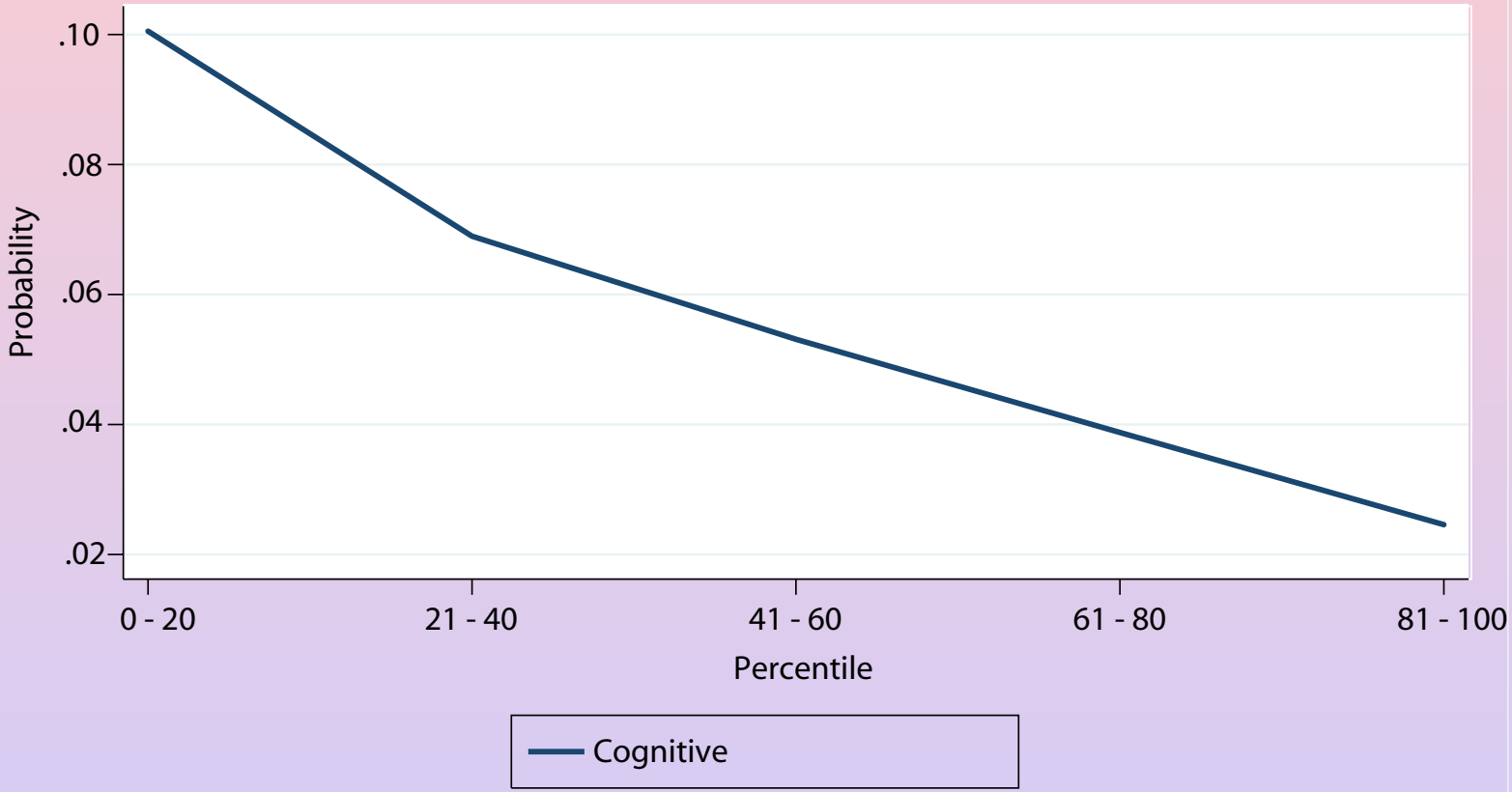
Source: Heckman, Stixrud, and Urzua (2006).

Probability of being single with children (females)



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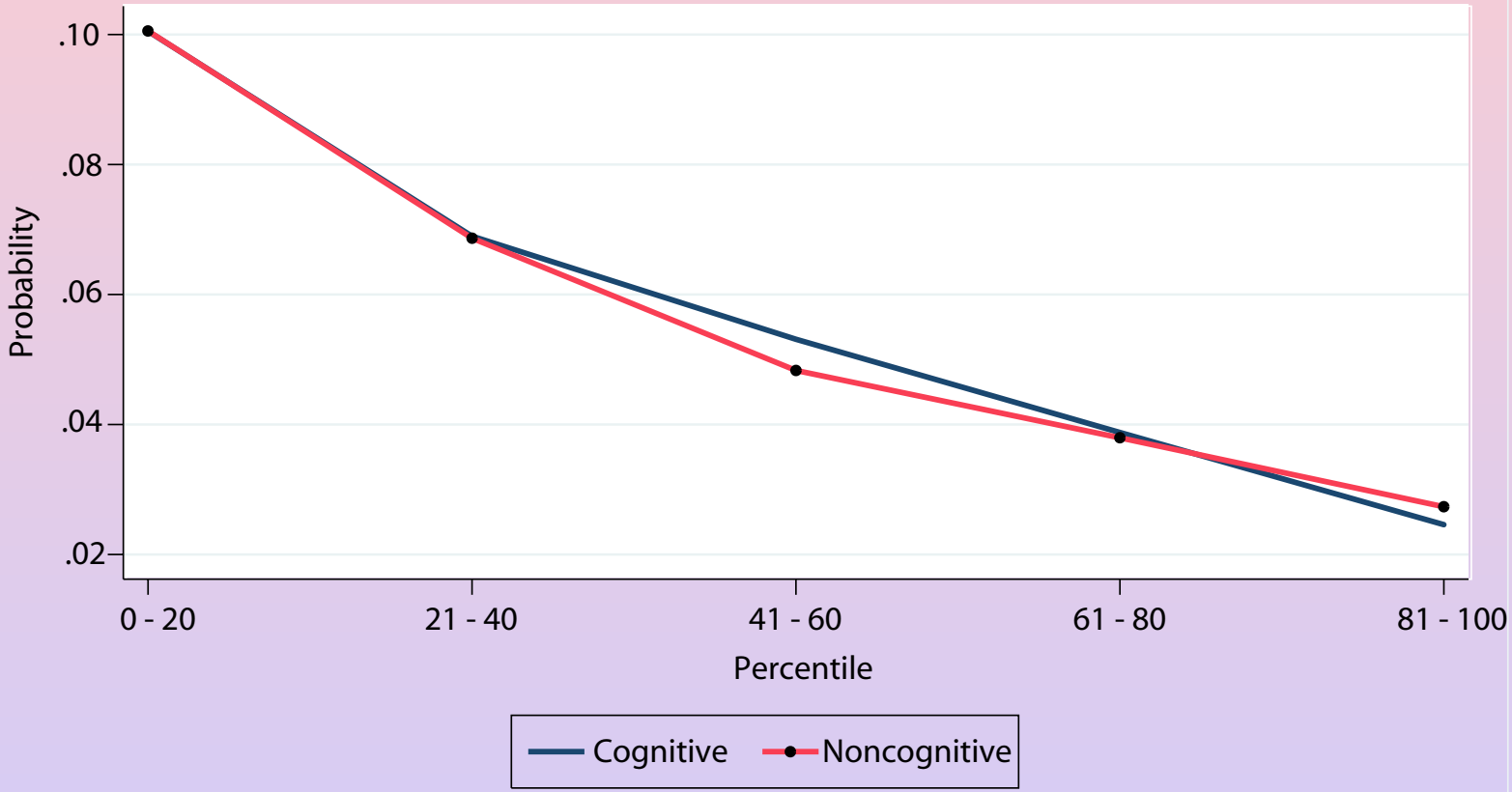

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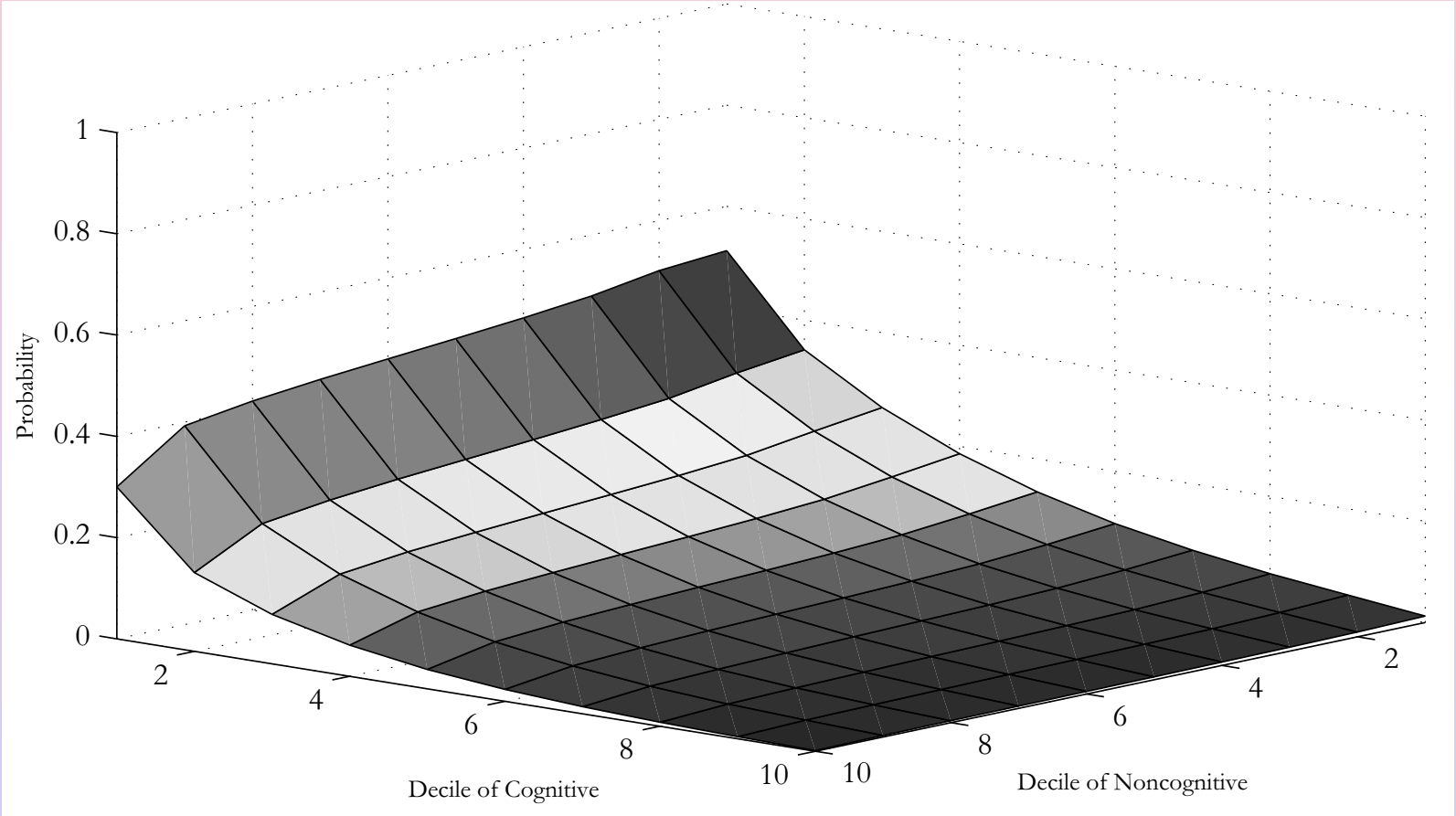
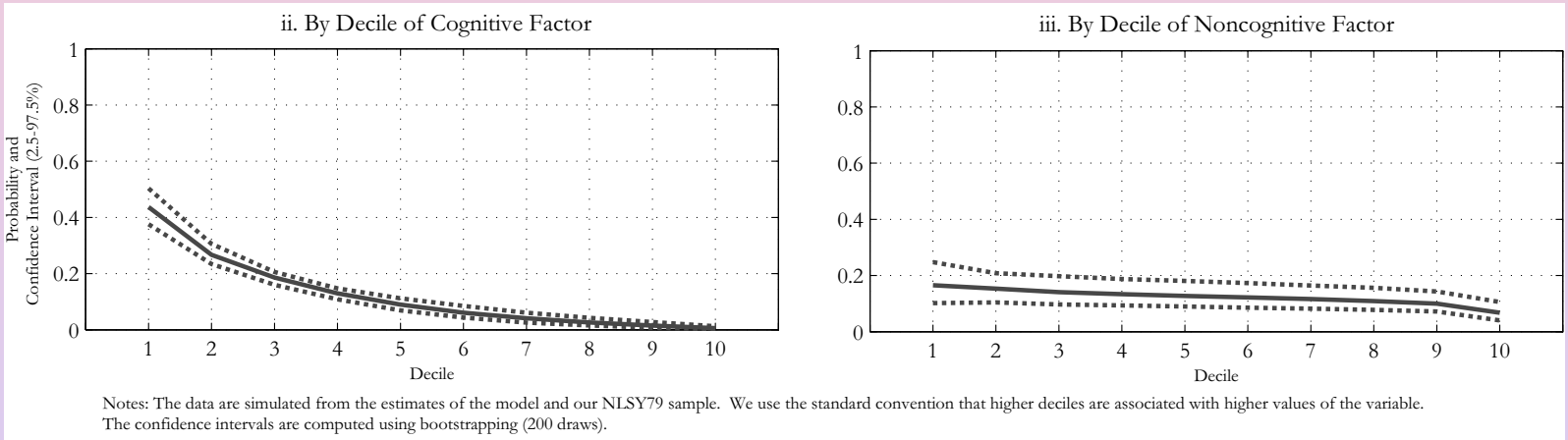
Source: Heckman, Stixrud, and Urzua (2006).

Probability of being a high school dropout by age 30 (males)

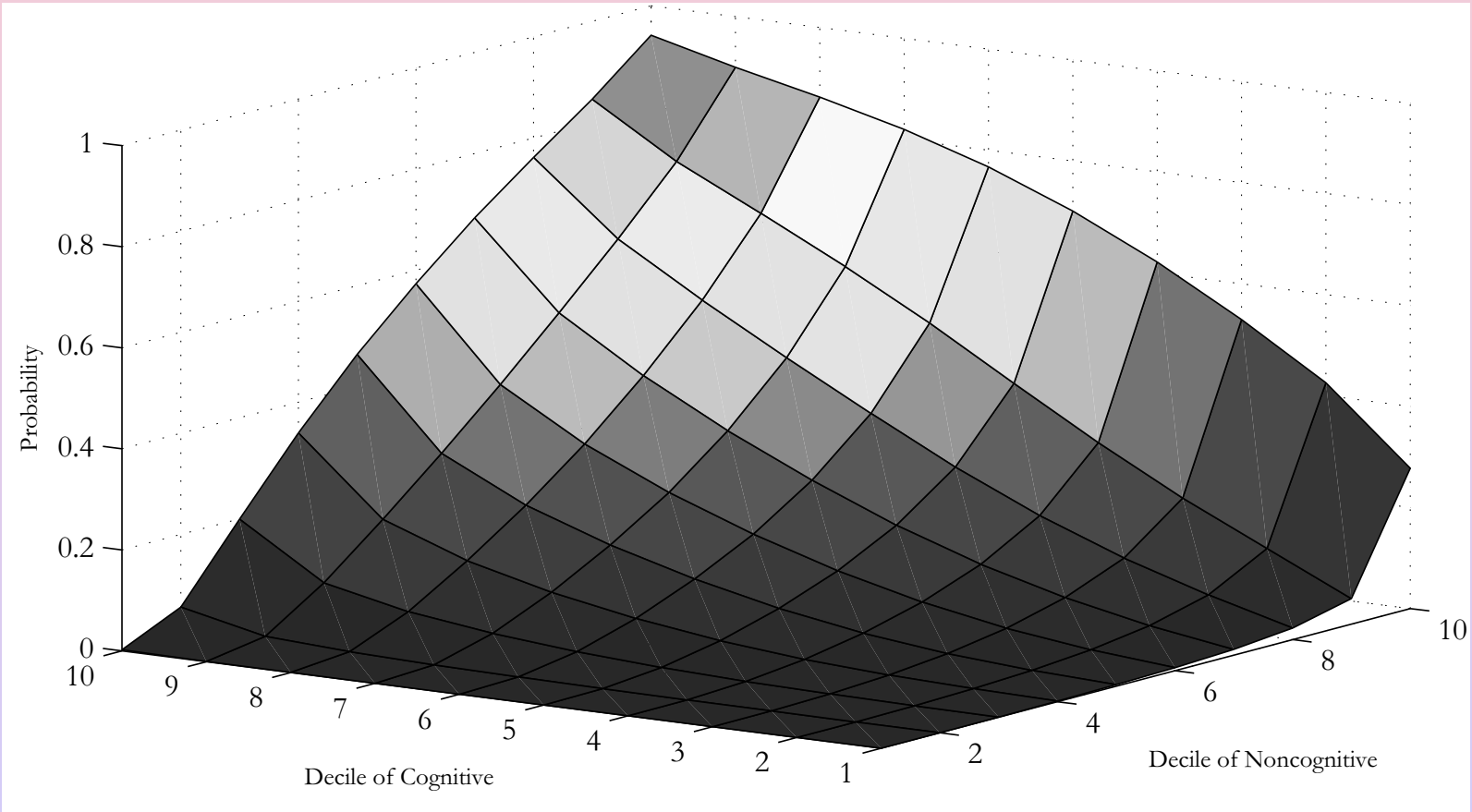


Probability of being a high school dropout by age 30 (males)



Notes: The data are simulated from the estimates of the model and our NLSY79 sample. We use the standard convention that higher deciles are associated with higher values of the variable. The confidence intervals are computed using bootstrapping (200 draws).

Probability of being a 4-year college graduate by age 30 (males)



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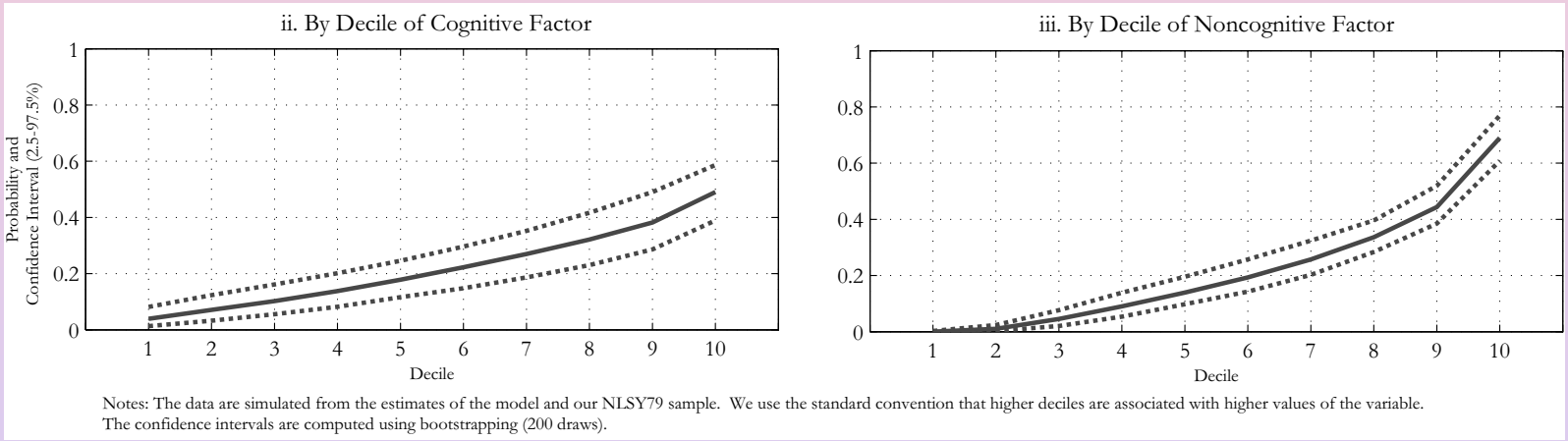
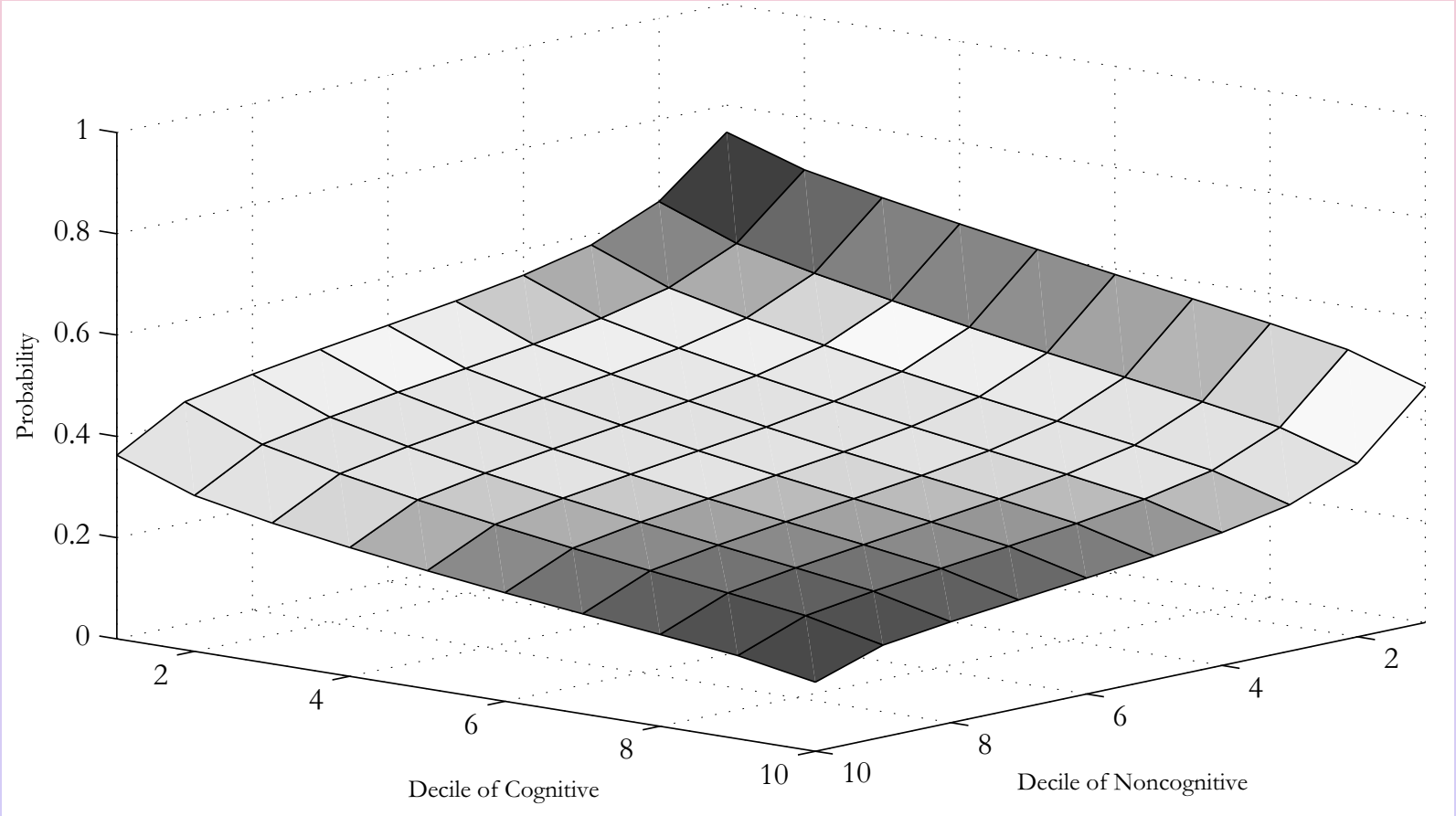


Notes: The data are simulated from the estimates of the model and our NLSY79 sample. We use the standard convention that higher deciles are associated with higher values of the variable. The confidence intervals are computed using bootstrapping (200 draws).

Probability of daily smoking by age 18 (males)



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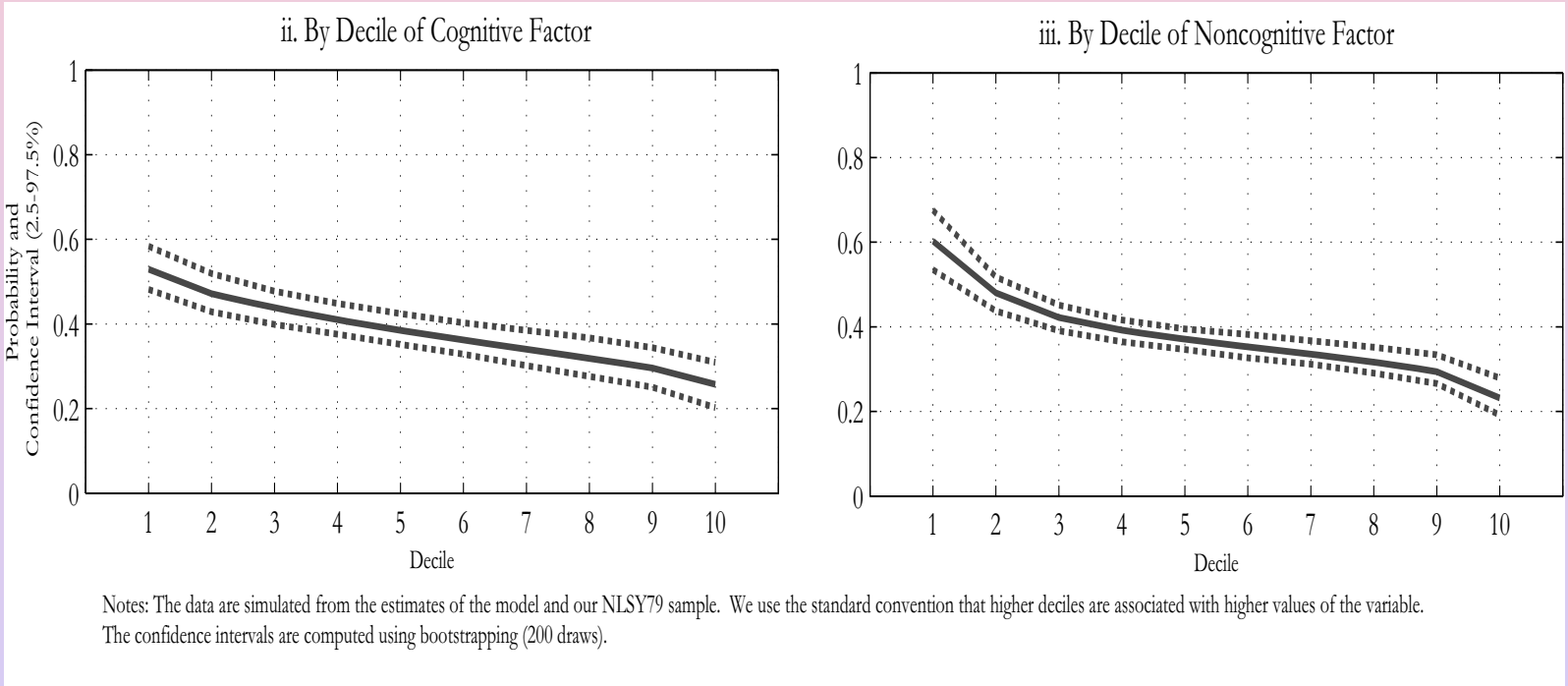
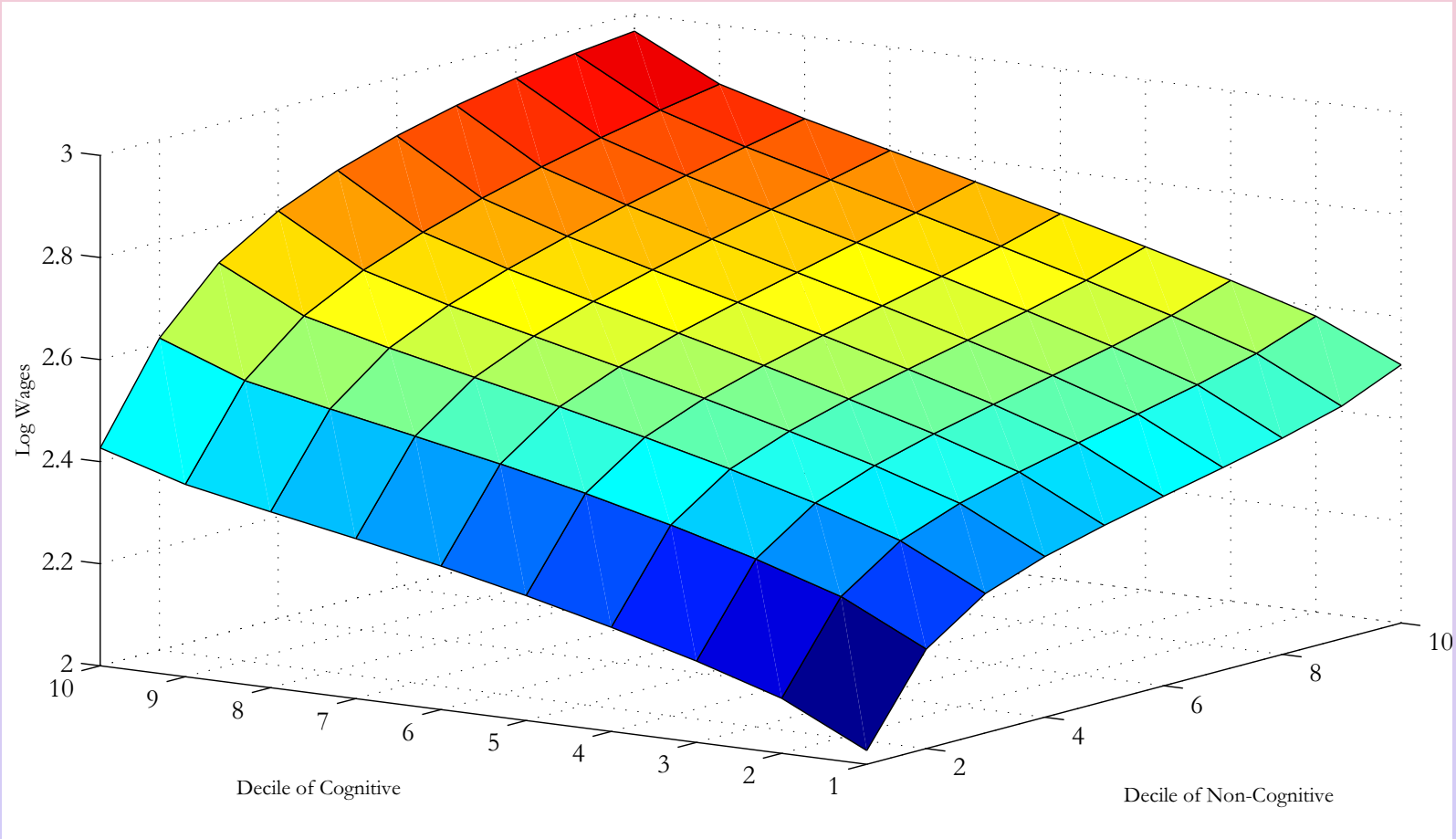


Notes: The data are simulated from the estimates of the model and our NLSY79 sample. We use the standard convention that higher deciles are associated with higher values of the variable. The confidence intervals are computed using bootstrapping (200 draws).

Mean log wages by age 30 (males)



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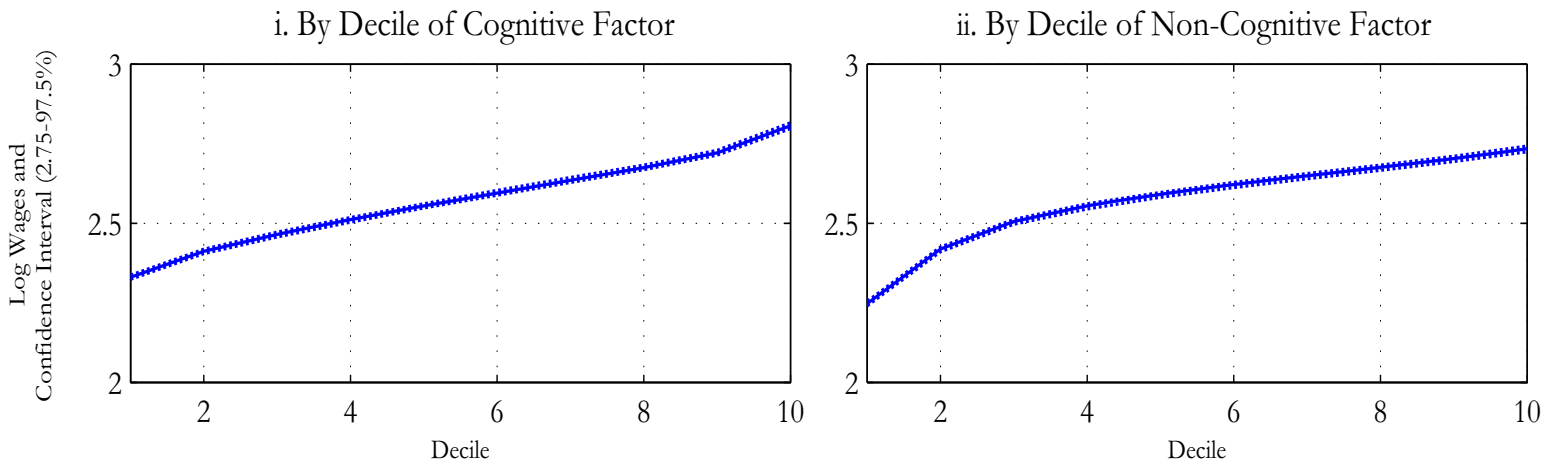

Notes: The data are simulated from the estimates of the model and our NLSY79 sample. We use the standard convention that higher deciles are associated with higher values of the variable. The confidence intervals are computed using bootstrapping (50 draws).

- Controlling for ability, minorities are *more likely* to attend college than others despite their lower family incomes (Cameron and Heckman, 2001).

Abilities and Outcomes

- Gaps in the abilities that play such an important role in determining diverse adult labor market and health outcomes open up early across income groups.

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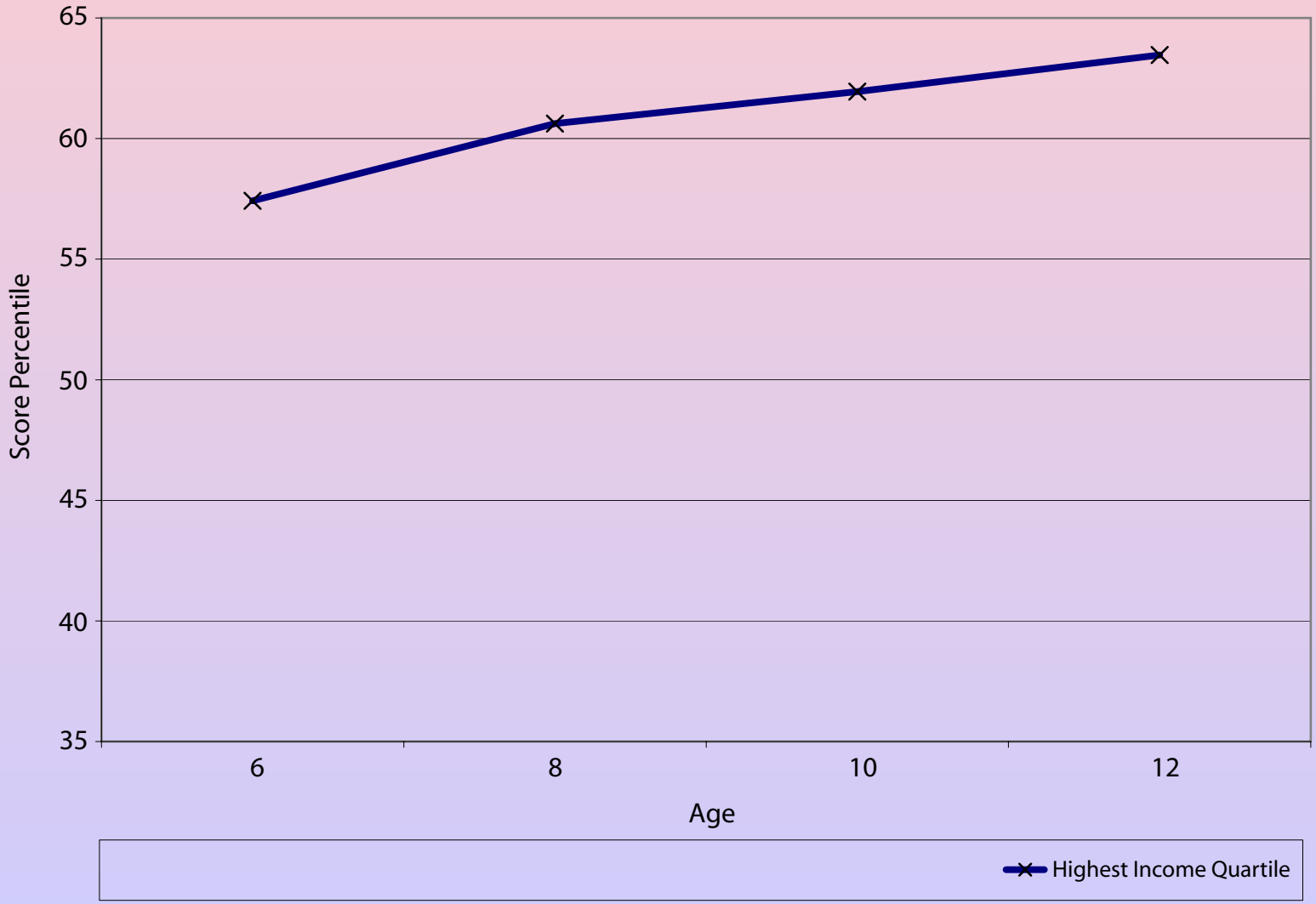
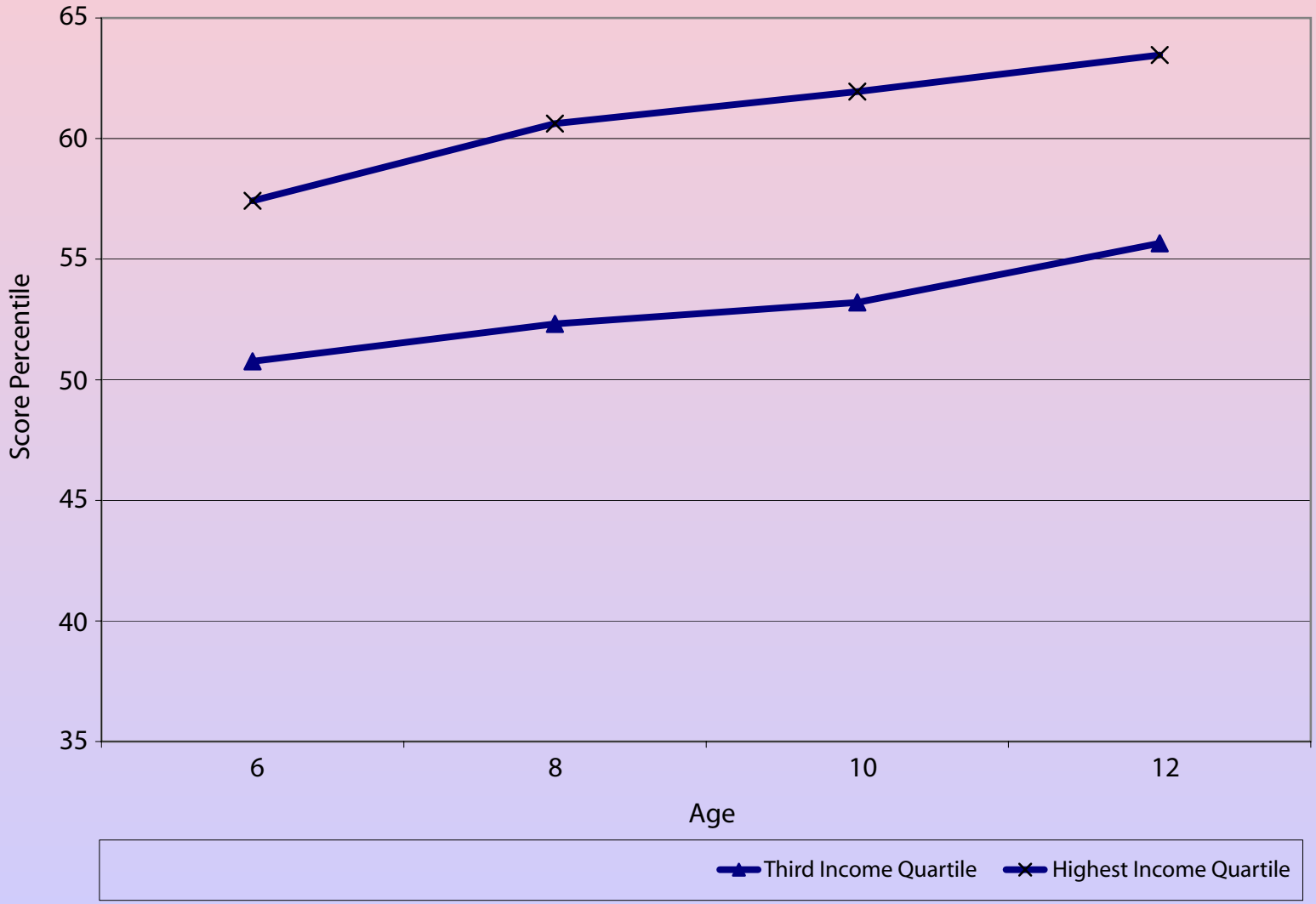
- Schooling after the second grade plays only a minor role in alleviating these gaps.
- Measures of schooling quality (teacher/pupil ratios and teacher salaries) that receive so much attention in public forums play only a minor role in creating or eliminating the gaps after the first few years of schooling.

Average percentile rank on PIAT-Math score, by income quartile



Average percentile rank on PIAT-Math score, by income quartile



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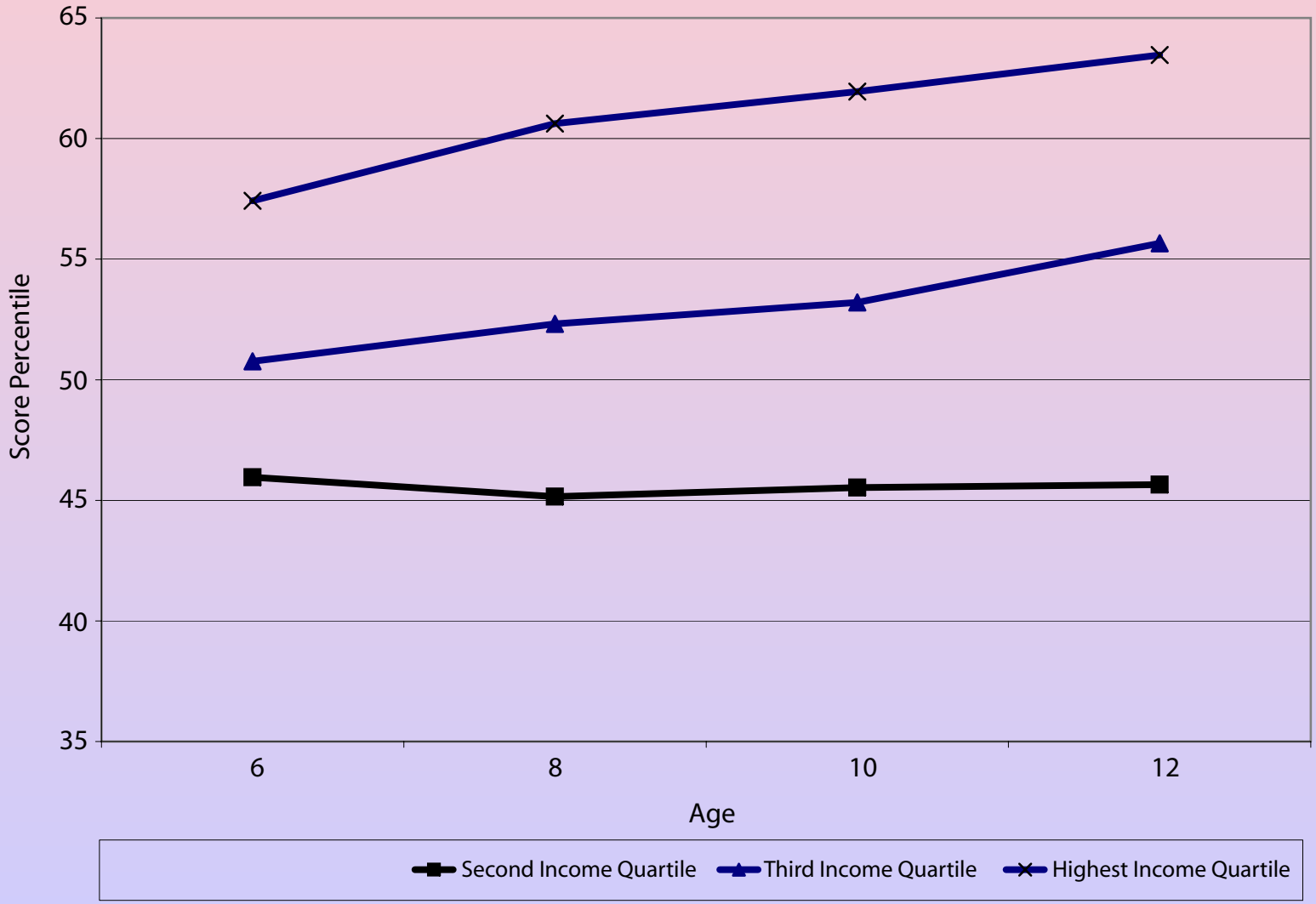
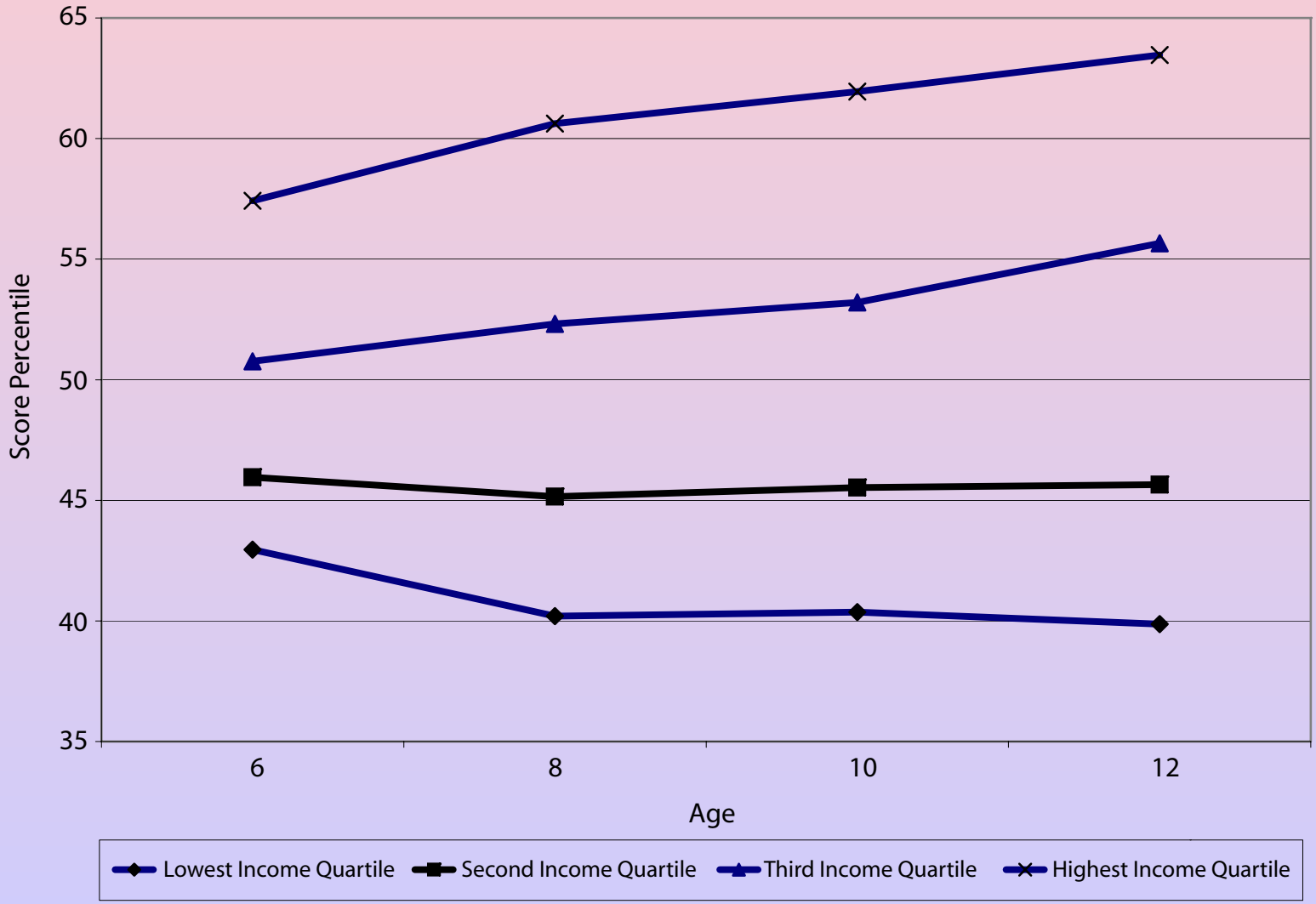
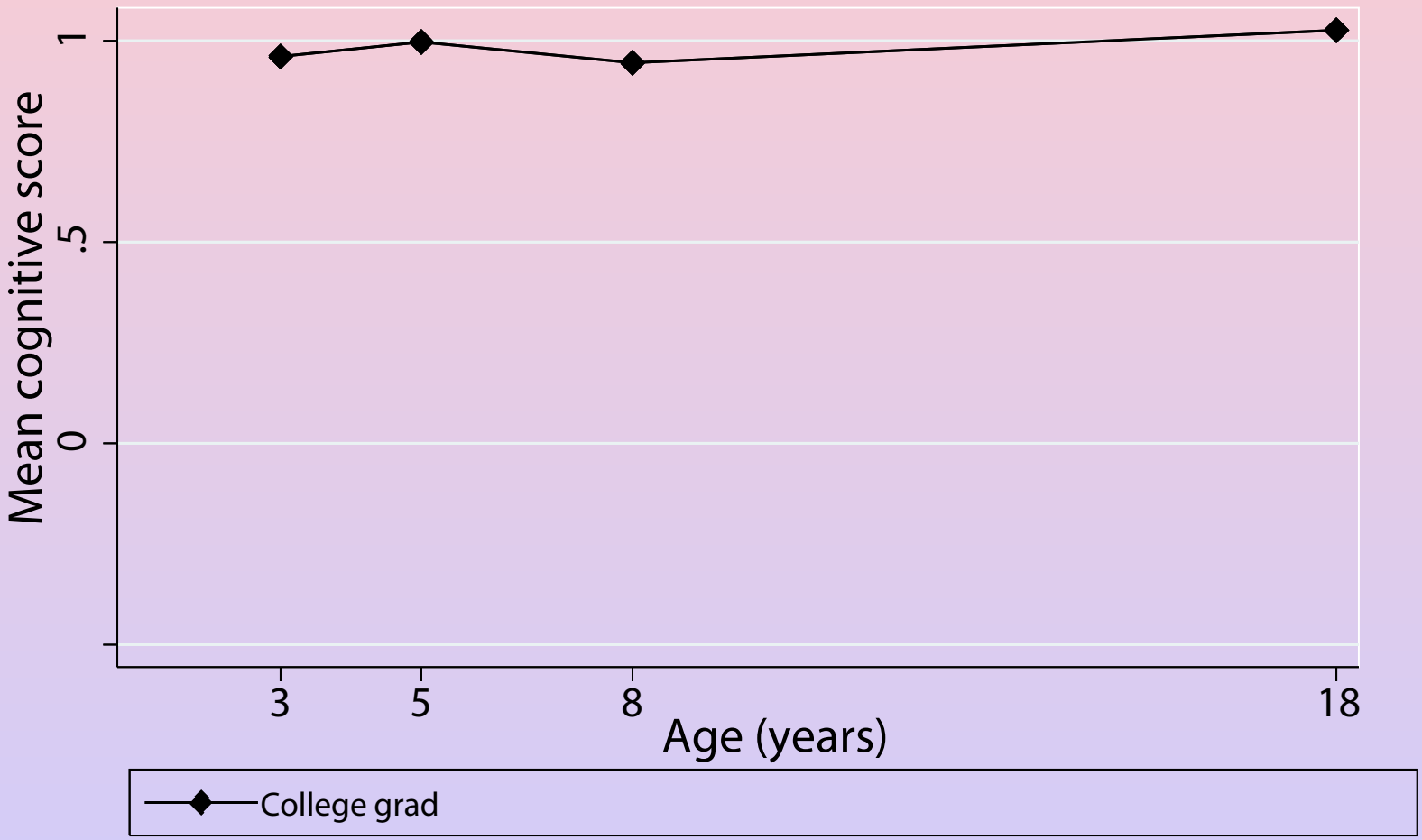


Average percentile rank on PIAT-Math score, by income quartile

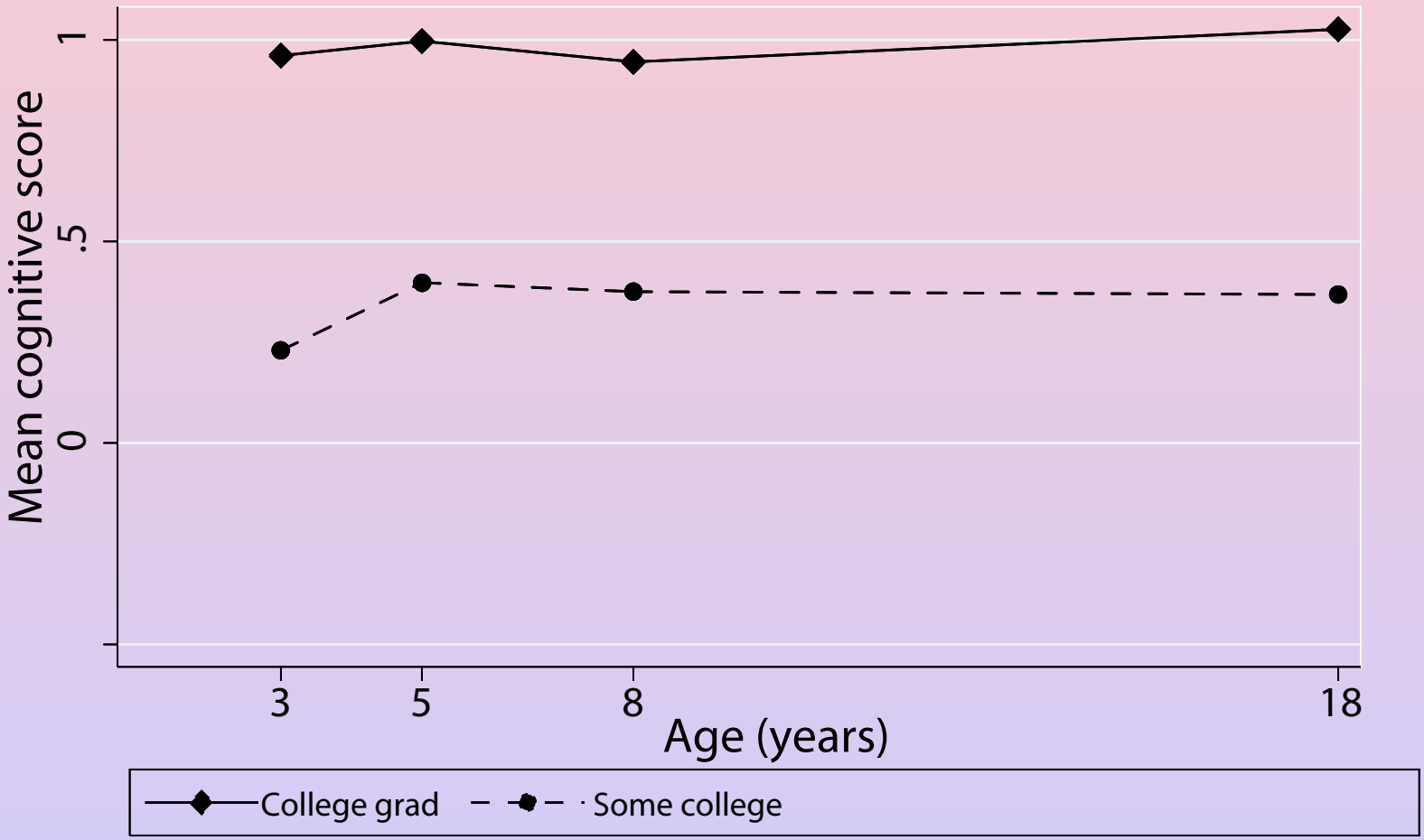


Trend in mean cognitive score by maternal education



Each score standardized within observed sample. Using all observations and assuming data missing at random. Source: Brooks-Gunn et al. (2006).

Trend in mean cognitive score by maternal education



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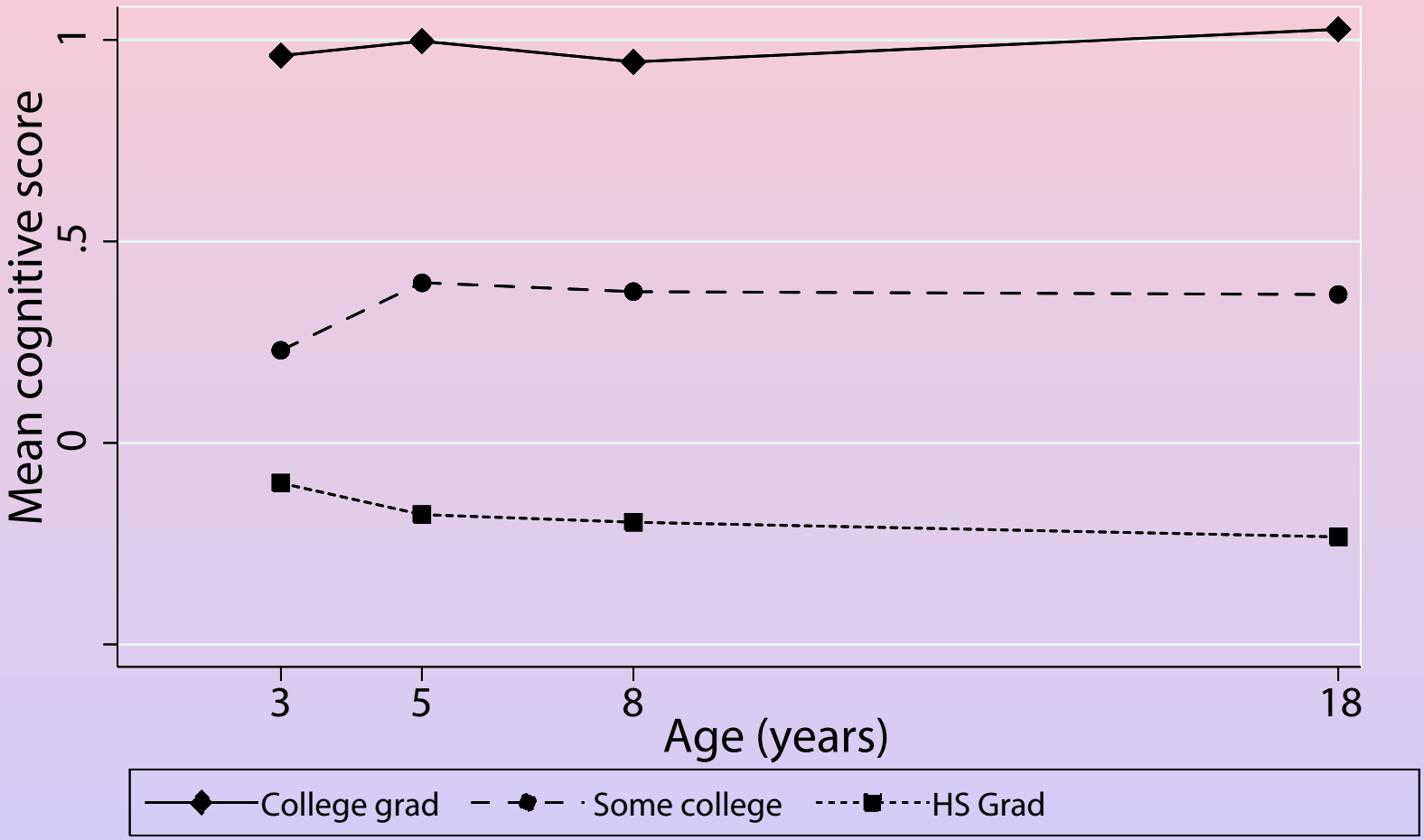

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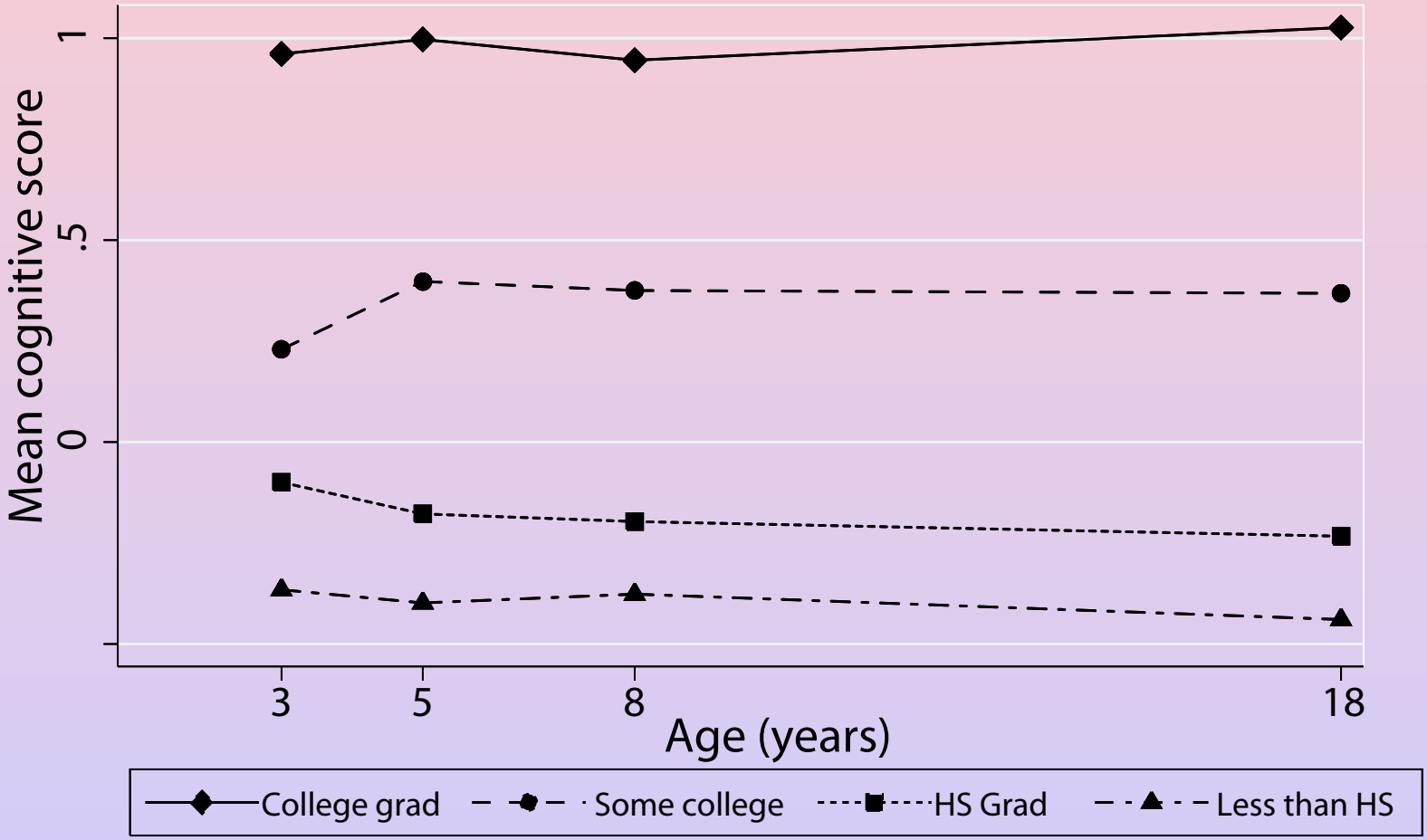

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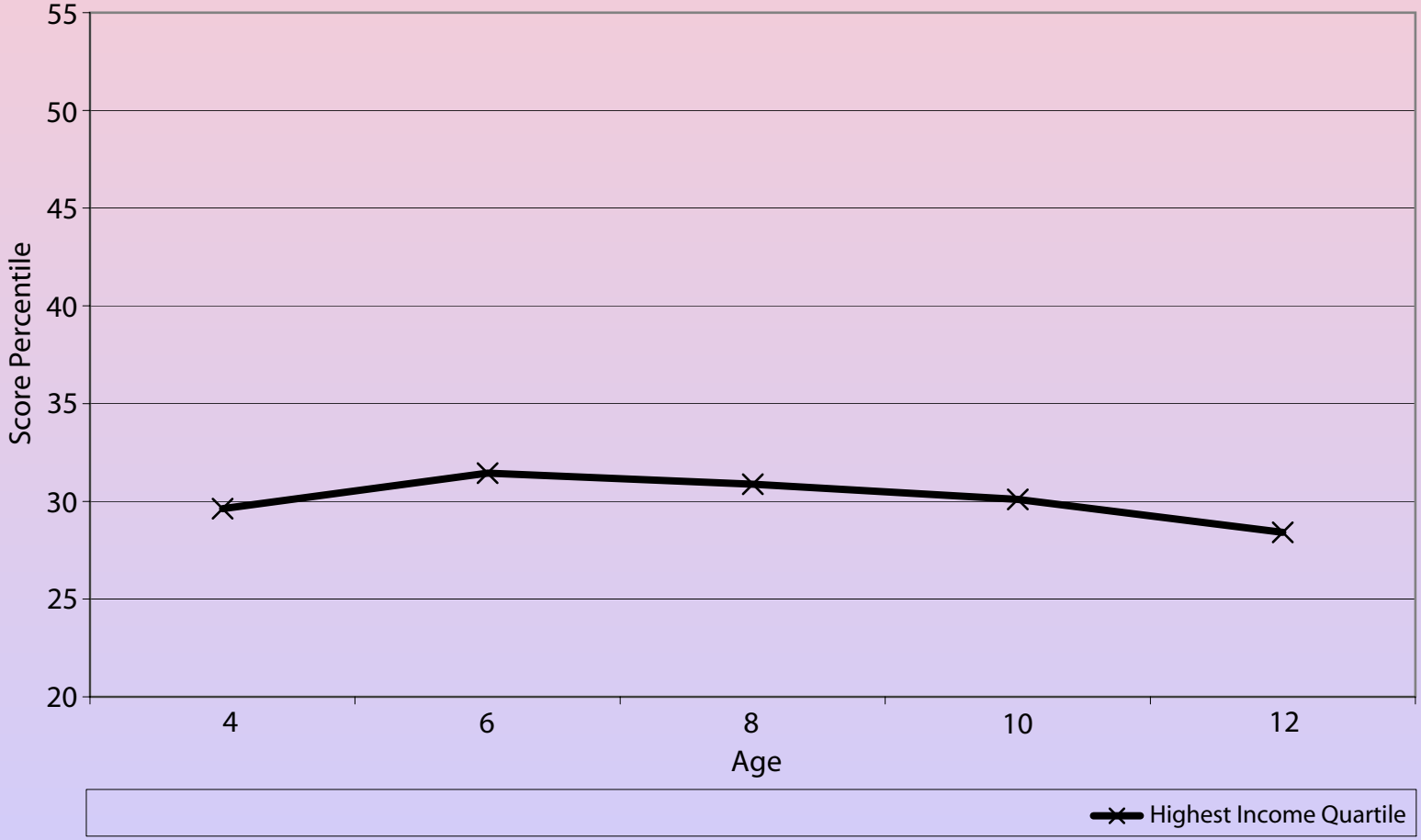
Average percentile rank on anti-social score, by income quartile



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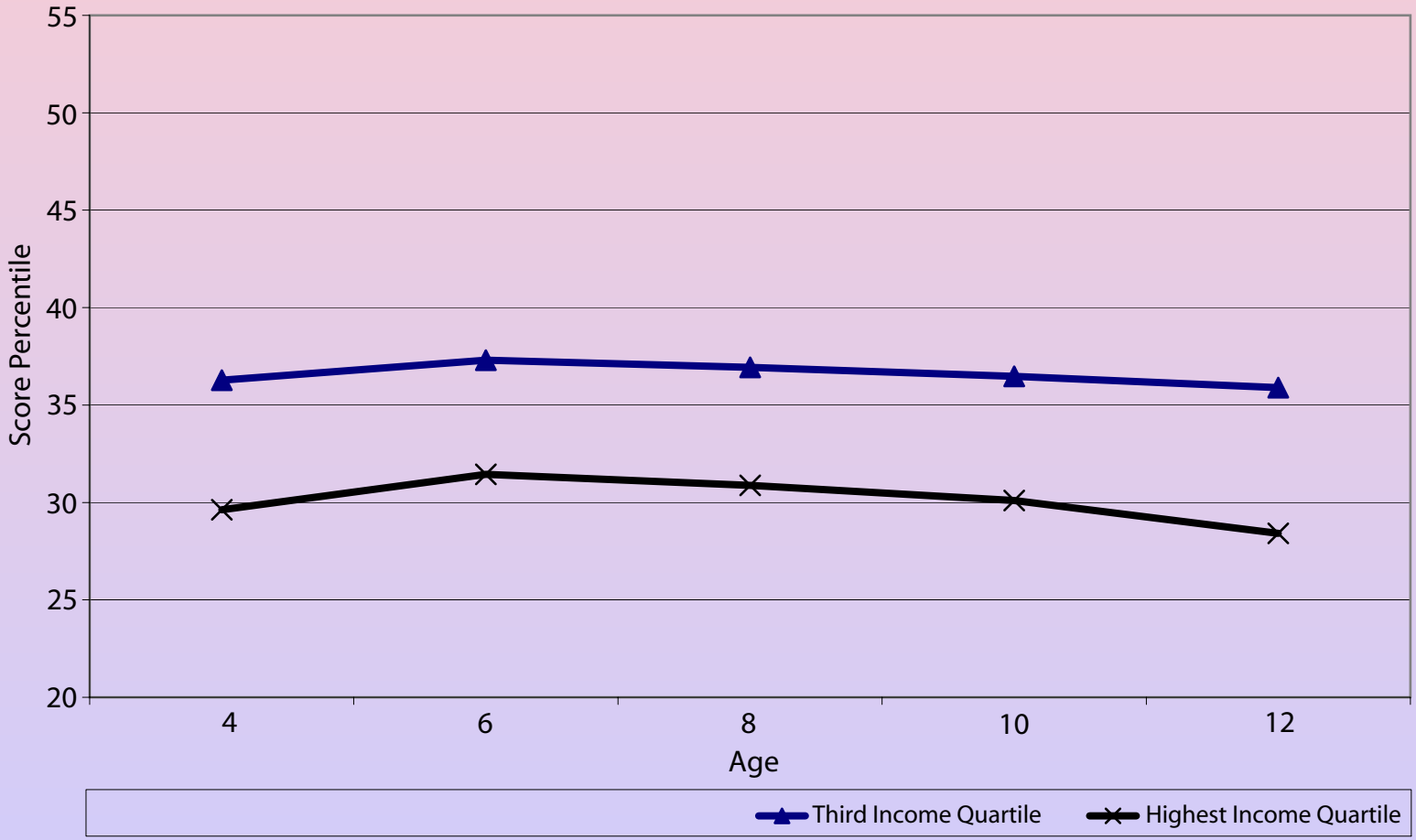

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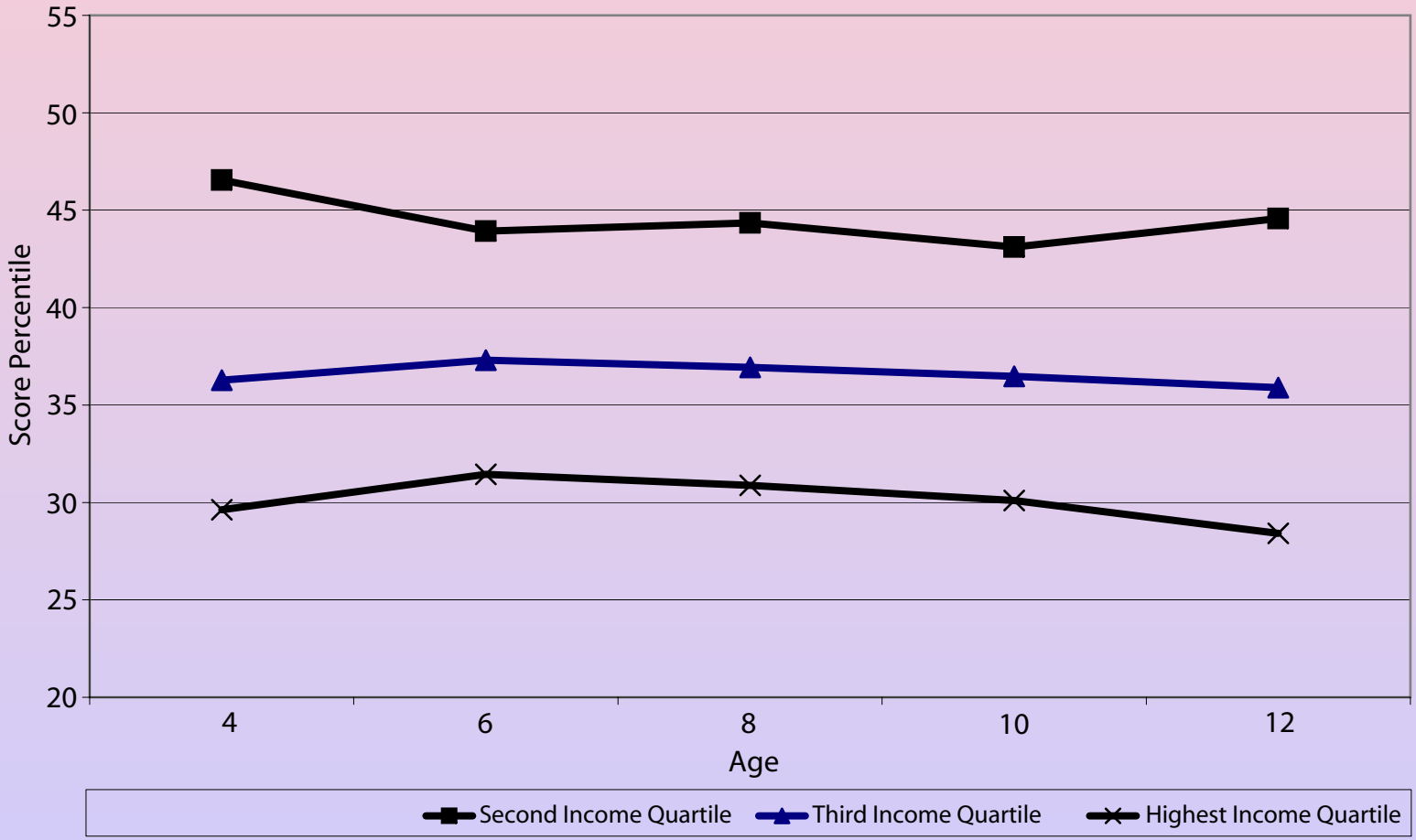

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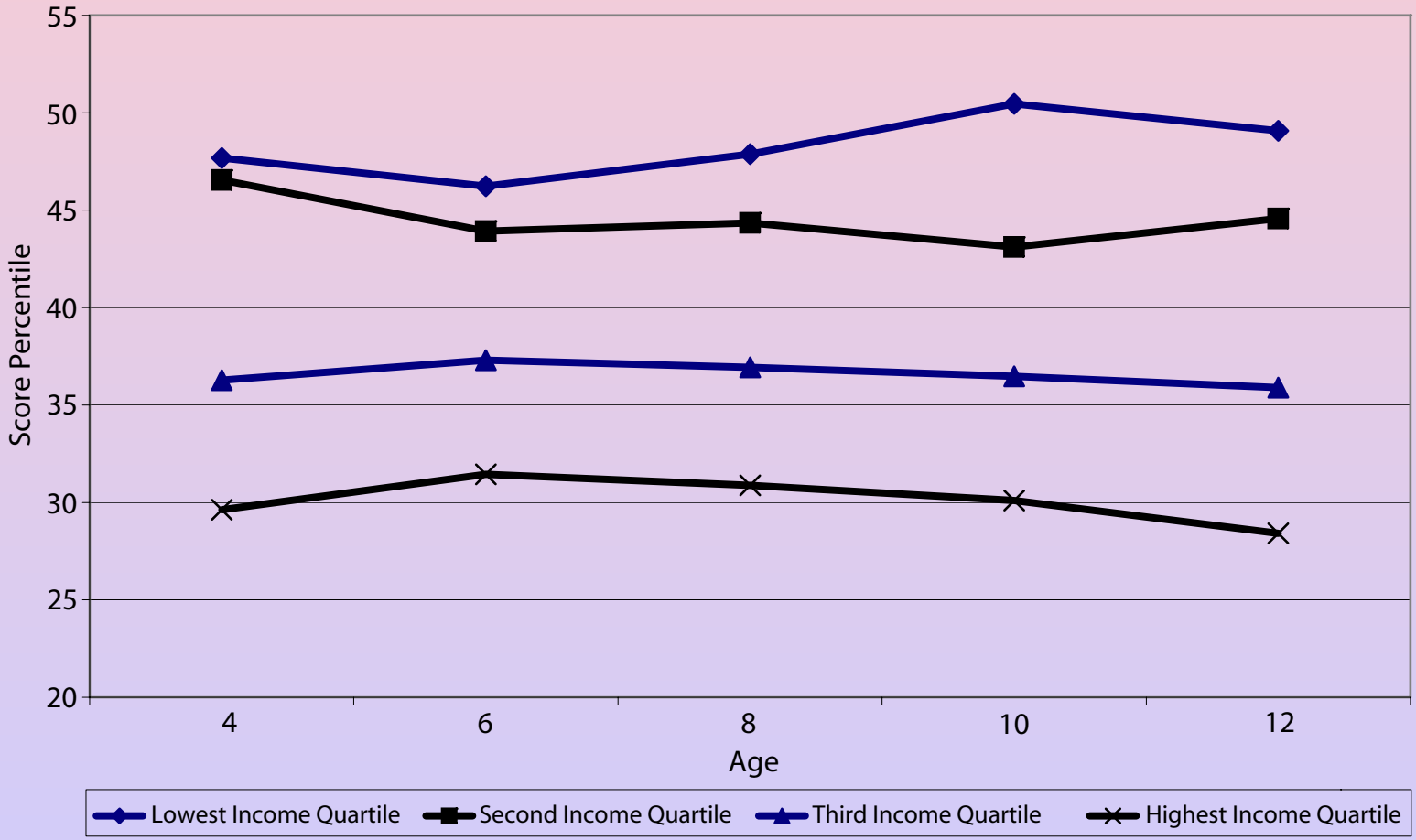
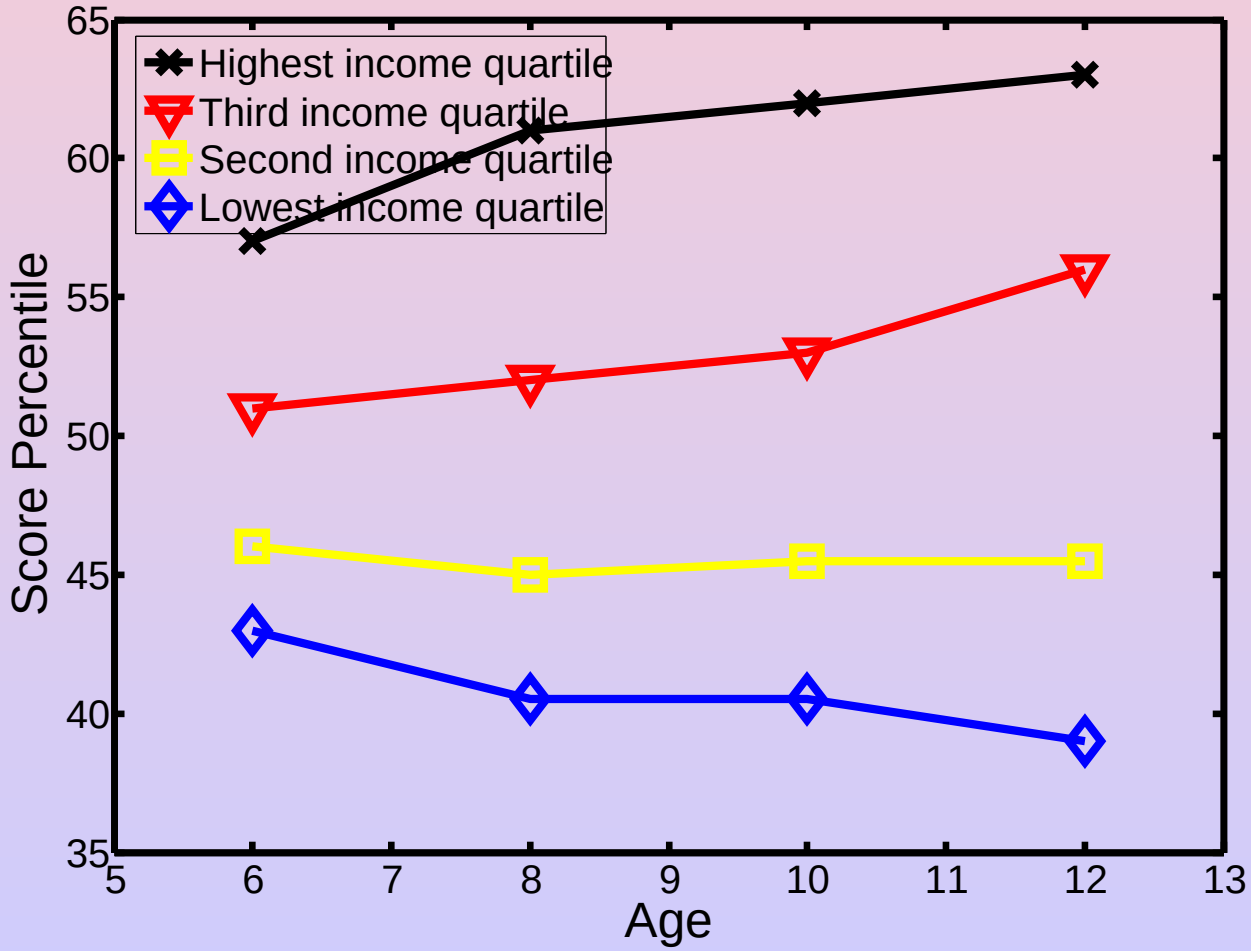


Abilities and Outcomes

- Once one controls for early family background factors using regression, the gaps in ability greatly diminish.

Residualized average PIAT-Math score percentiles, by income quartile

Before adjustments:



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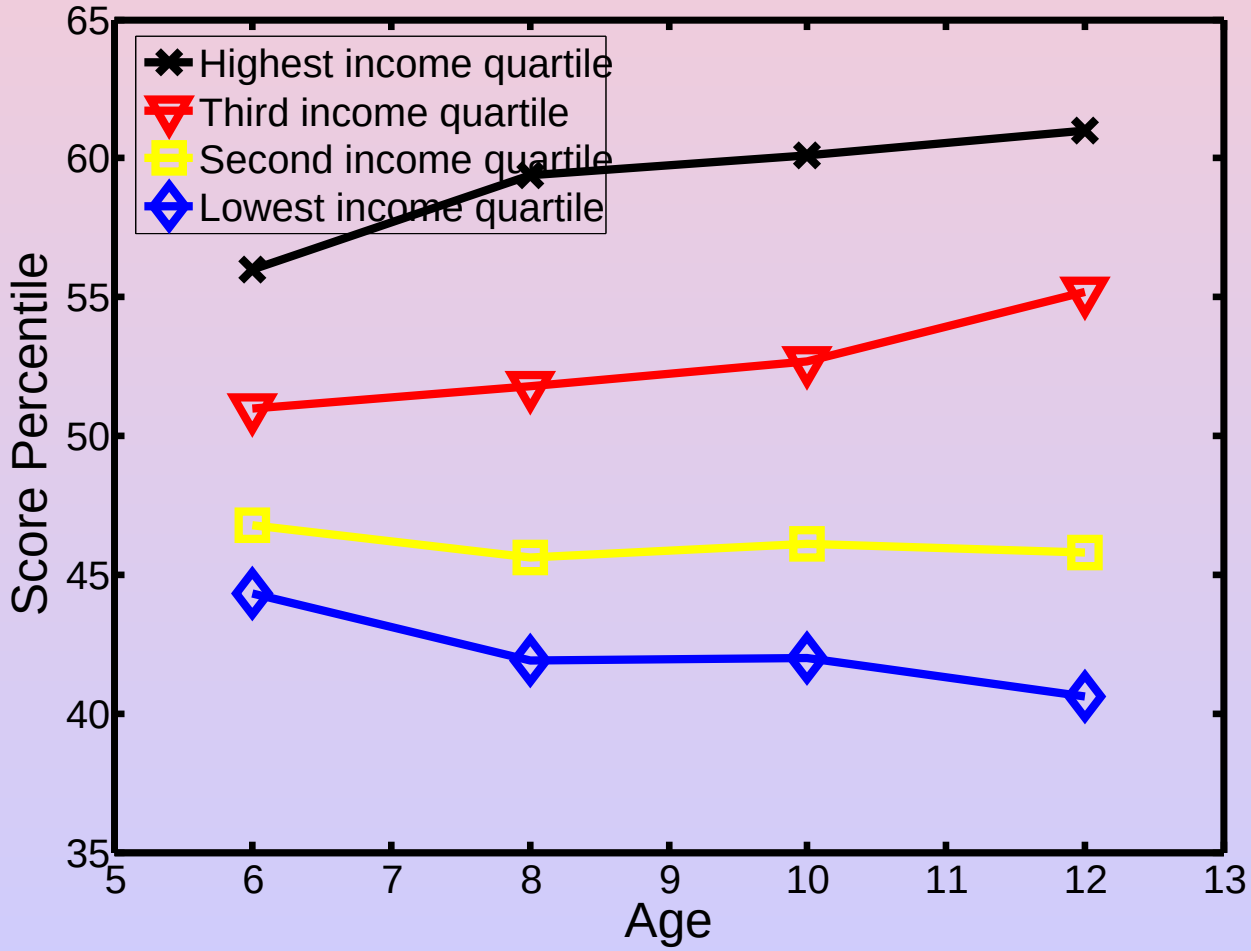
After adjustments:



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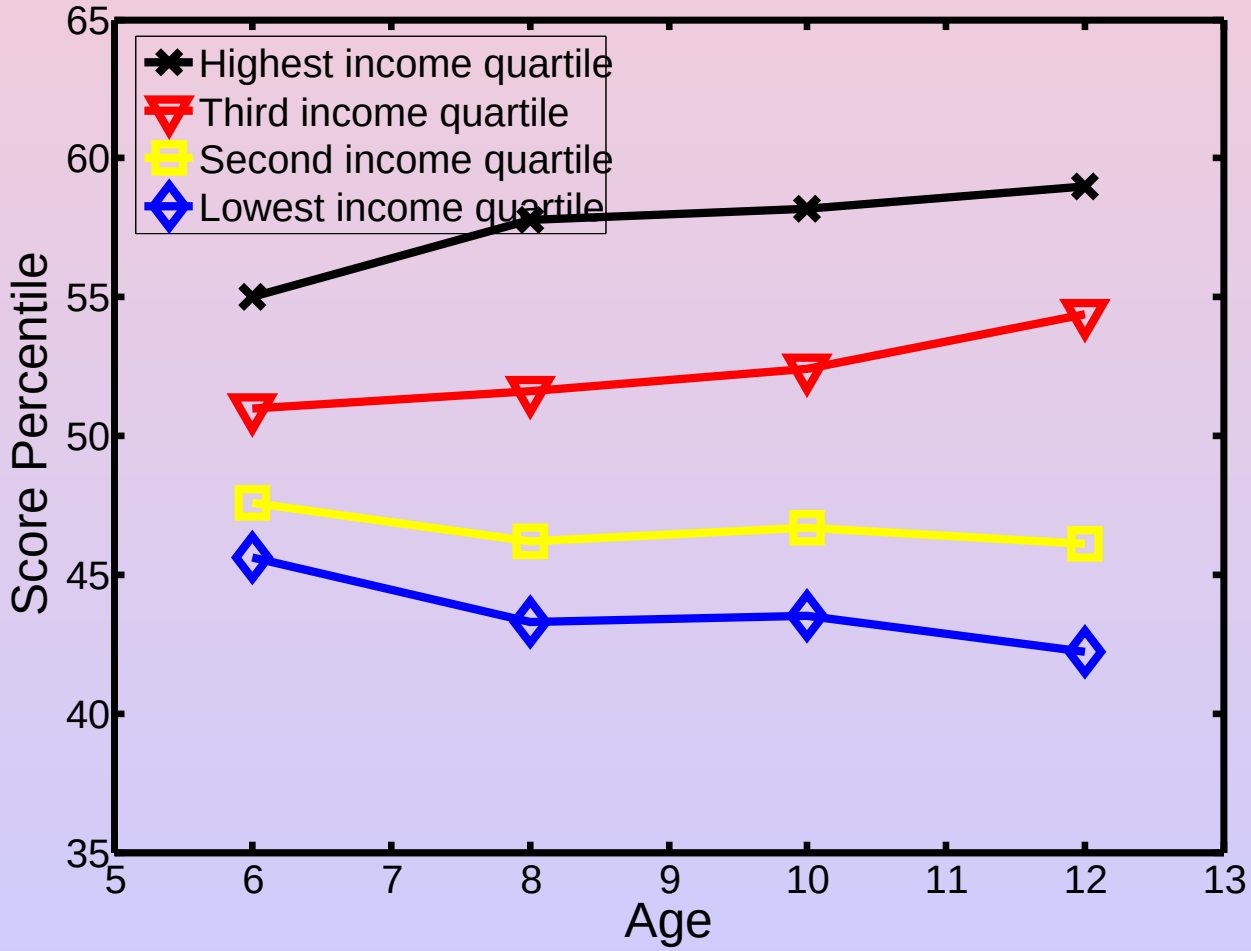

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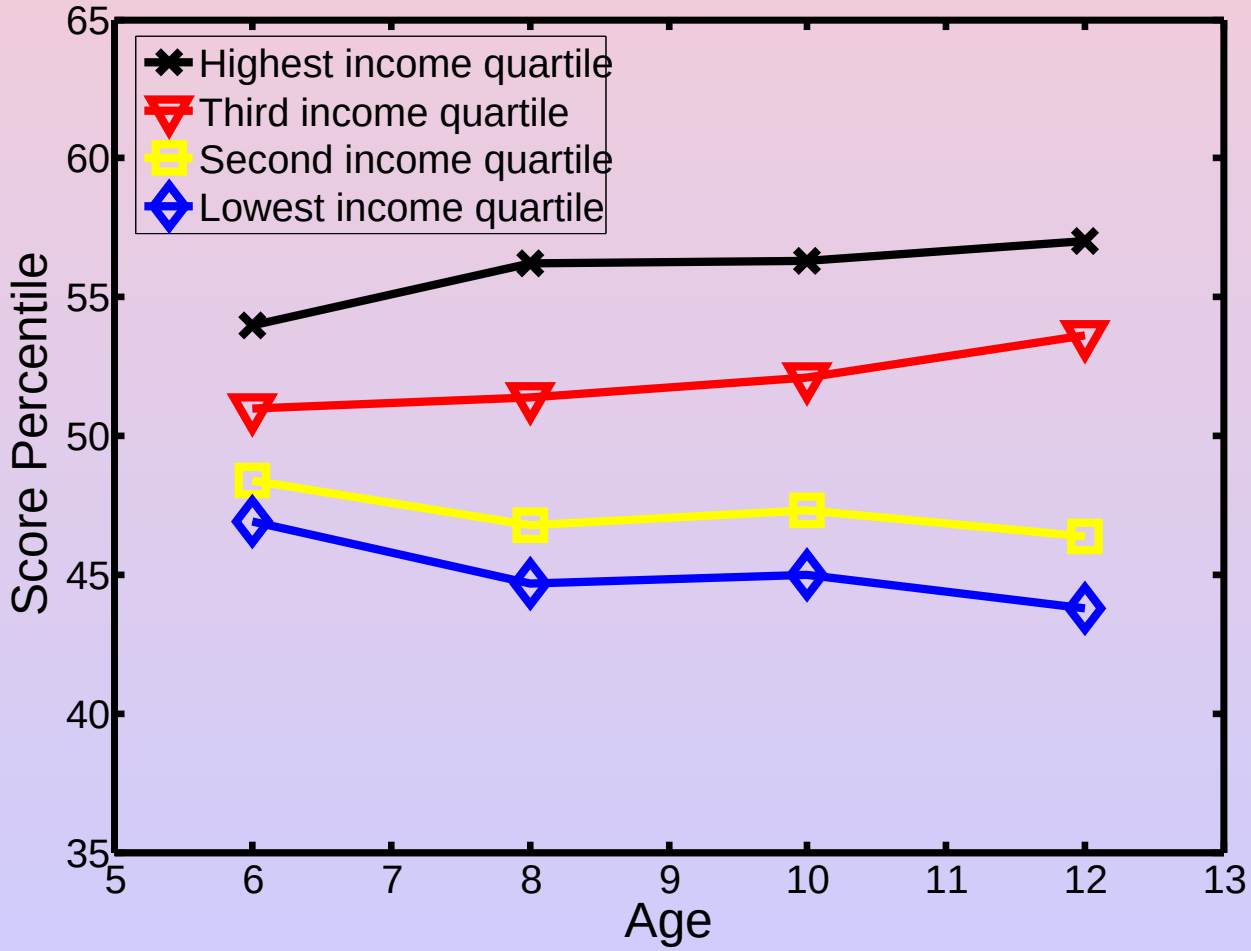

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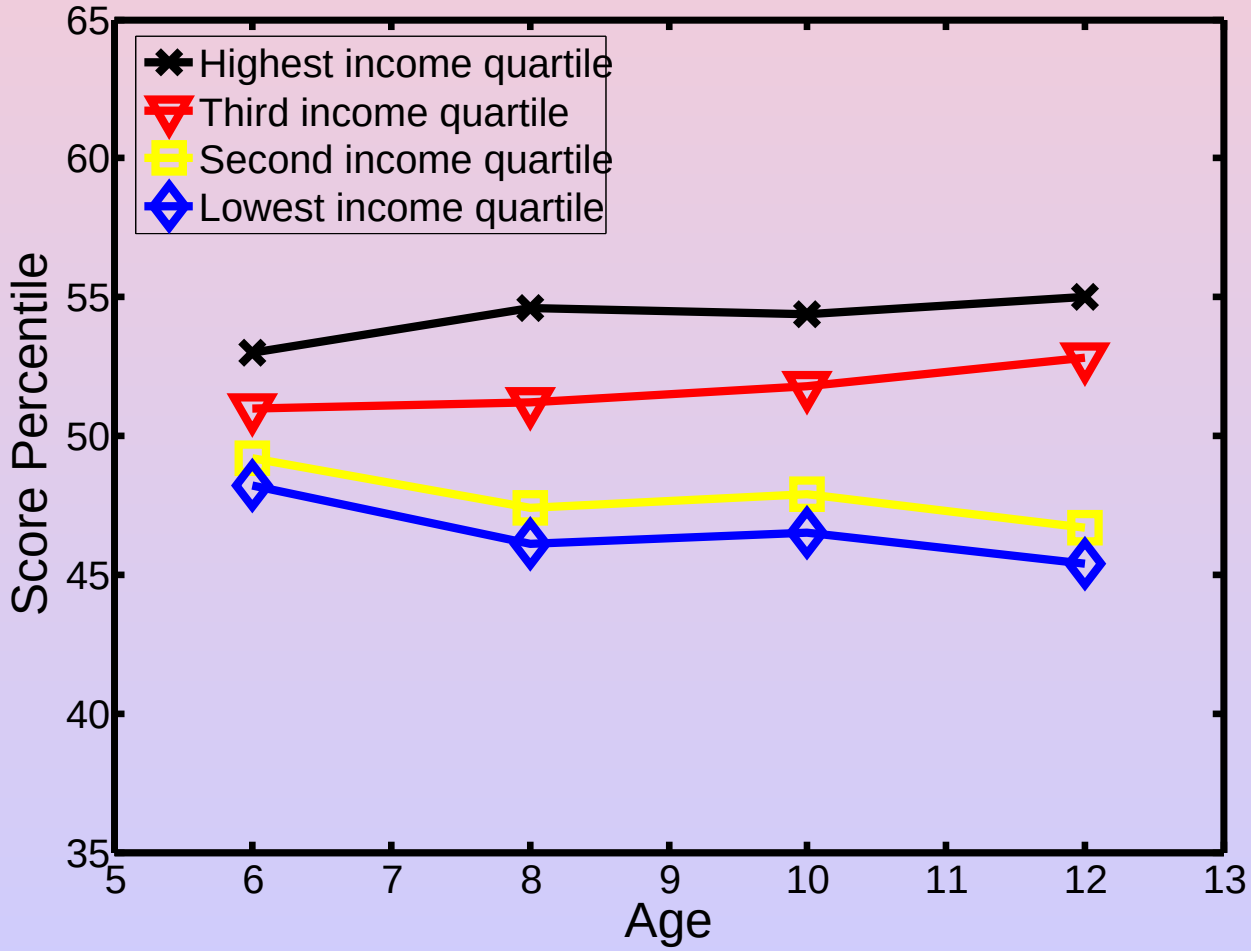

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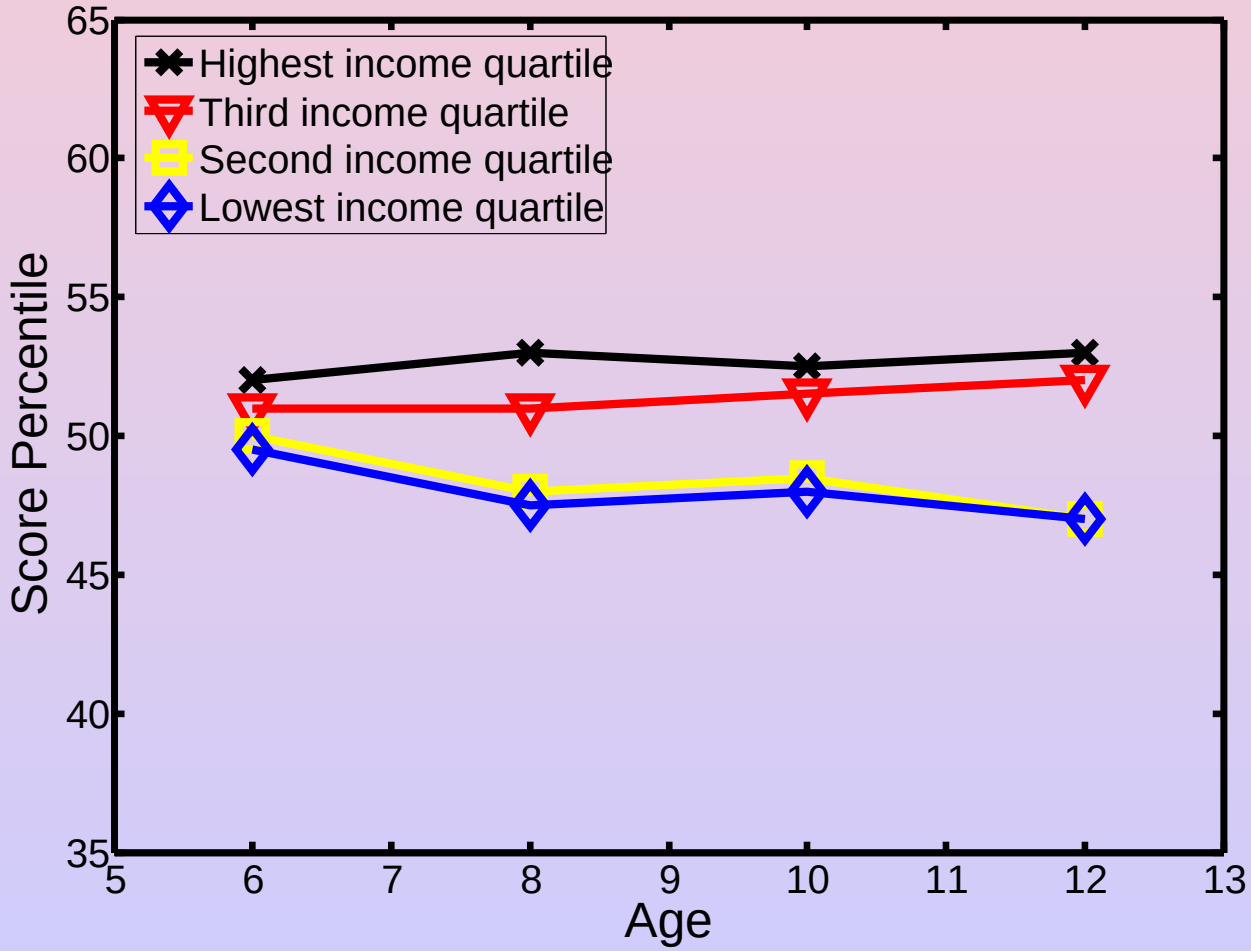

Residualized average anti-social score percentile, by income quartile

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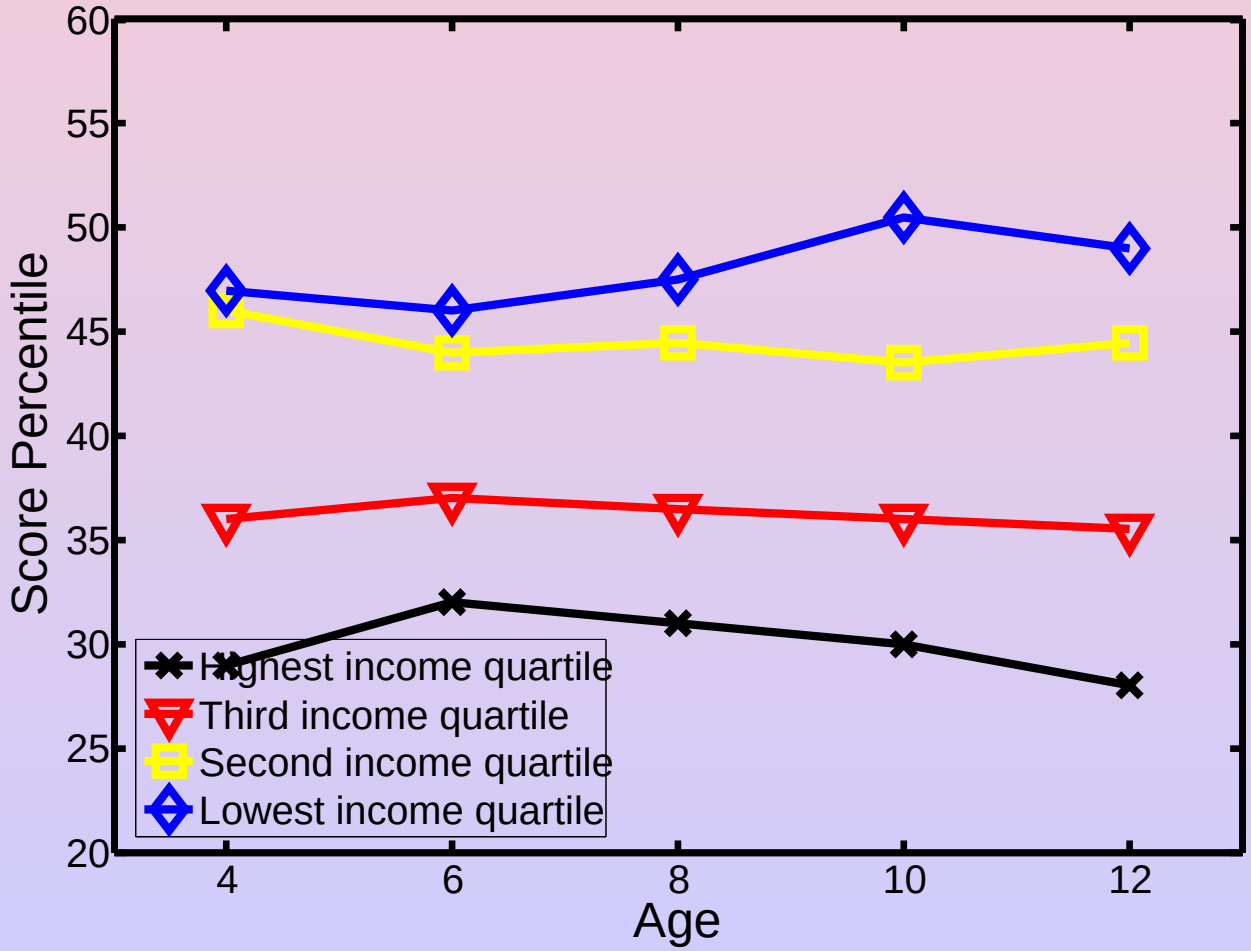

Residualized average anti-social score percentile, by income quartile

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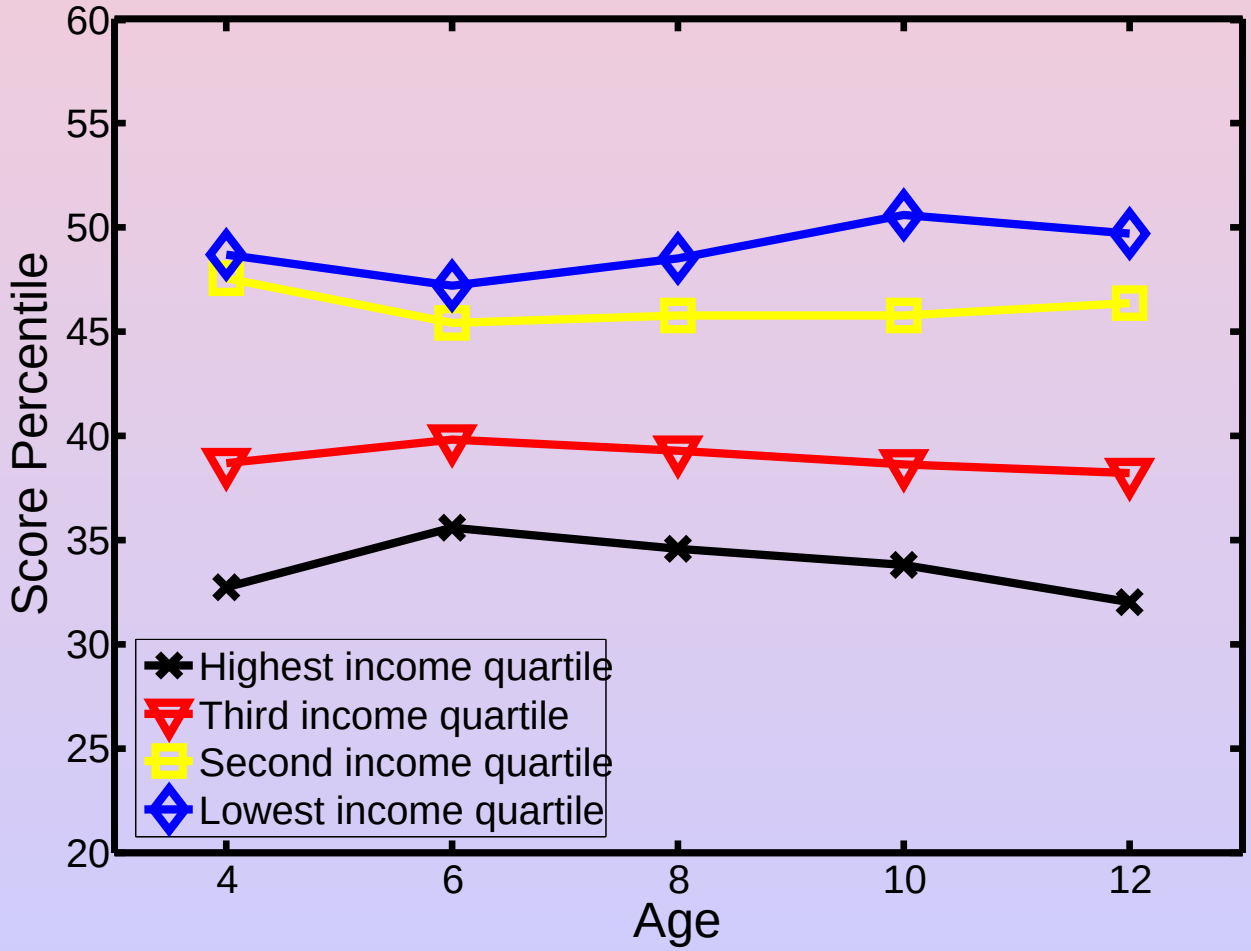

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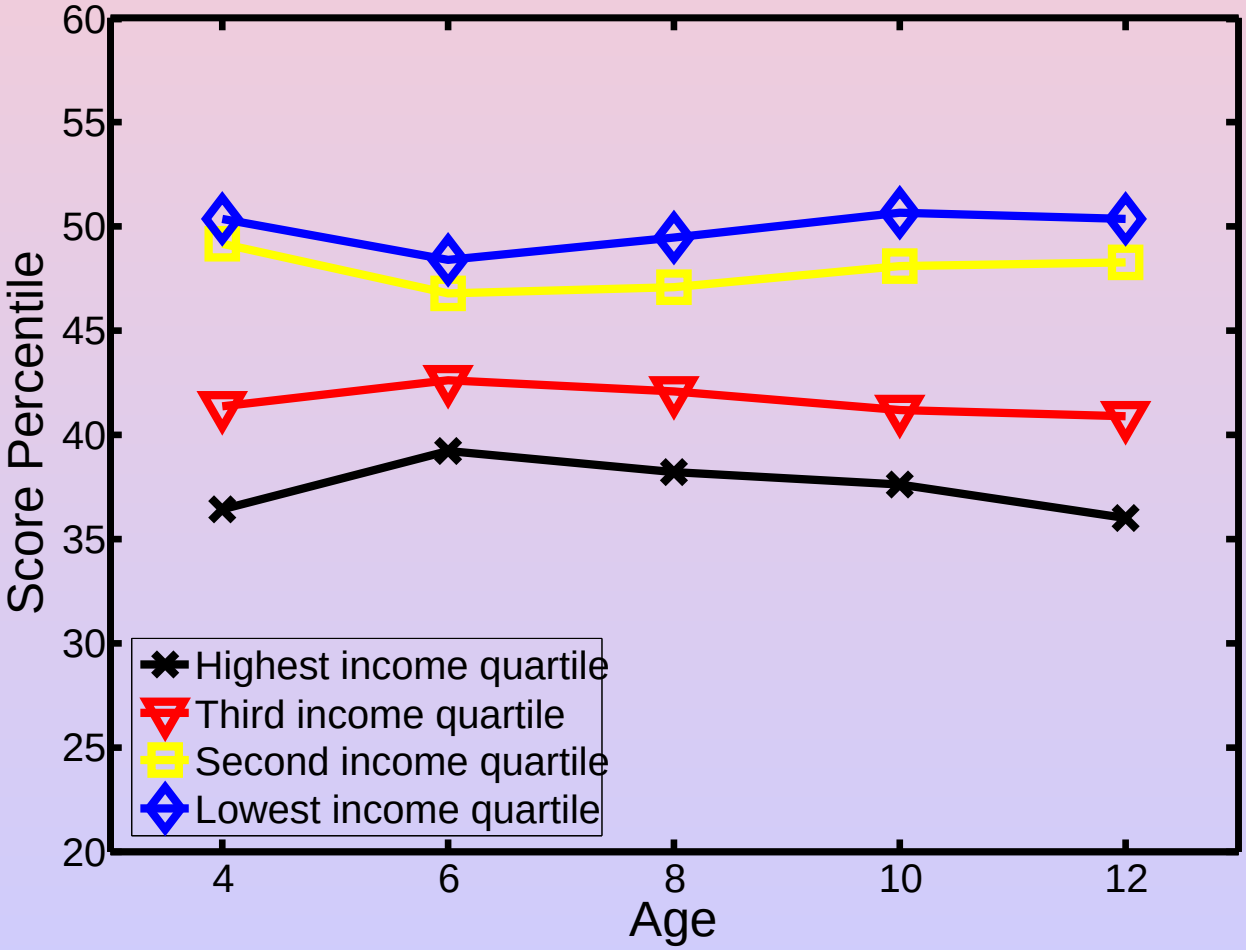

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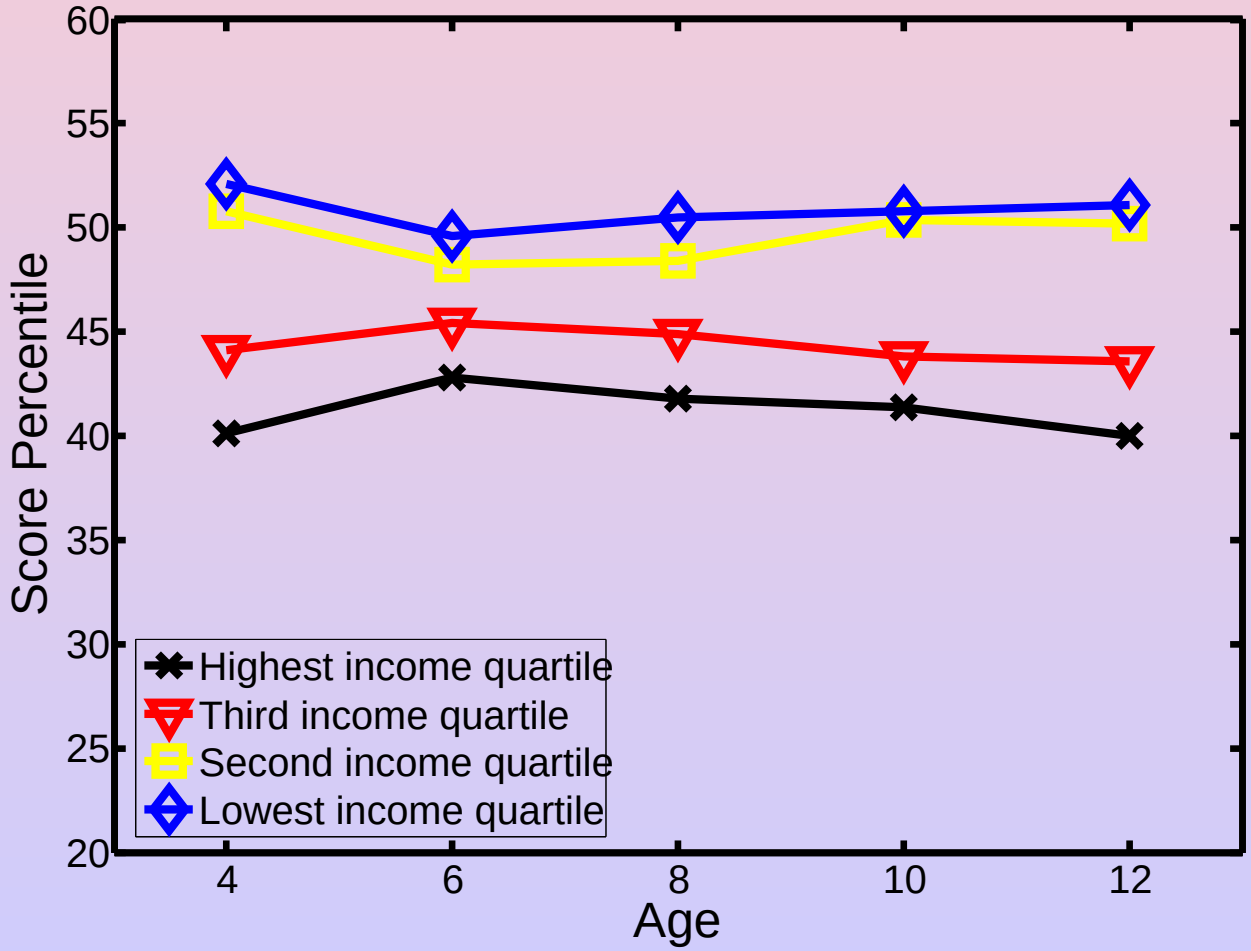

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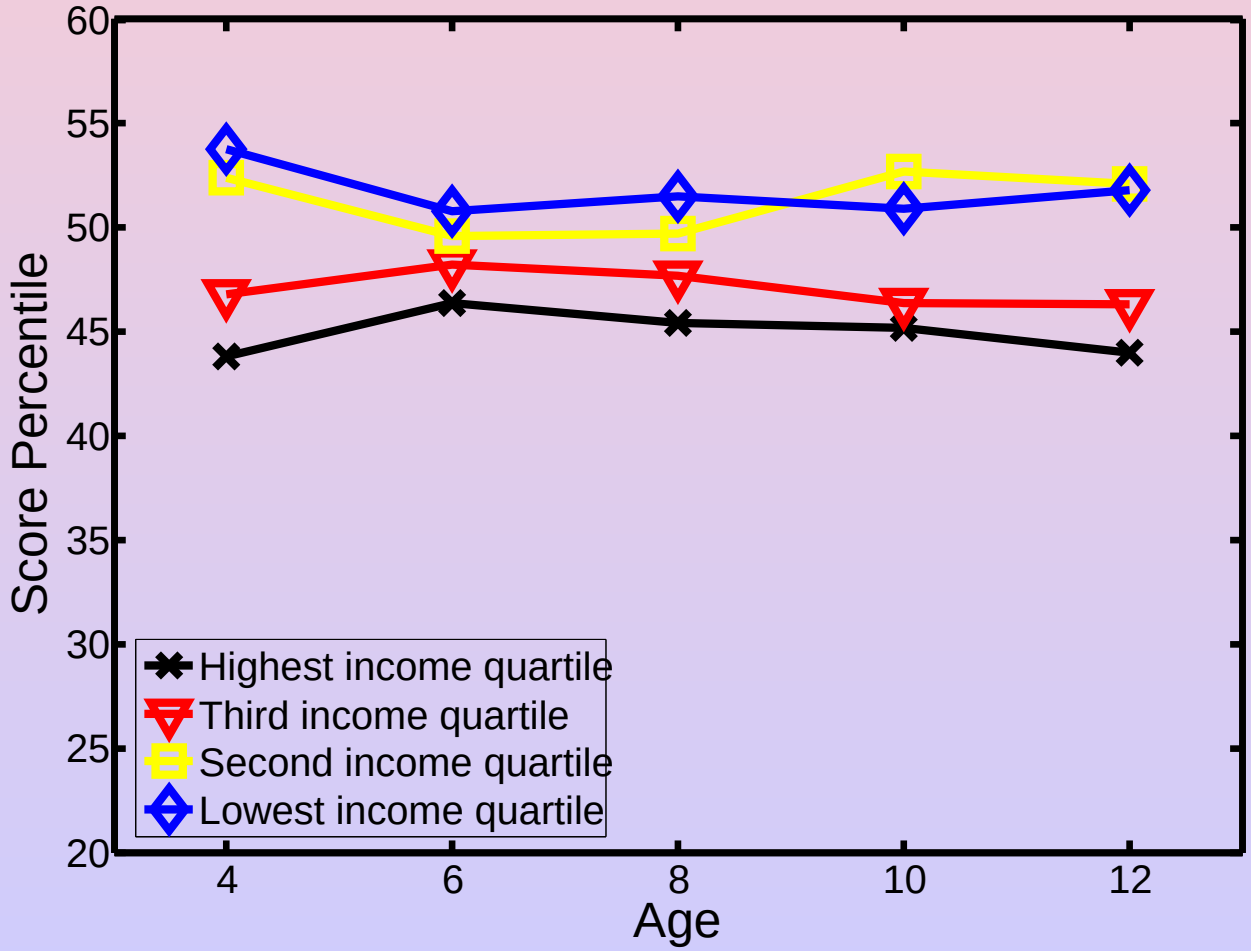

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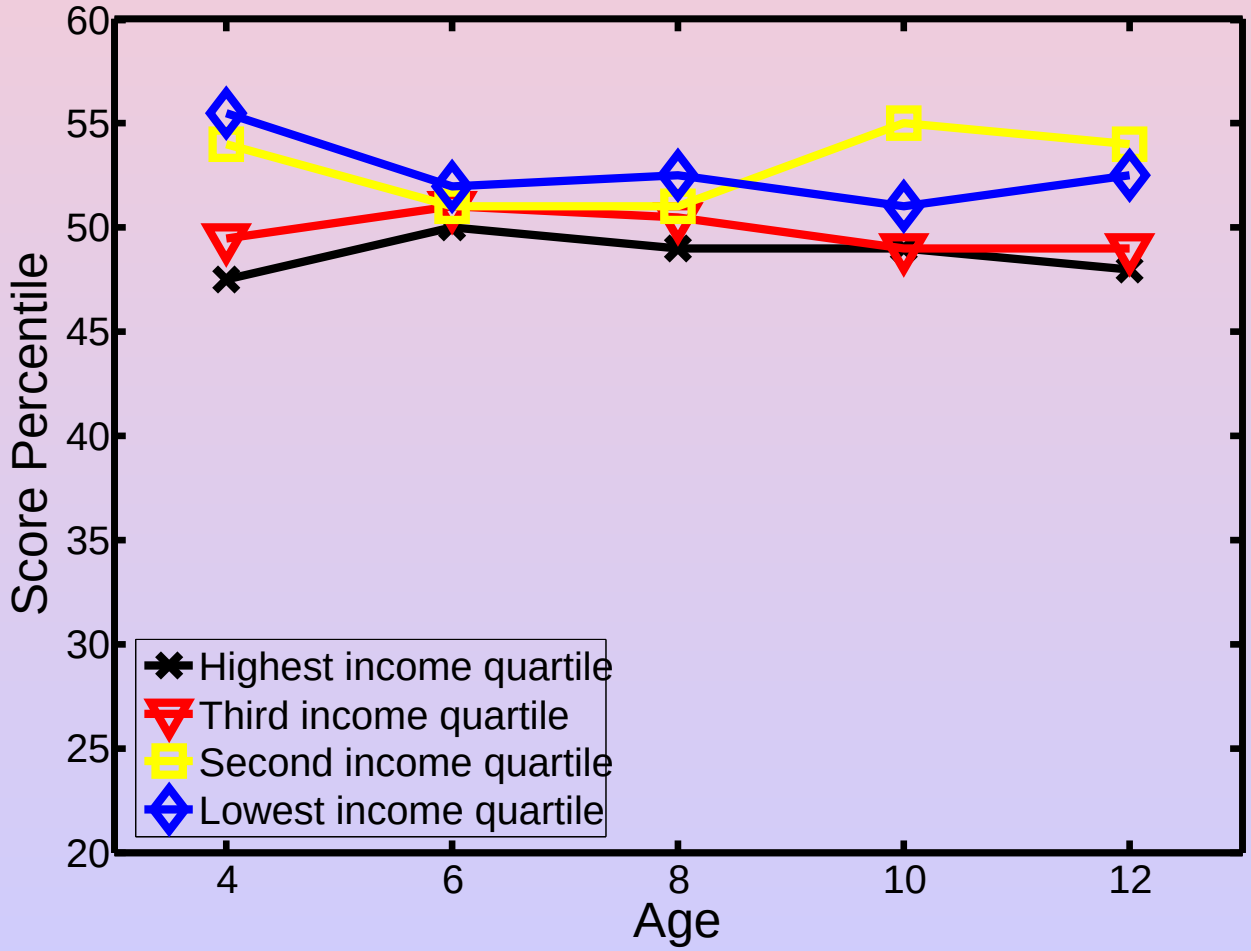
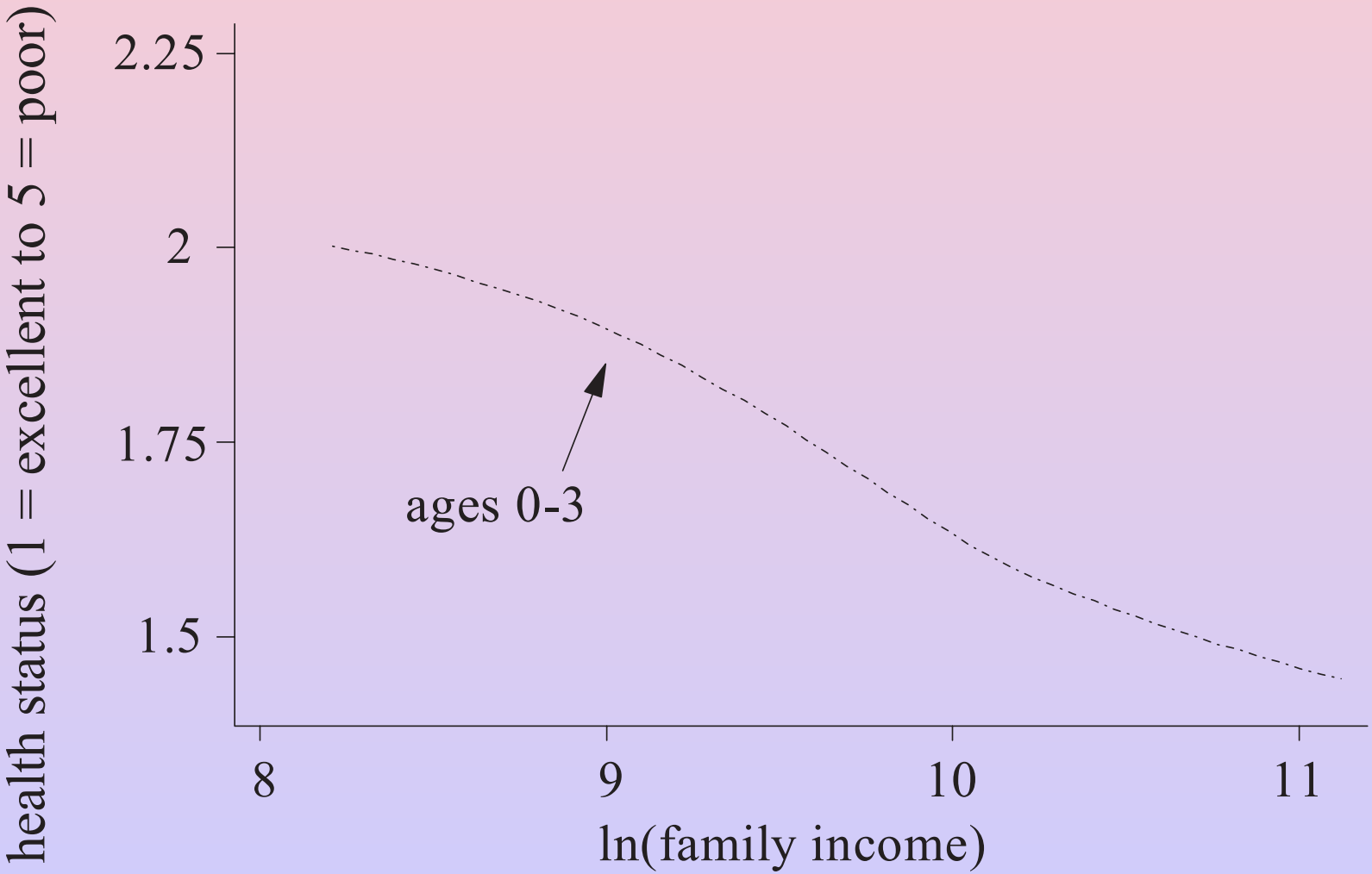


Gaps also emerge in health. These appear to be divergent with age, at least in the U.S.

Health and income for children and adults, U.S. National Health Interview Survey 1986-1995. From Case, A., Lubotsky, D. & Paxson, C. (2002), American Economic Review, Vol. 92, 1308-1334.



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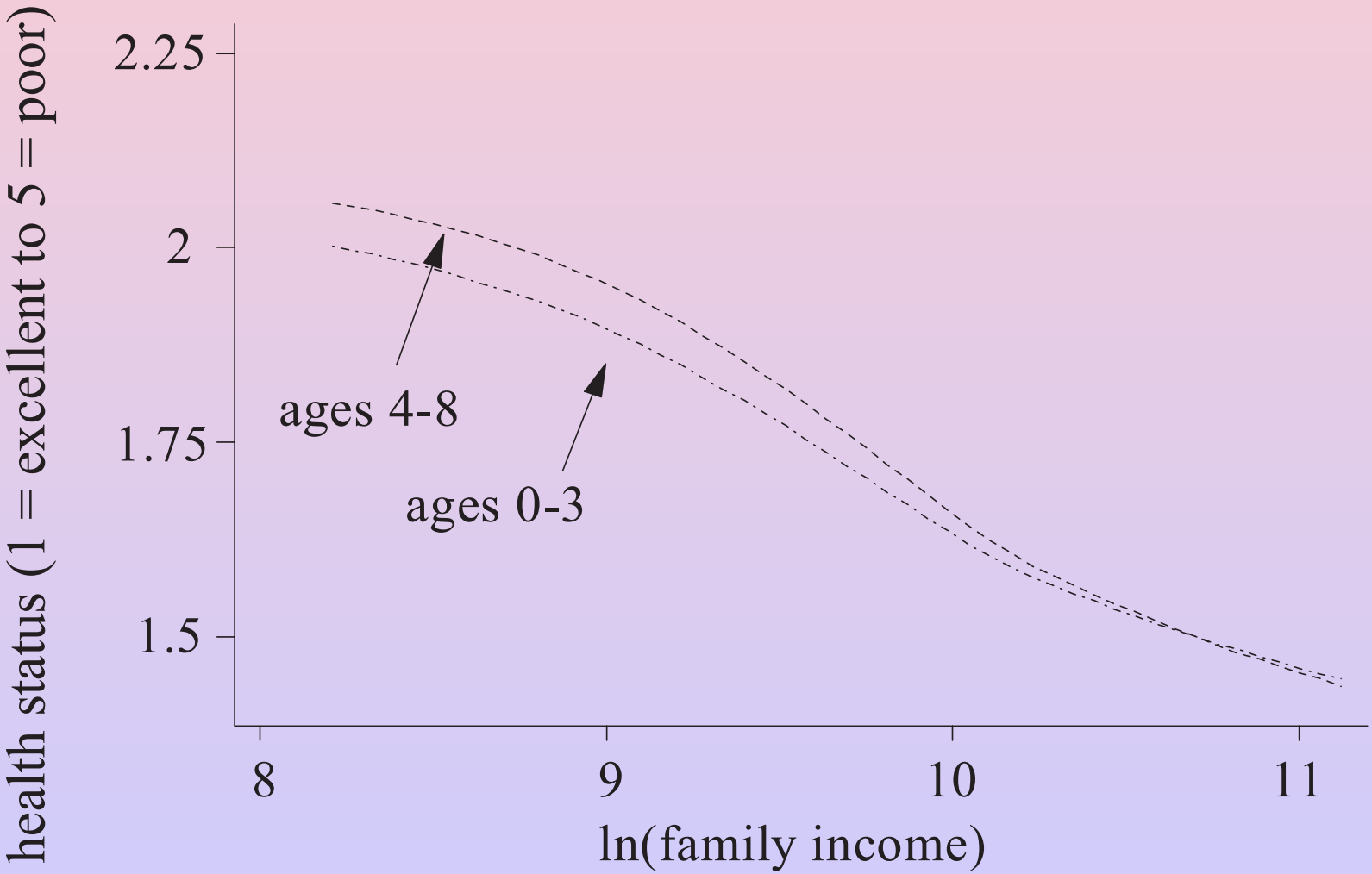

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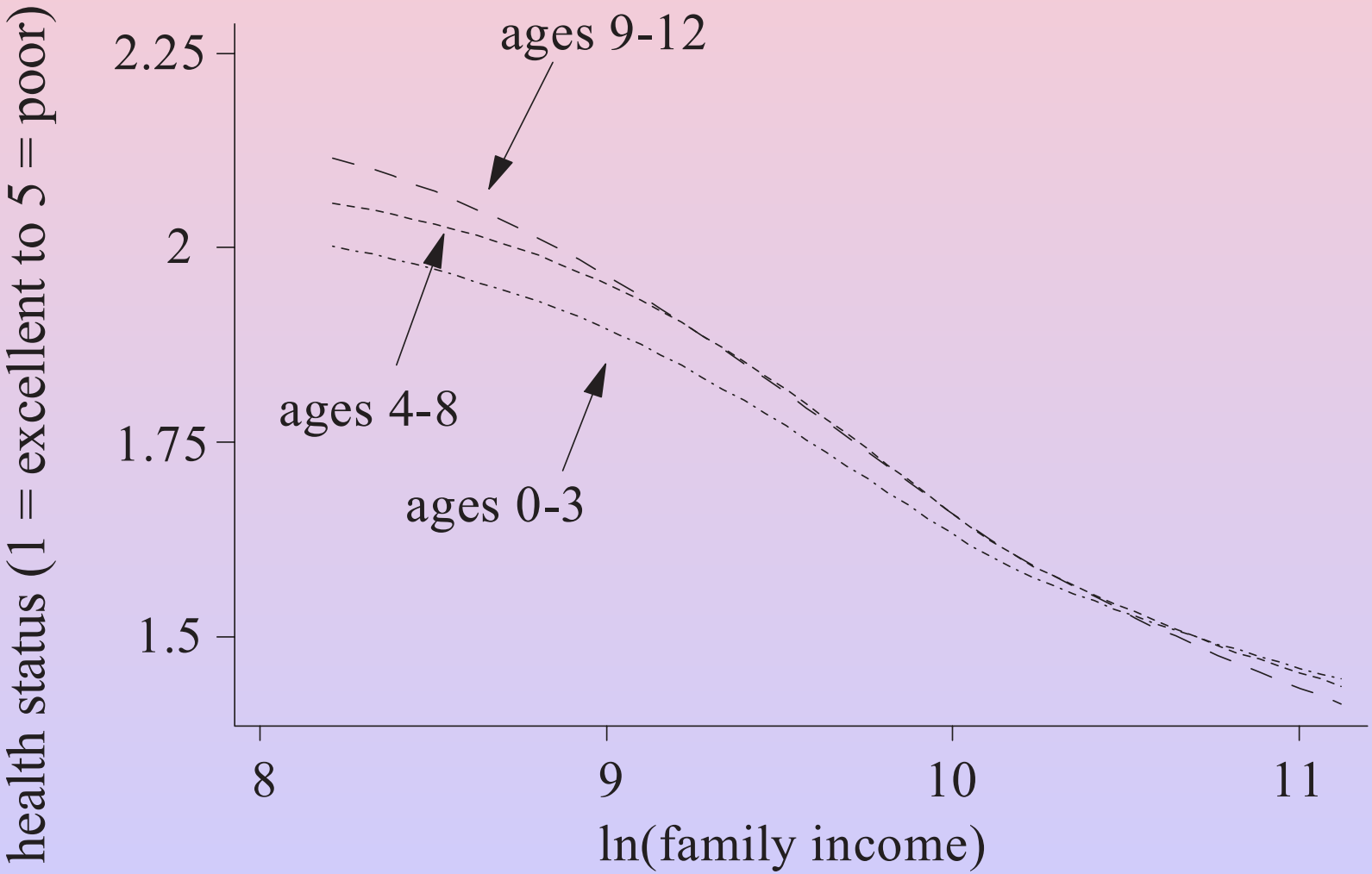

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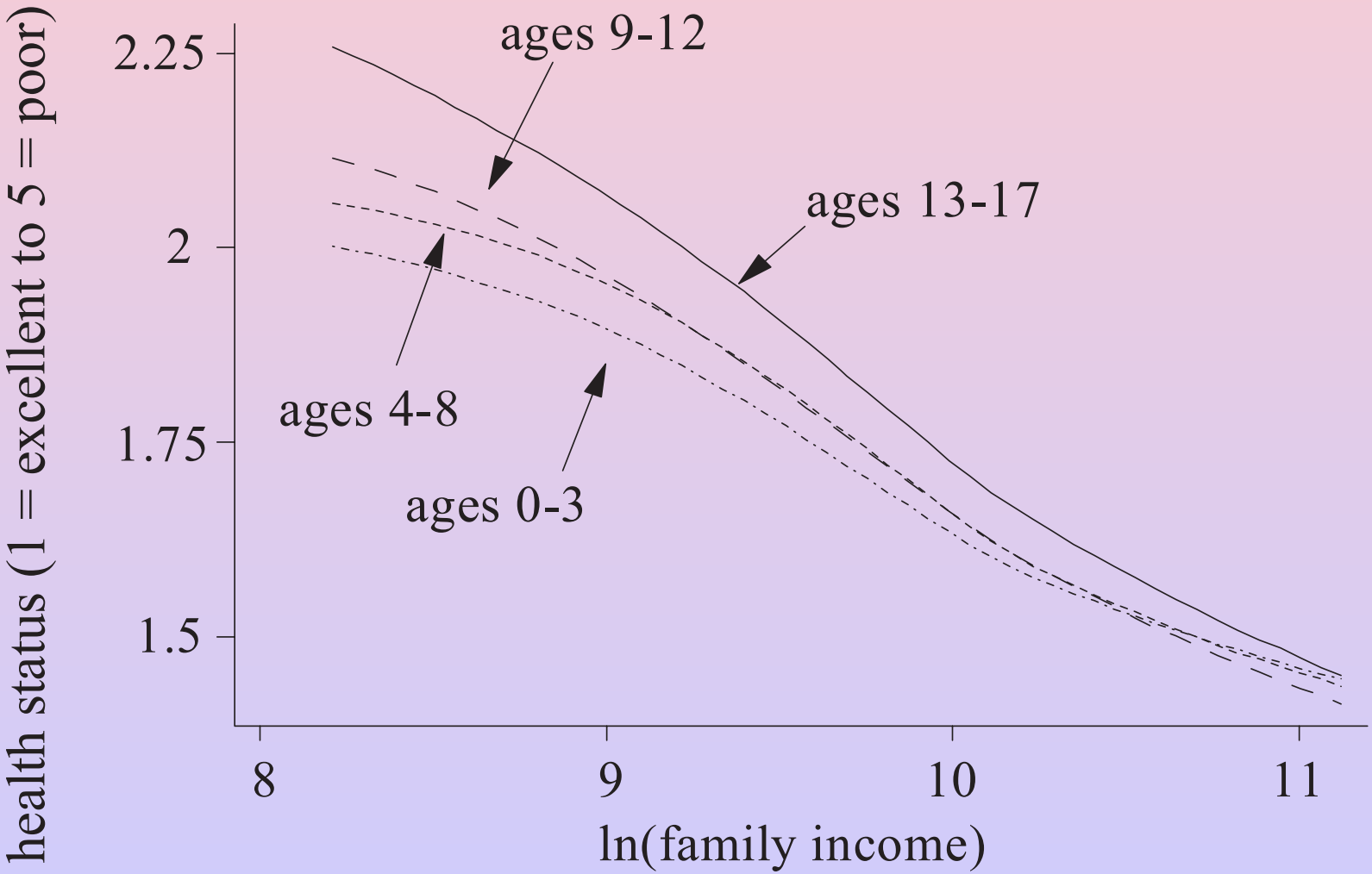

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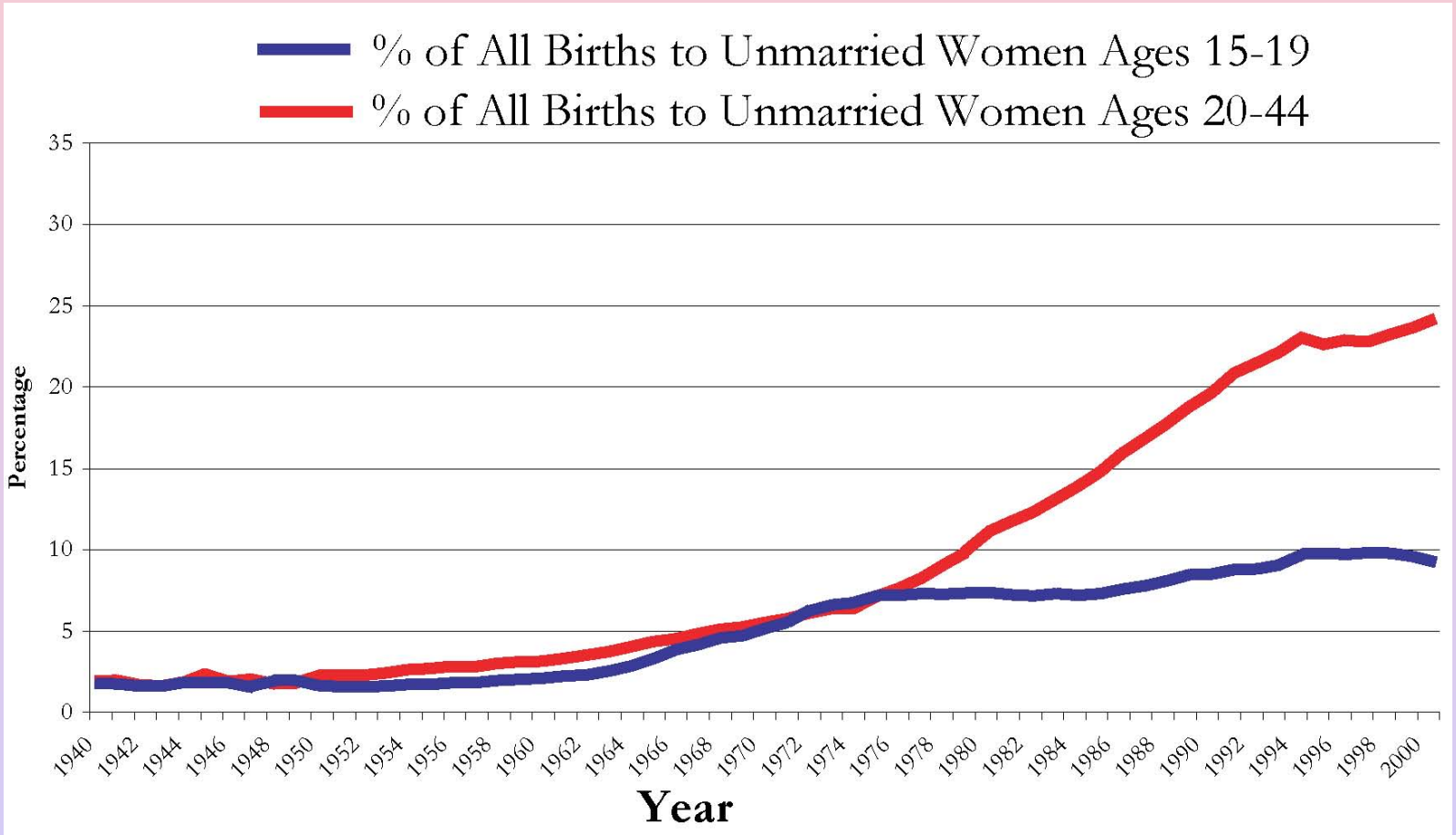
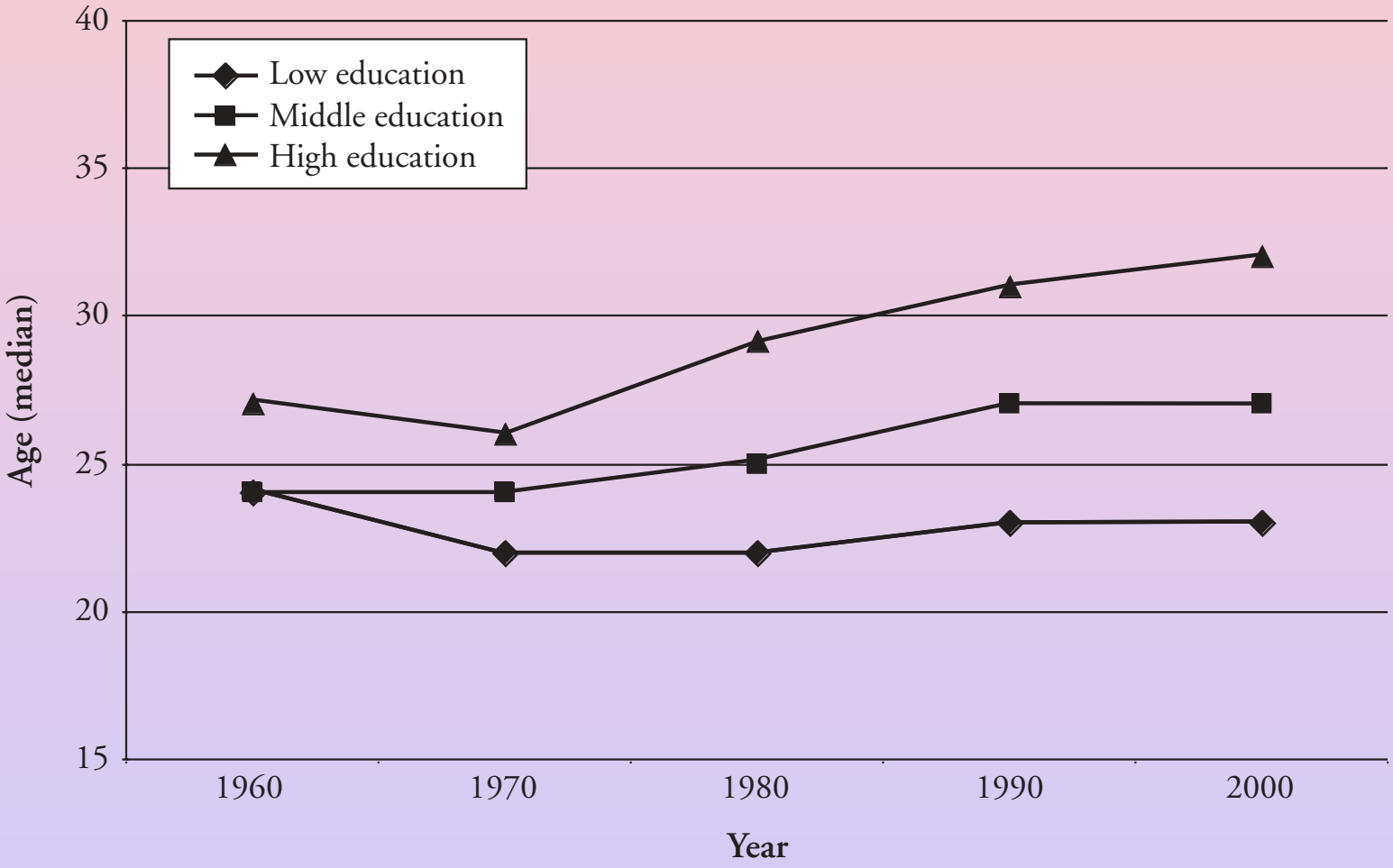
- Those in more advantaged environments are receiving more.

Trends in unhealthy child environments



Note: Birth rates to unmarried women from Ventura and Bachrach (2000). Other measures are the author's calculations based on weighted CPS March 1968-2000 data. Poverty is defined as those households under the federal poverty line in the given year.

Trends in Mothers' Median Age, 1960 to 2000



Note: Low education includes mothers in the bottom education quartile, middle education includes mothers in the middle two education quartiles, and high education includes mothers in the top education quartile.

Source: PUMS (1960–2000).

A Gap

- A gap is emerging between the environments of children of more educated women and children of less educated.

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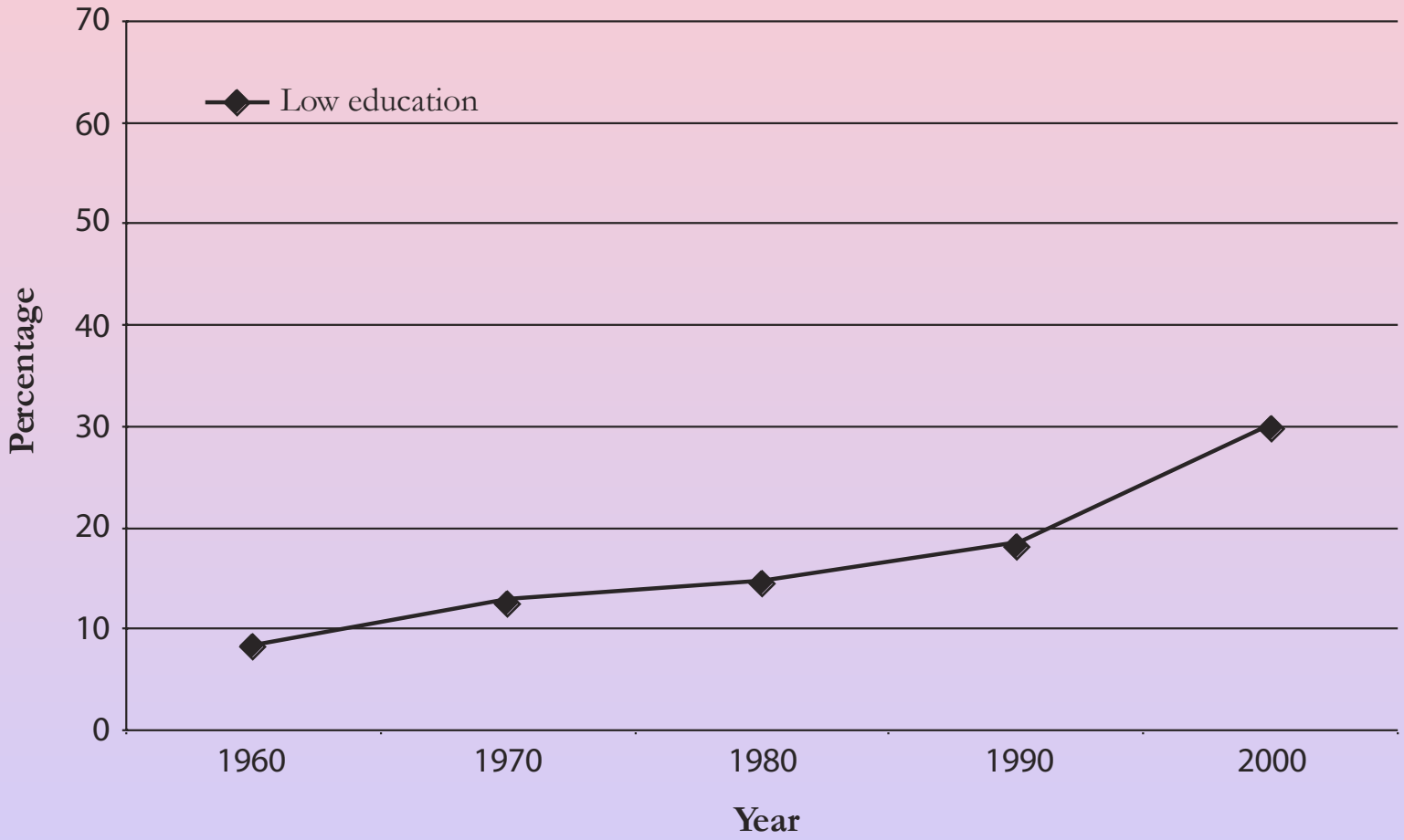
- In the U.S., this is a concern because the percentage of less educated women is rising and they bear and raise a disproportionate number of children.
- This raises an environmental version of concerns similar to those raised by the eugenics movement a century ago.

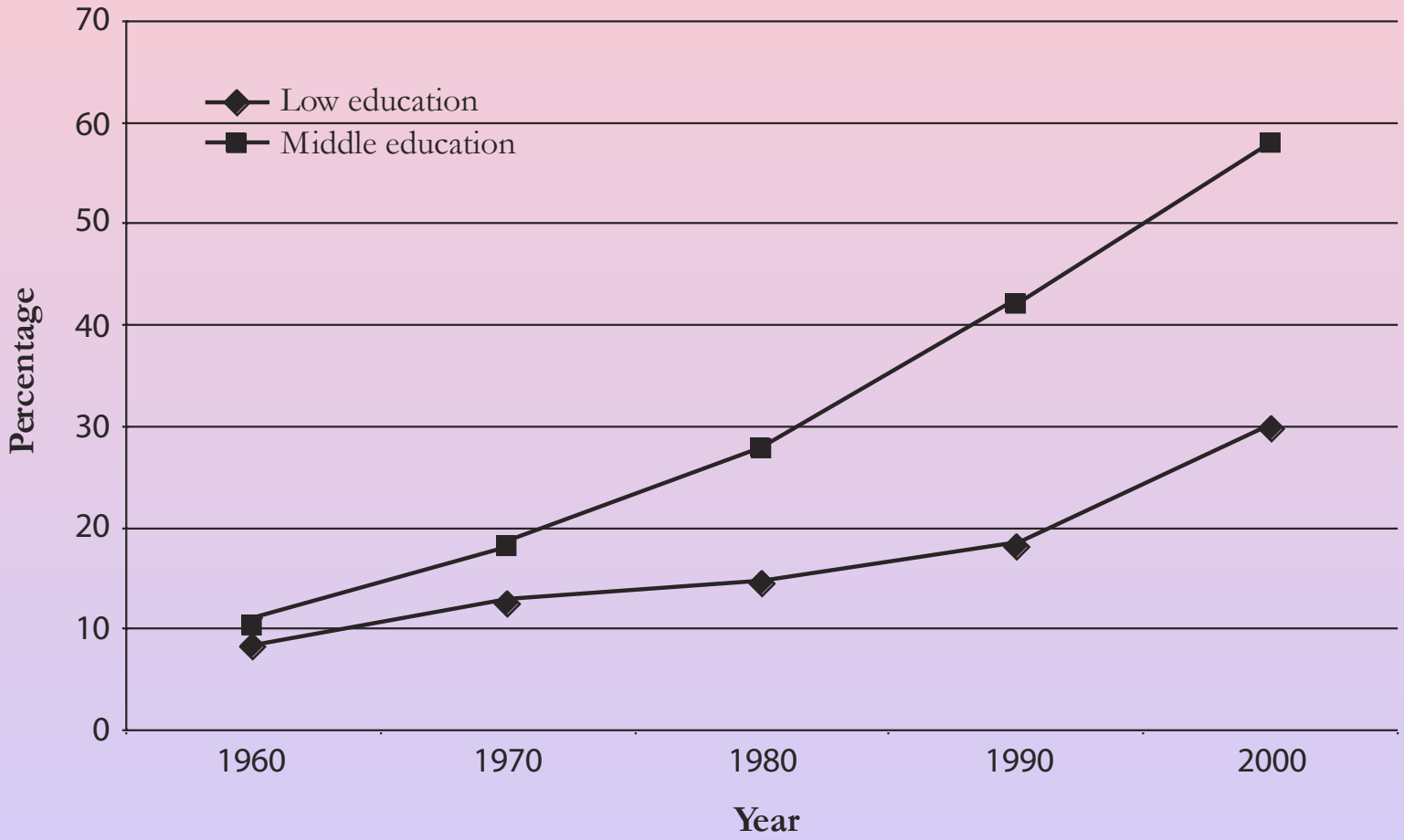
Trends in Mothers' Employment, 1960 to 2000



Note: Employment is defined as working at least 27 weeks per year for 15 hours per week.

Source: PUMS (1960-2000).

Trends in Mothers' Employment, 1960 to 2000



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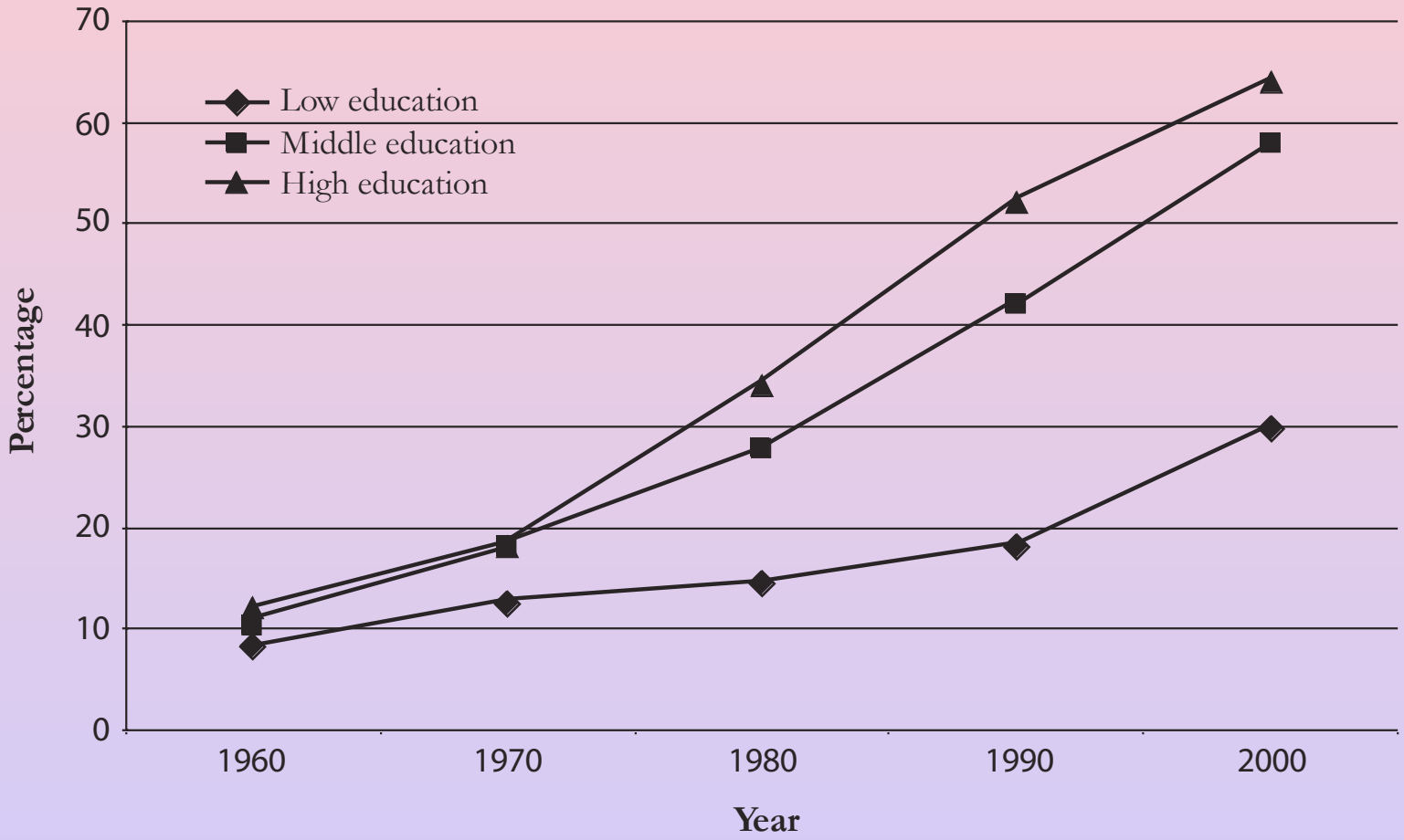
Source: PUMS (1960-2000).

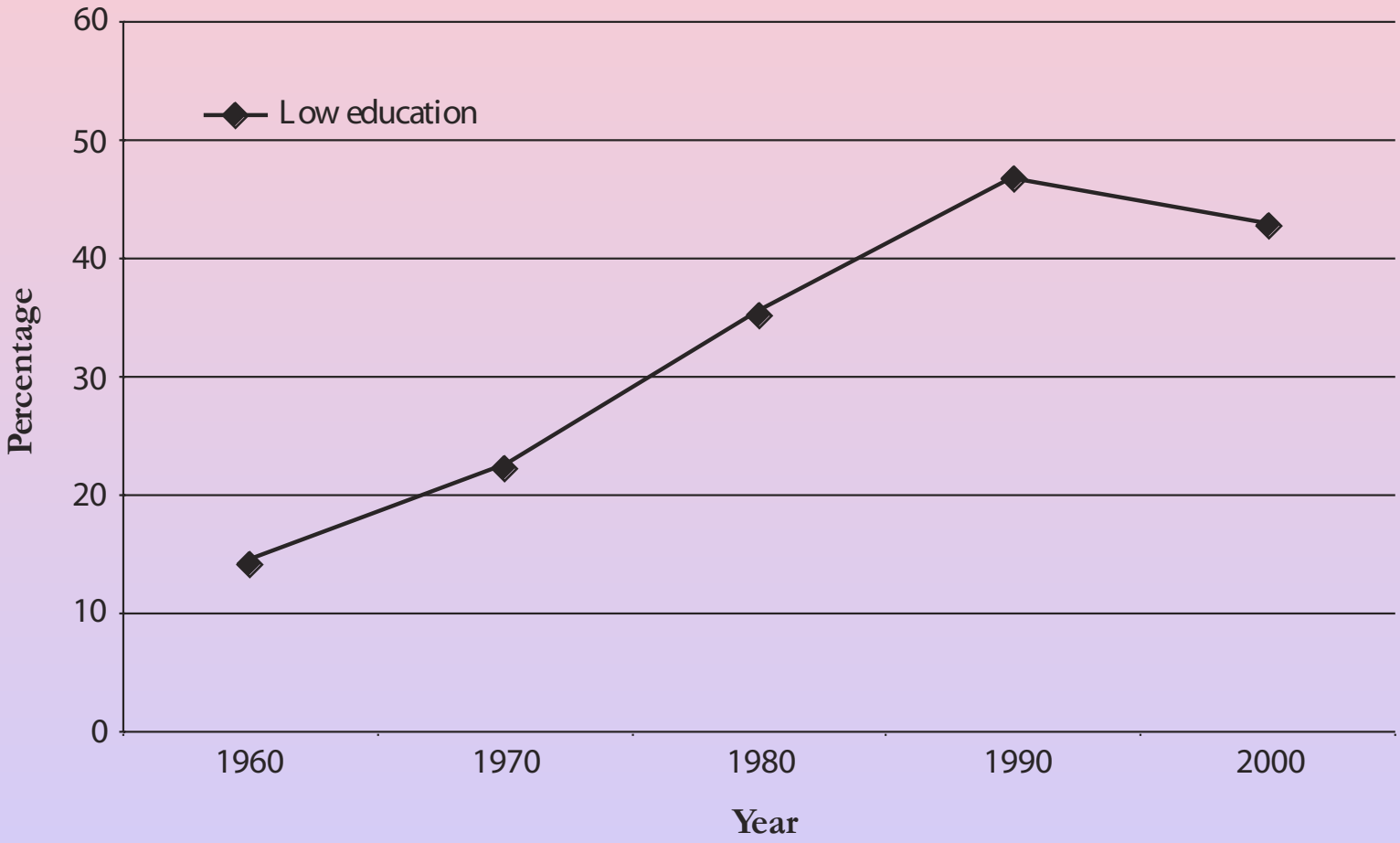
Trends in Mothers' Employment, 1960 to 2000



Note: Employment is defined as working at least 27 weeks per year for 15 hours per week.

Source: PUMS (1960-2000).

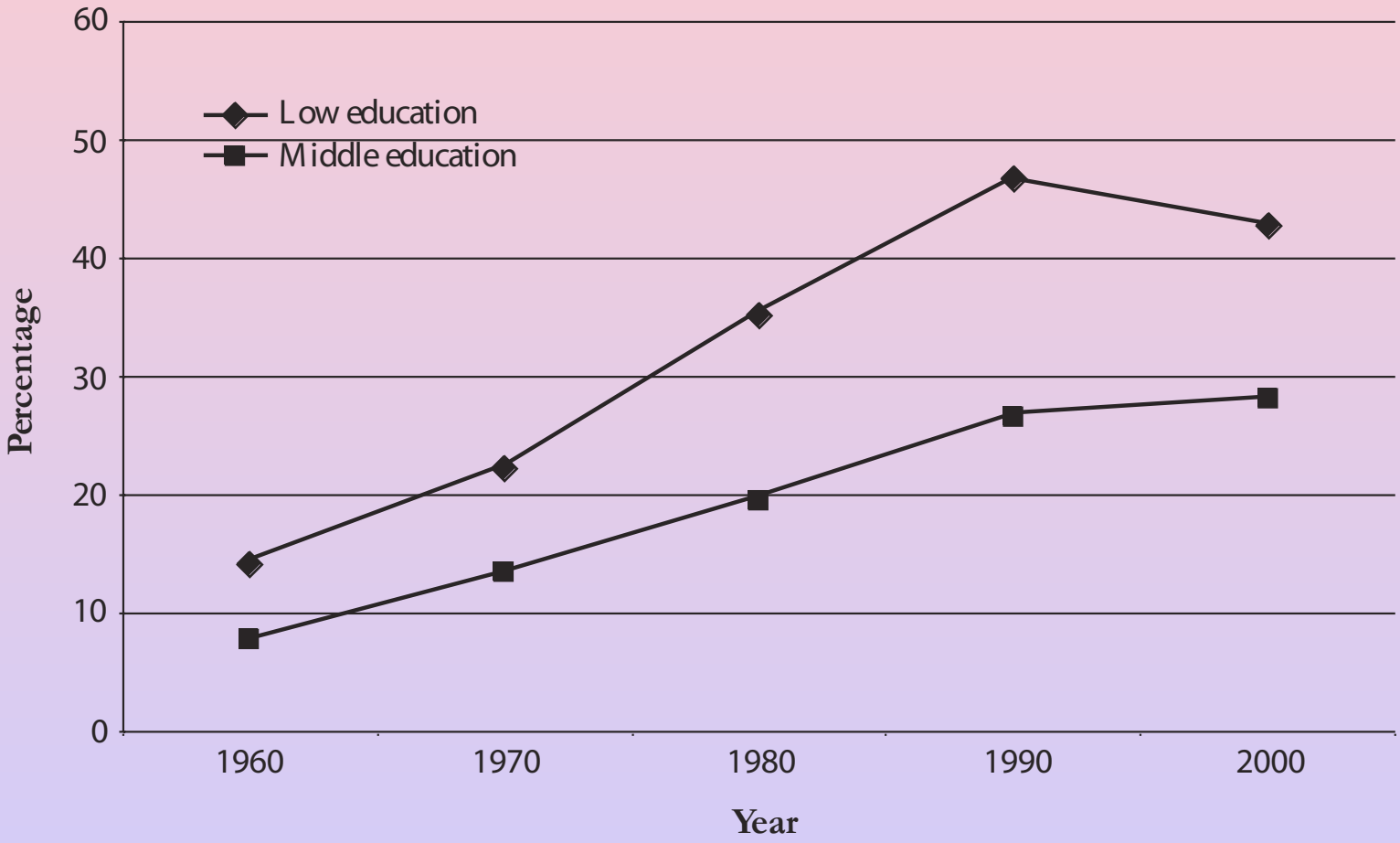
Trends in Single Motherhood, 1960 to 2000



Note: Single motherhood is defined as not being married or not living with a spouse.

Source: PUMS (1960-2000).

Trends in Single Motherhood, 1960 to 2000



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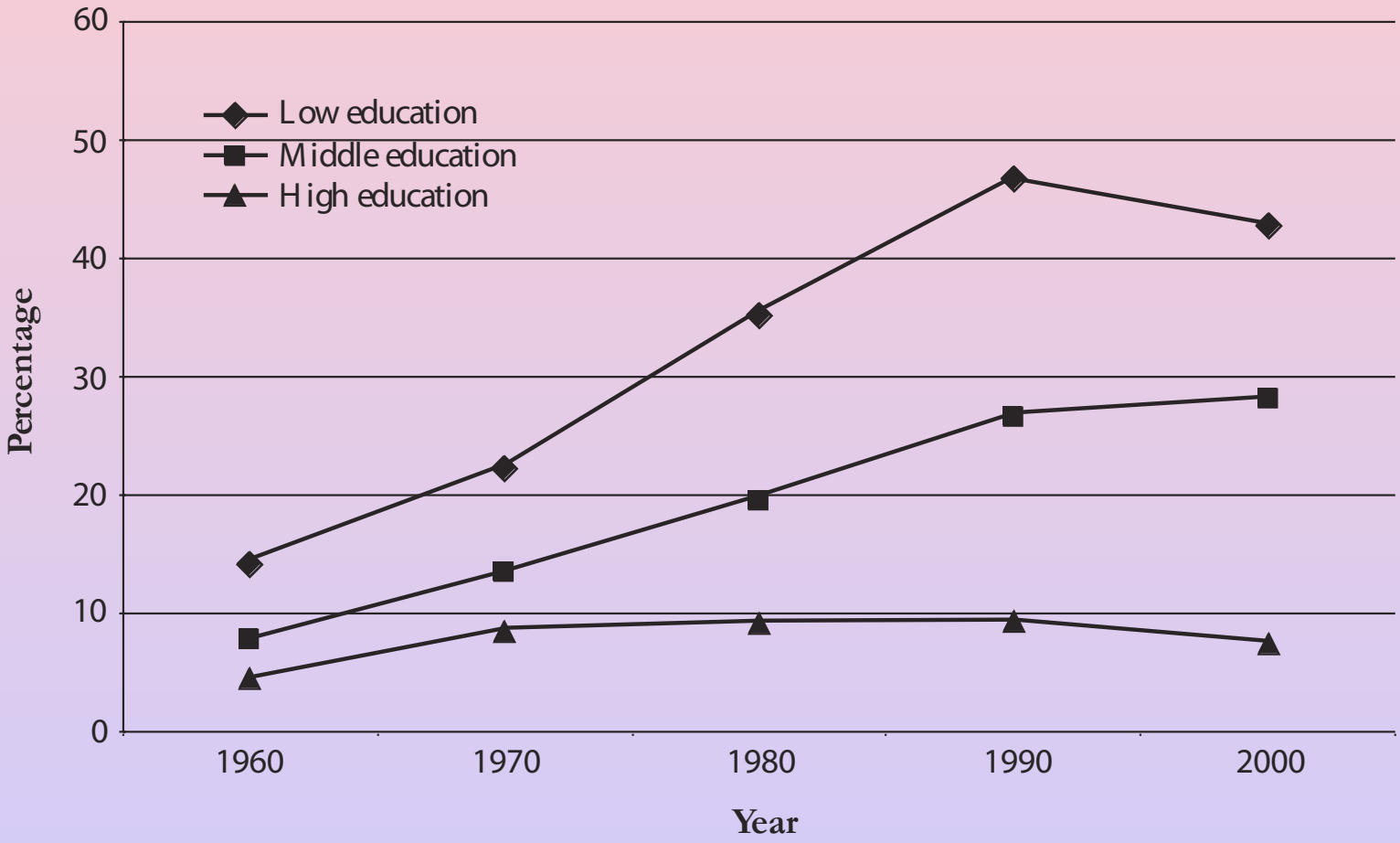
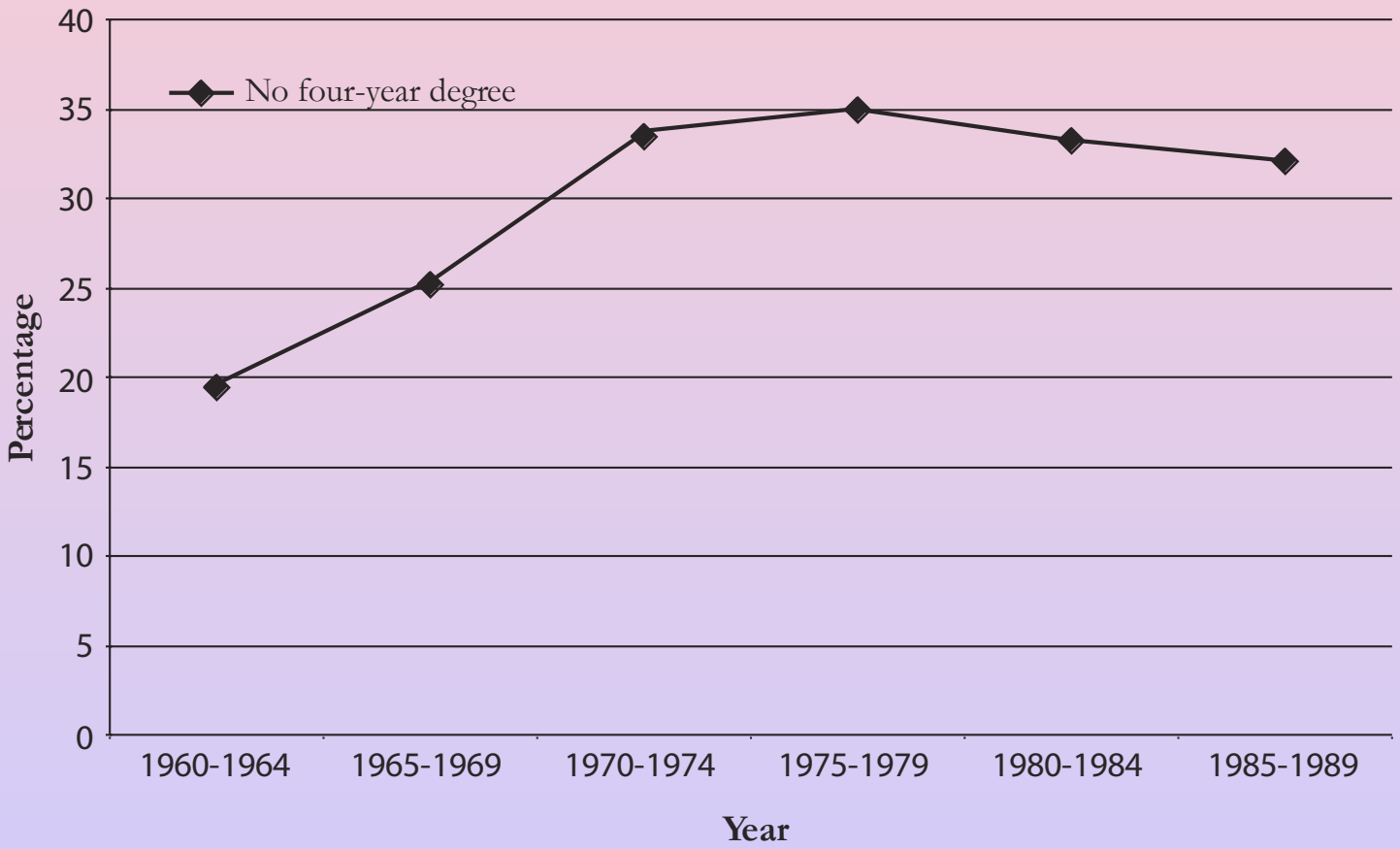


Note: Single motherhood is defined as not being married or not living with a spouse.

Source: PUMS (1960-2000).

Trends in Divorce During the First 10 Years of Marriage for Marriage Cohorts, 1960–1964 to 1985–1989



Source: Martin (2004a).

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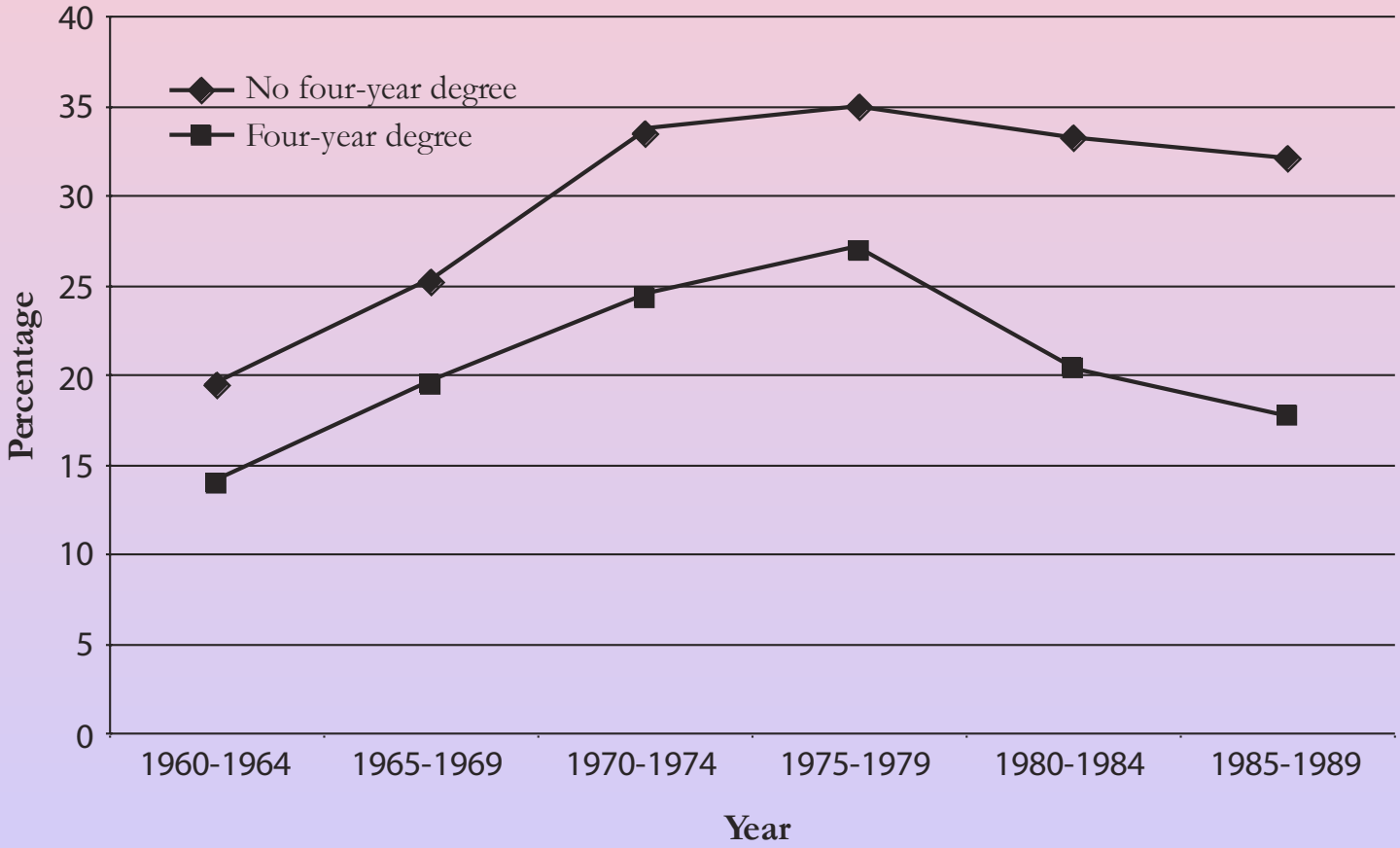
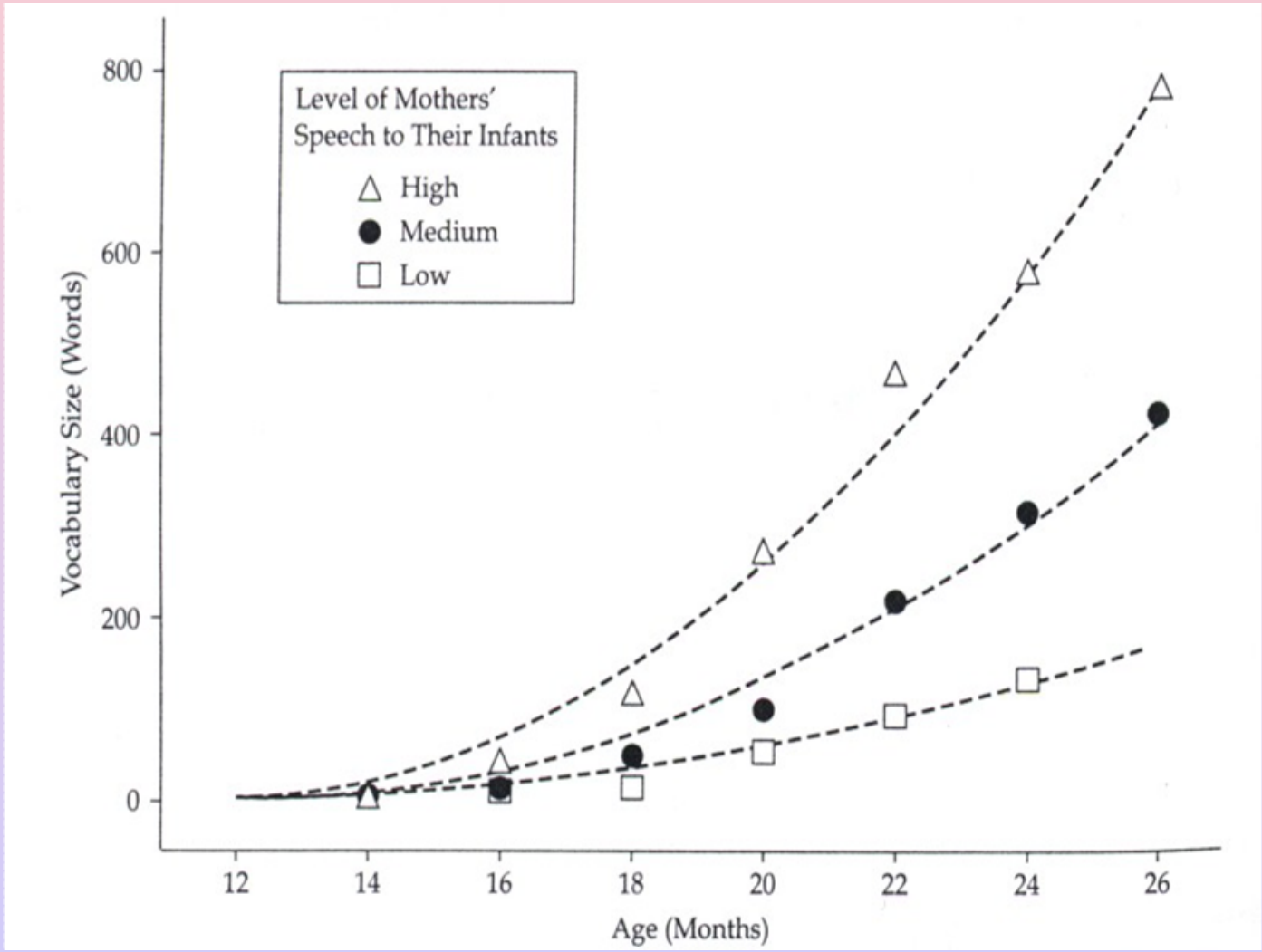


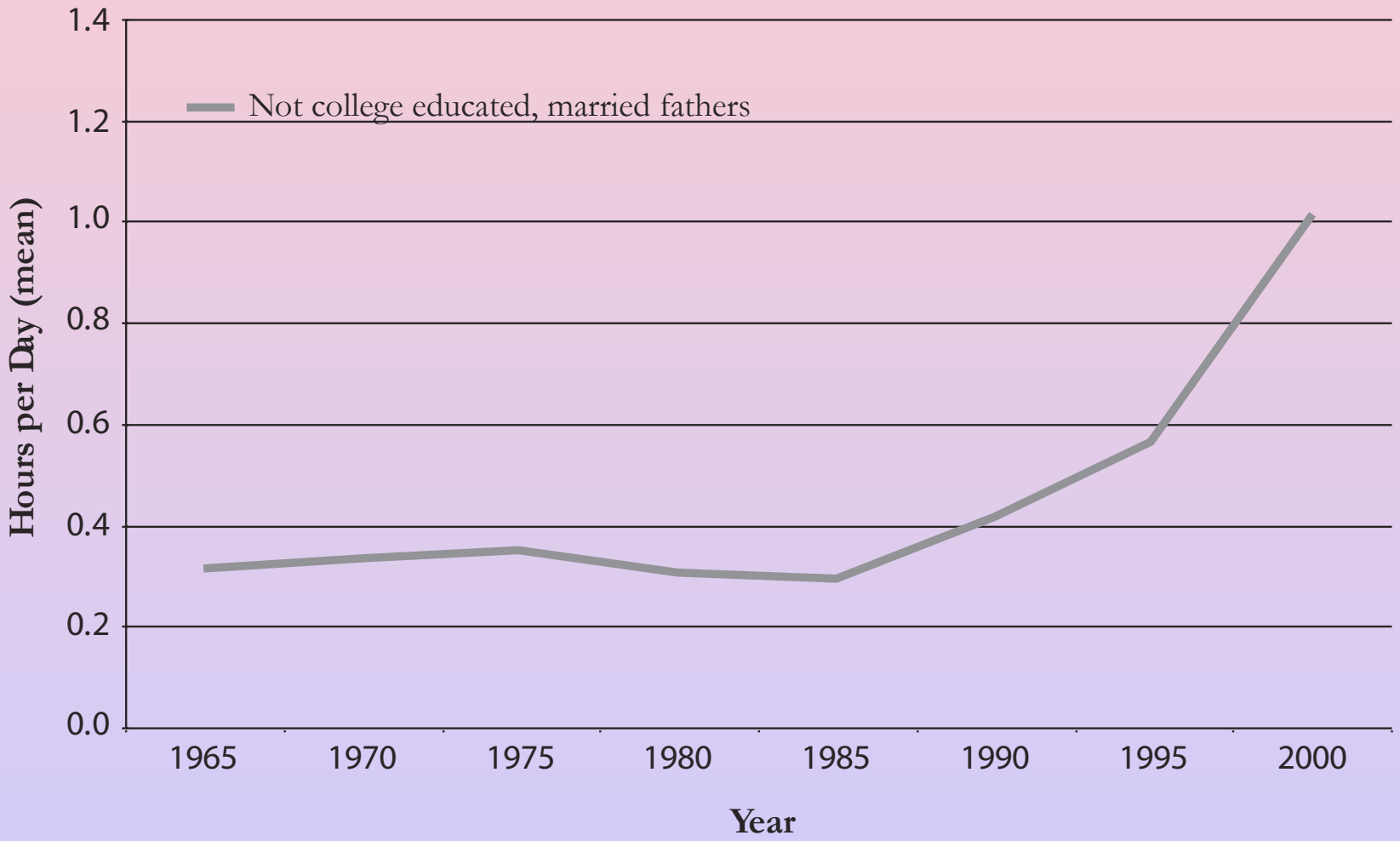
Source: Martin (2004a).

Mothers' Speech and Child Vocabulary



Source: Huttenlocher *et al.* (1991)

Trends in Fathers' Involvement, 1965 to 1998



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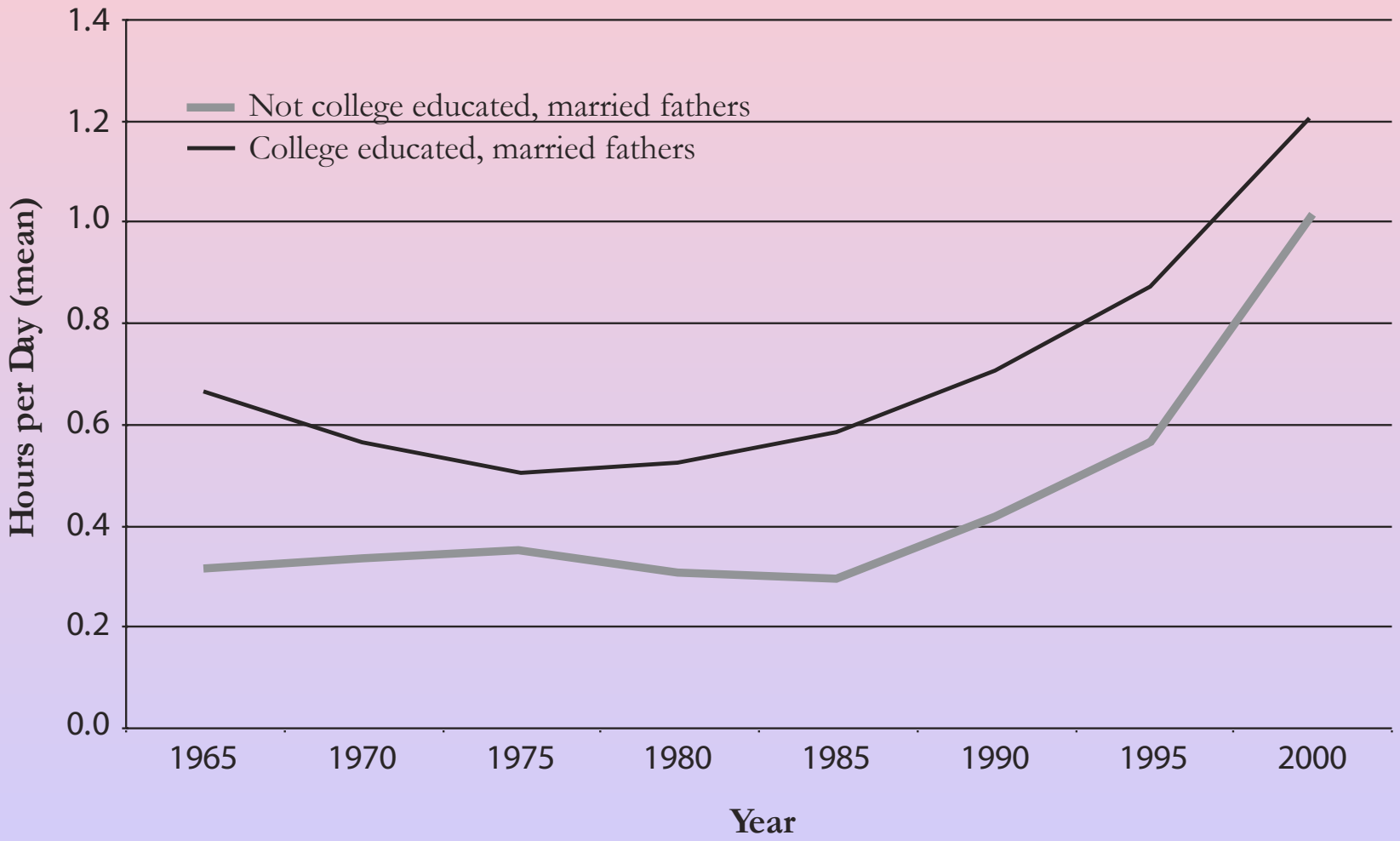

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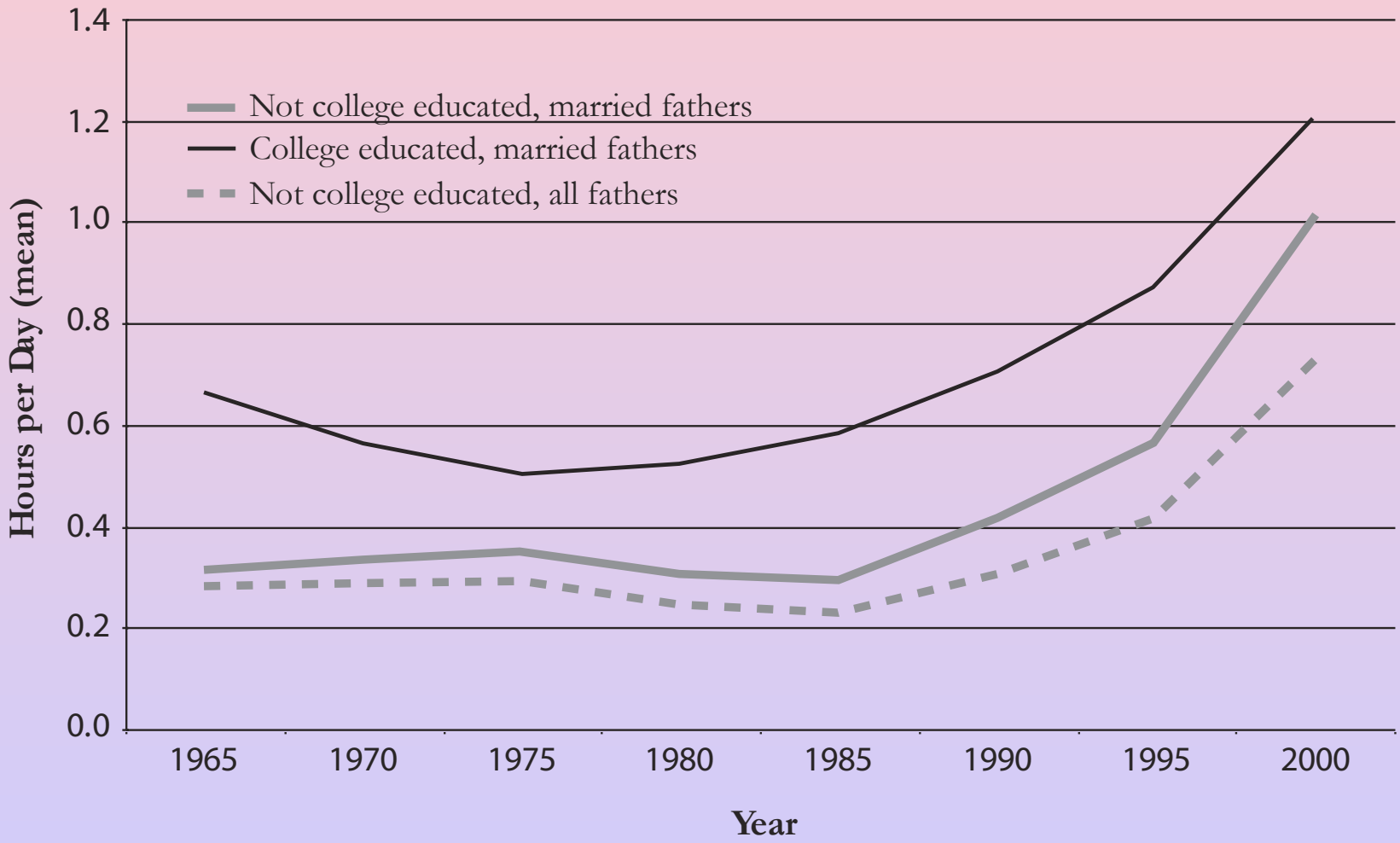

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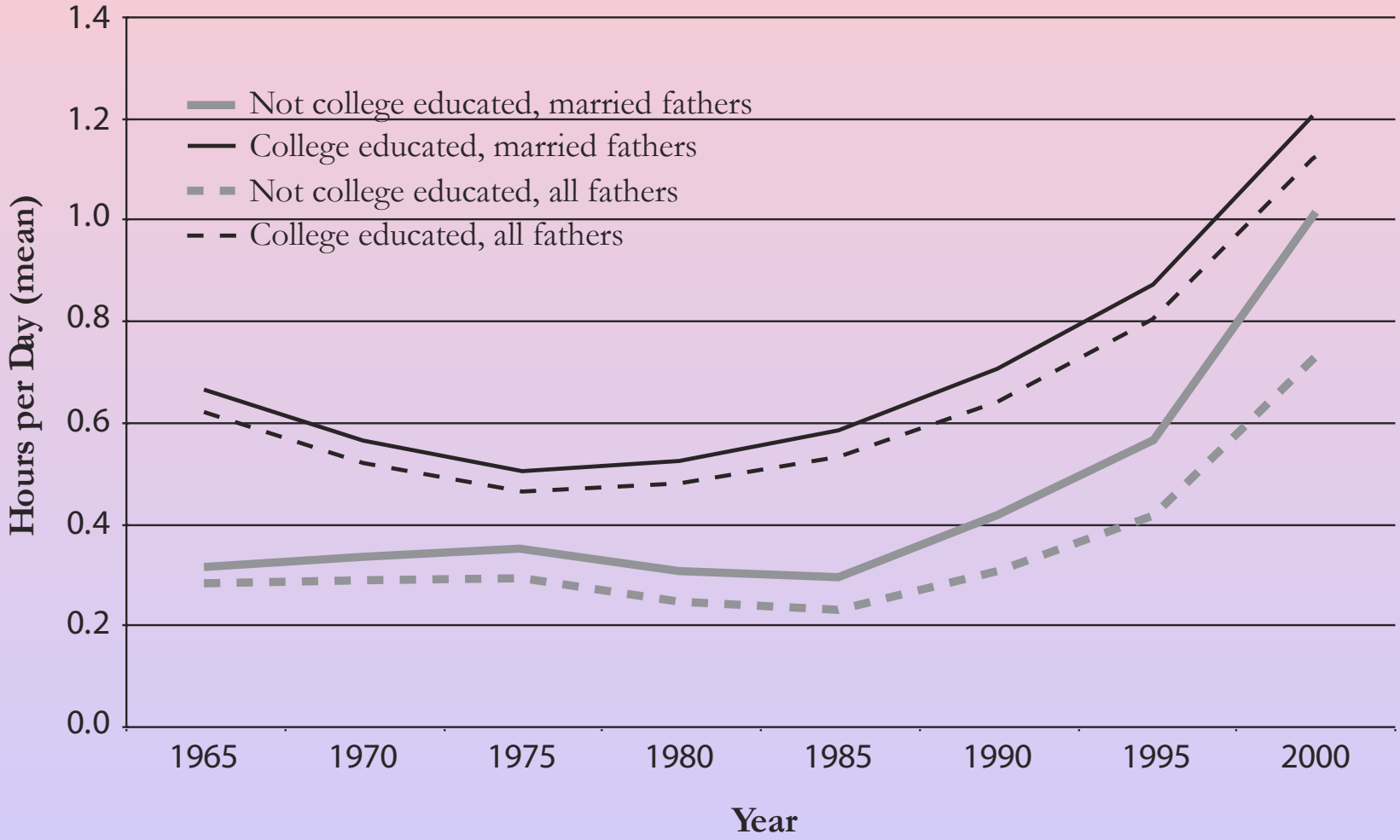

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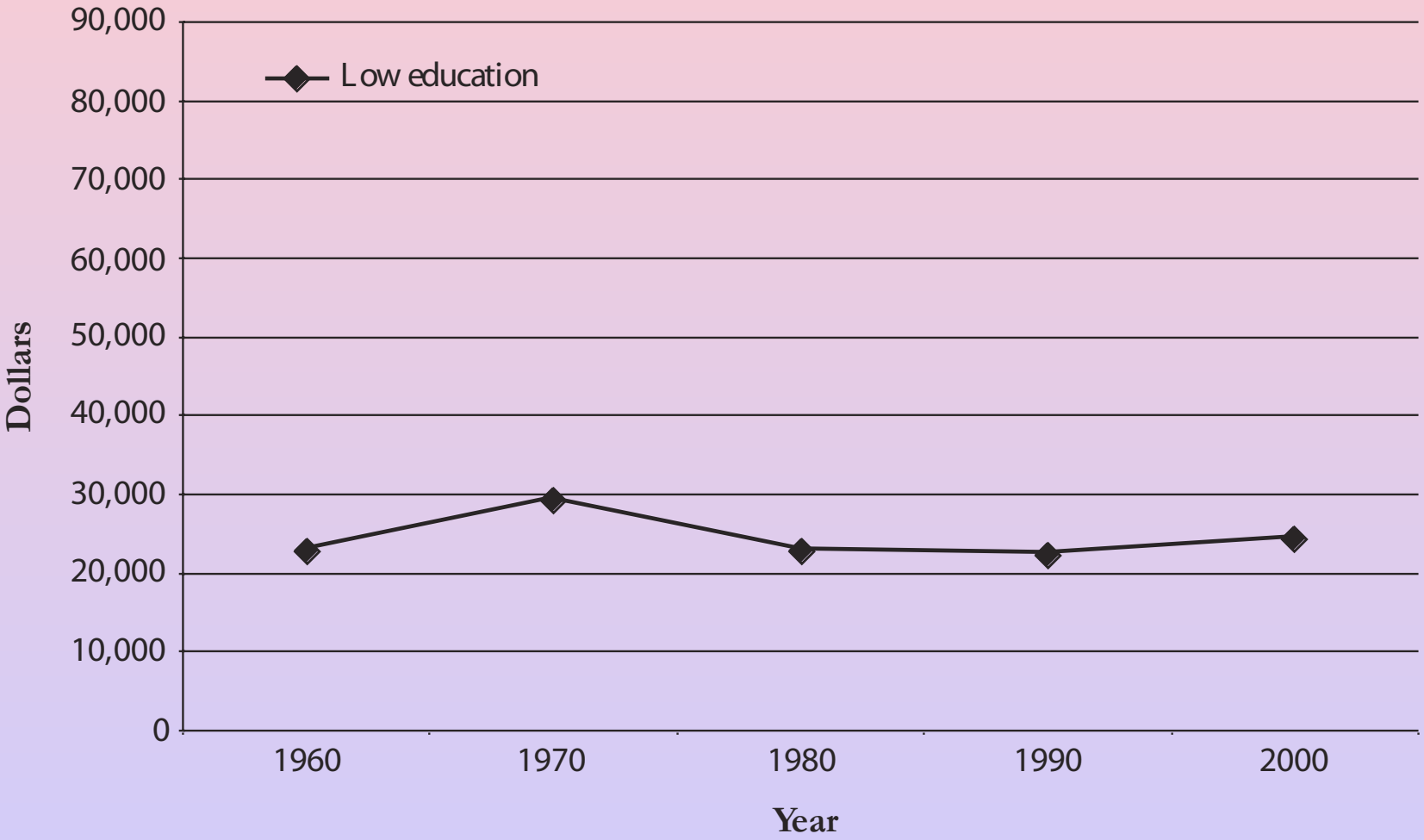
Trends in Median Family Income, 1960 to 2000



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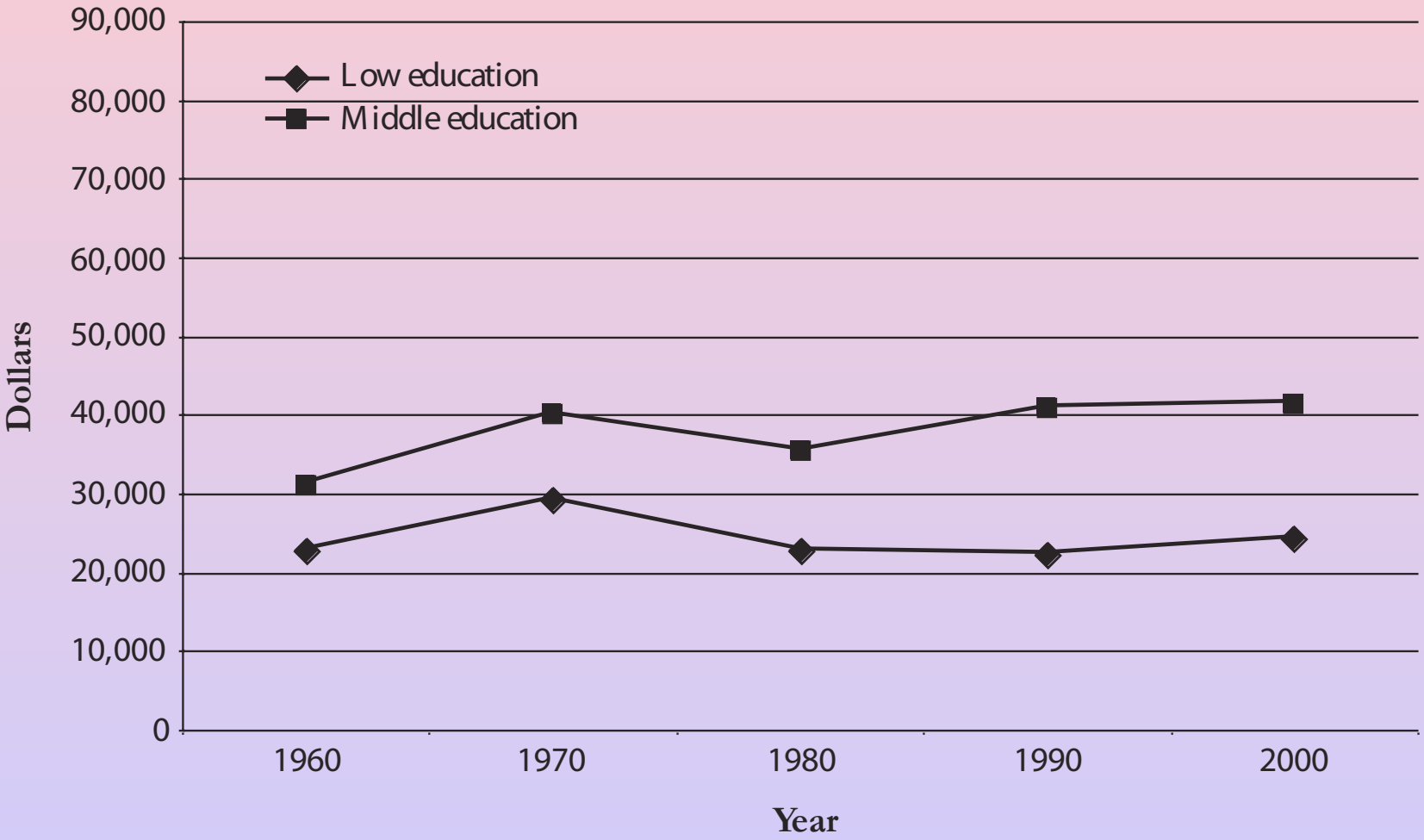

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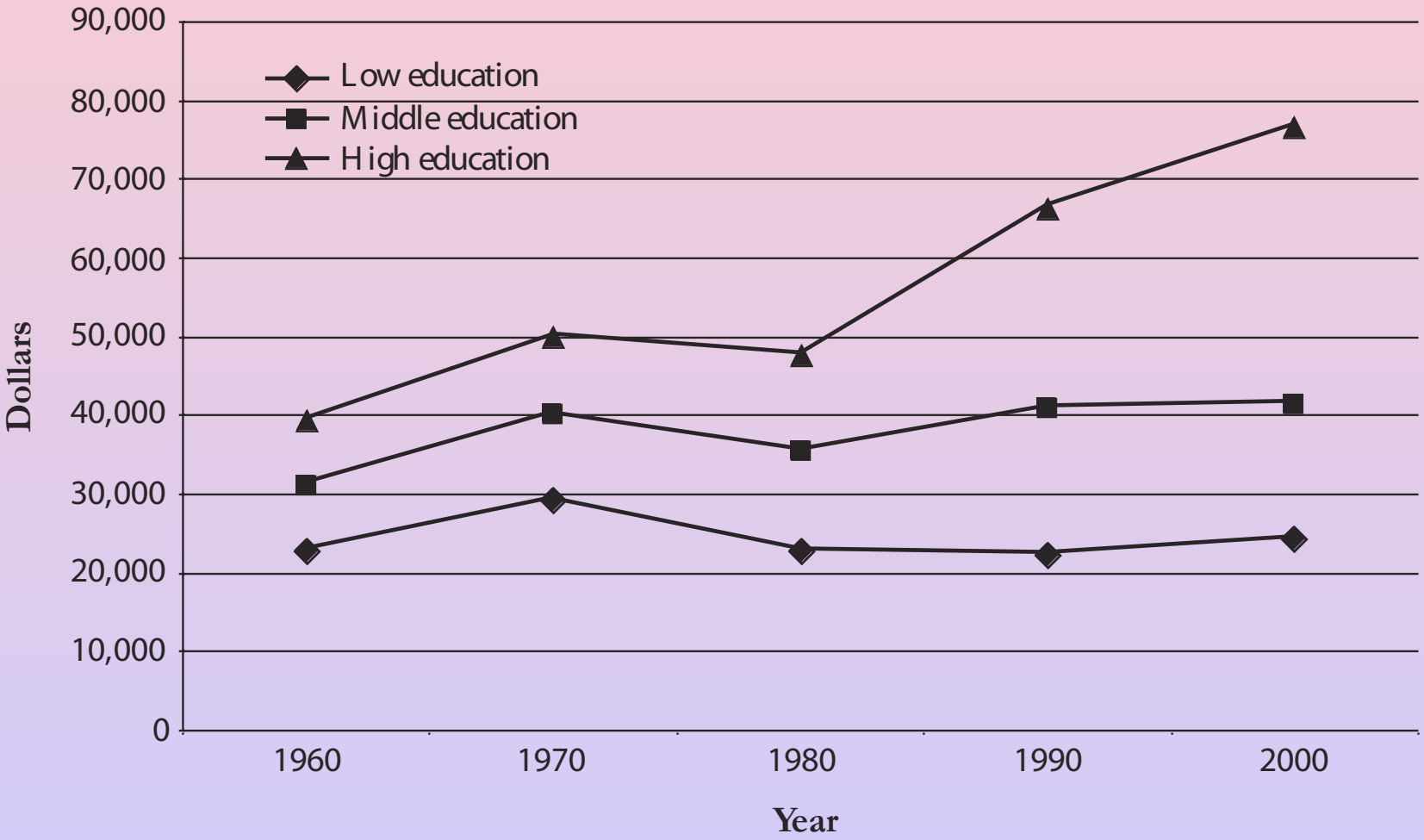

Source: PUMS (1960–2000).

Risk Factors Among Less-Educated Families, by Parents' Relationship Status

Risk Factor	Relationship Status		
	Married	Cohabiting	Single
Mothers' Health			
Depression	10.2	15.0[a]	14.9[a]
Prenatal drug use	1.0	6.3[a]	8.8[a,b]
Prenatal smoking	10.4	25.5[a]	25.9[a]
Fathers' Health			
Substance abuse	4.3	4.1[a]	7.6[a,b]
Disability	5.8	7.5[a]	6.6
Violence	2.0	3.5	6.1[a,b]
Incarceration	12.2	31.6[a]	39.2[a,b]
Family structure			
Father has a child with other partner	19.0	33.5[a]	44.1[a,b]
Mother has a child with other partner	21.6	40.8[a]	41.5[a]
Father not working	7.8	19.5[a]	39.2[a,b]
Income/needs ratio	2.28	1.46[a]	1.13[a,b]
Disrupt by age 1	8.9	30.9[a]	65.1[a,b]
Disrupt by age 3	16.9	47.6[a]	78.2[a,b]
Quality of Mothering			
Child was breast-fed	62.4	47.5[a]	38.9[a,b]
Nonpunitive interaction	4.79	4.48[a]	4.29[a,b]
Language stimulation	9.29	9.06[a]	9.03[a]

Source: Author's calculations, using data from the Fragile Families and Child Wellbeing Study.

Note: The sample is limited to mothers with a high school degree or less.

[a]Different from married at $p < .05$.

[b]Different from cohabiting at $p < .05$.

International Comparisons of Mothers' Age, Employment, and Single Motherhood, by Mothers' Education

Variable	Sweden	Finland	Germany	Netherlands	Canada	United Kingdom	United States
Mothers' Age (median)							
Low education	24	26	27	29	26	25	23
Middle education	30	30	31	31	29	29	26
High education	32	32	34	33	31	31	32
Mothers' Employment							
Low education	51.4	33.3	44.0	57.7	40.2	43.1	52.3
Middle education	85.9	44.9	49.7	78.9	60.4	55.7	74.5
High education	89.4	63.2	57.2	84.2	78.8	62.8	75.5
Single Motherhood							
Low education	24.8	14.0	31.9	8.9	31.8	43.4	29.9
Middle education	14.1	14.4	8.3	4.5	19.6	26.0	20.4
High education	6.2	4.5	6.9	2.1	10.0	14.0	7.7

Source: Calculations by Timothy Smeeding and Susanna Sundstrom, using data from the Luxembourg Income Study.

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- Dramatic example of effects of early environment.

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- The study shows with data that the insights of Freud about the effects of adverse early childhood environments are correct.
- The exact neural mechanisms have not yet been studied.
- Exactly what feature of early trauma or adverse environment affects child outcomes is not yet known.
- But the association noted by Freud appears to be correct.

What are Adverse Childhood Experiences?

Experiences in childhood or adolescence that represent medical or social problems of national importance:

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$\Rightarrow$ growing up with domestic violence, substance abuse, mental illness, parental loss, or crime in the home.

ACE Study Findings

Adverse childhood life experiences affect adult:

- Disease burden and medical care costs

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- Subsequent generations.

Adverse Childhood Experiences Score

Number of categories (not events) is summed...

ACE Score	Prevalence
0	33%
1	25%
2	15%
3	10%
4	6%
5 or more	11%

- Two out of three adults experienced at least one category of ACE.

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- Two out of three adults experienced at least one category of ACE.
- Women are 50% more likely than men to have an ACE Score ≥ 5.

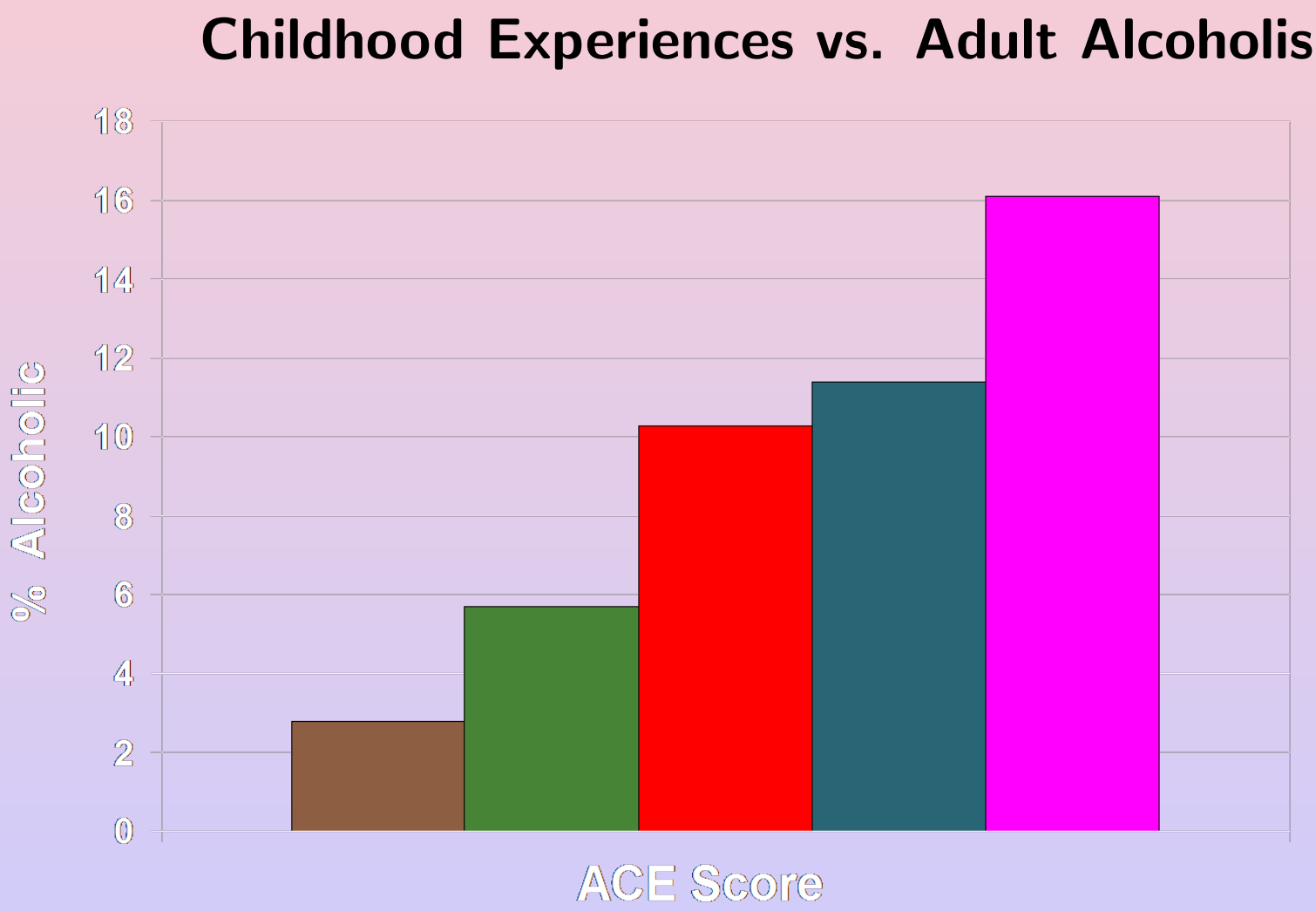
Disease

ACEs Increase Likelihood of Heart Disease*

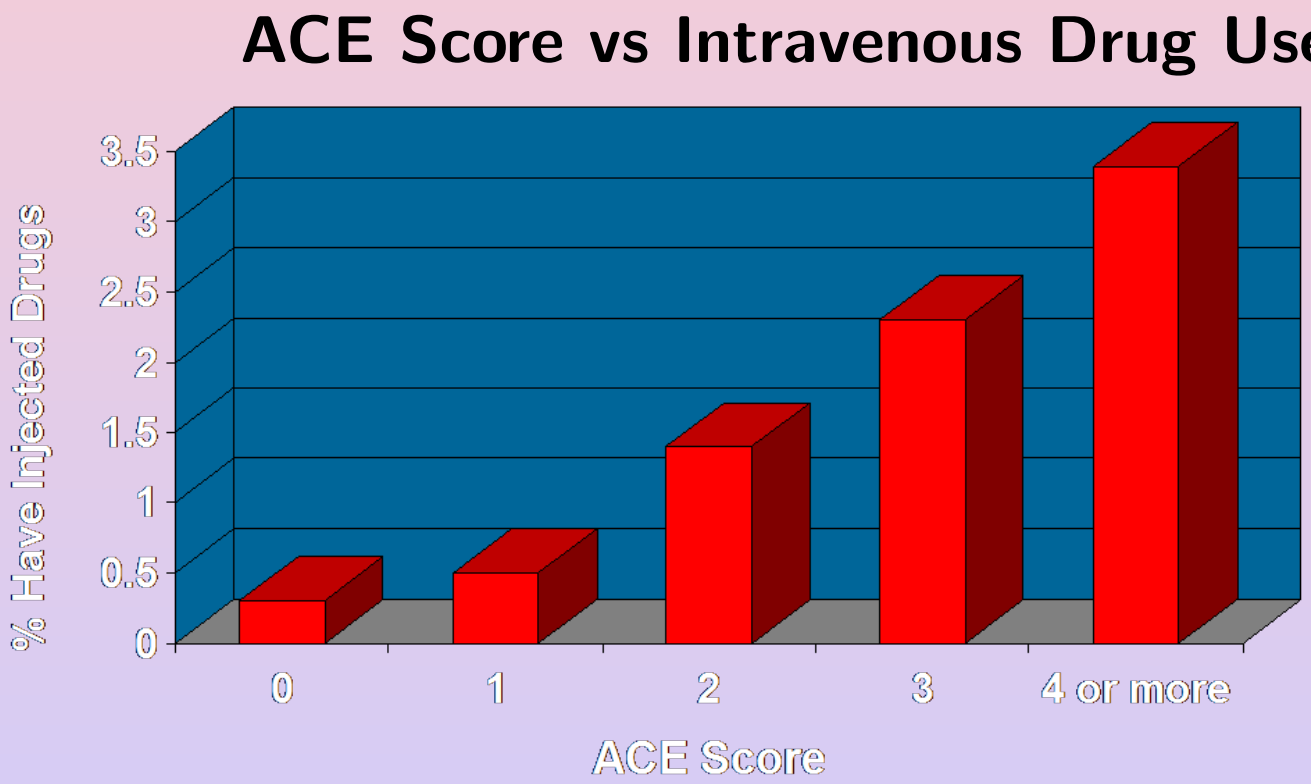
• Emotional abuse	1.7x
• Physical abuse	1.5x
• Sexual abuse	1.4x
• Domestic violence	1.4x
• Mental illness	1.4x
• Substance abuse	1.3x
• Household criminal	1.7x
• Emotional neglect	1.3x
• Physical neglect	1.4x

**After* correction for age, race, education, and conventional risk factors like smoking and diabetes.
Circulation, Sept 2004.

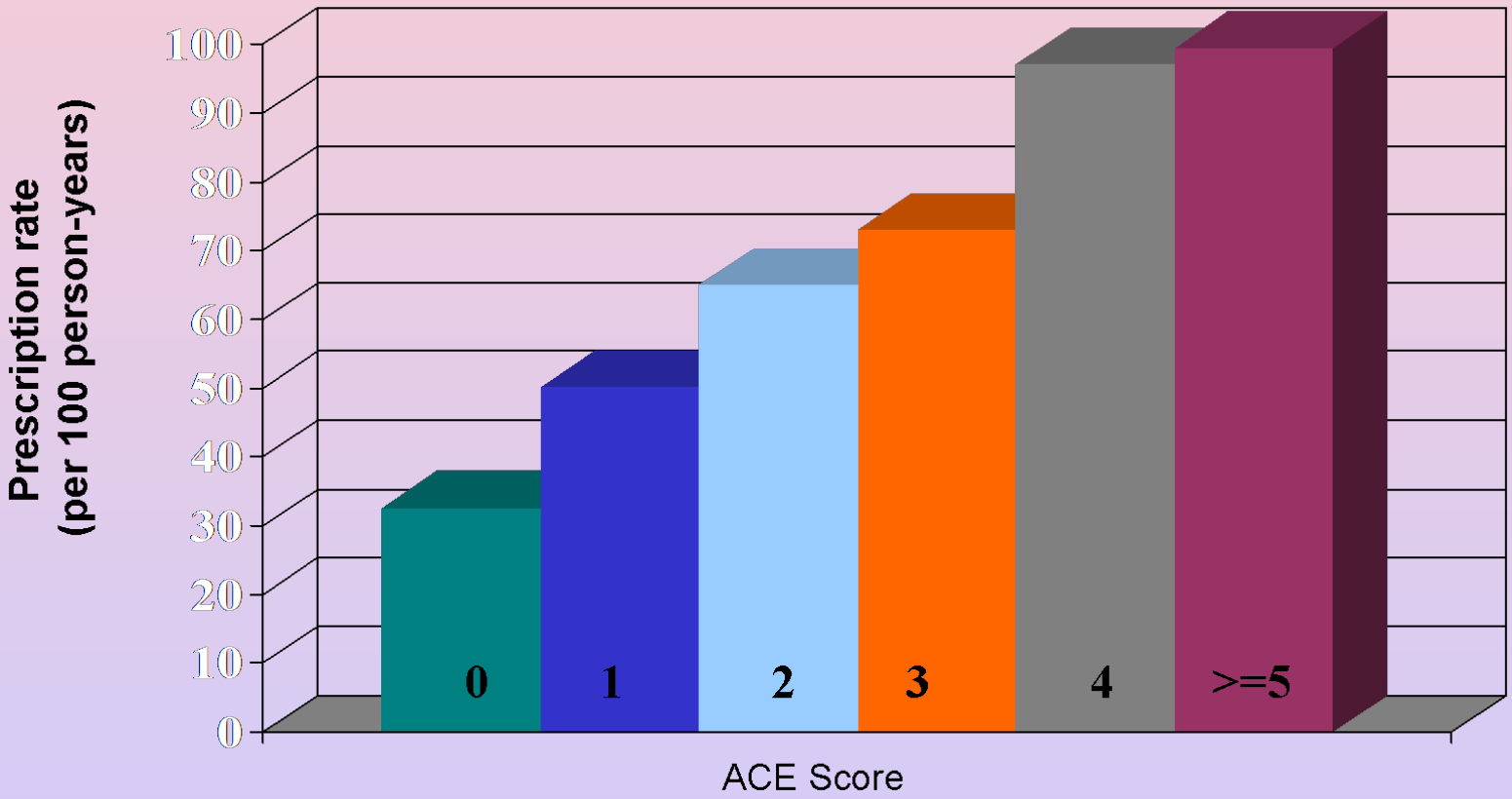
Health Risk


Childhood Experiences vs. Adult Alcoholism
% Alcoholic
0
2
4
6
8
10
12
14
16
18
ACE Score

Health Risk

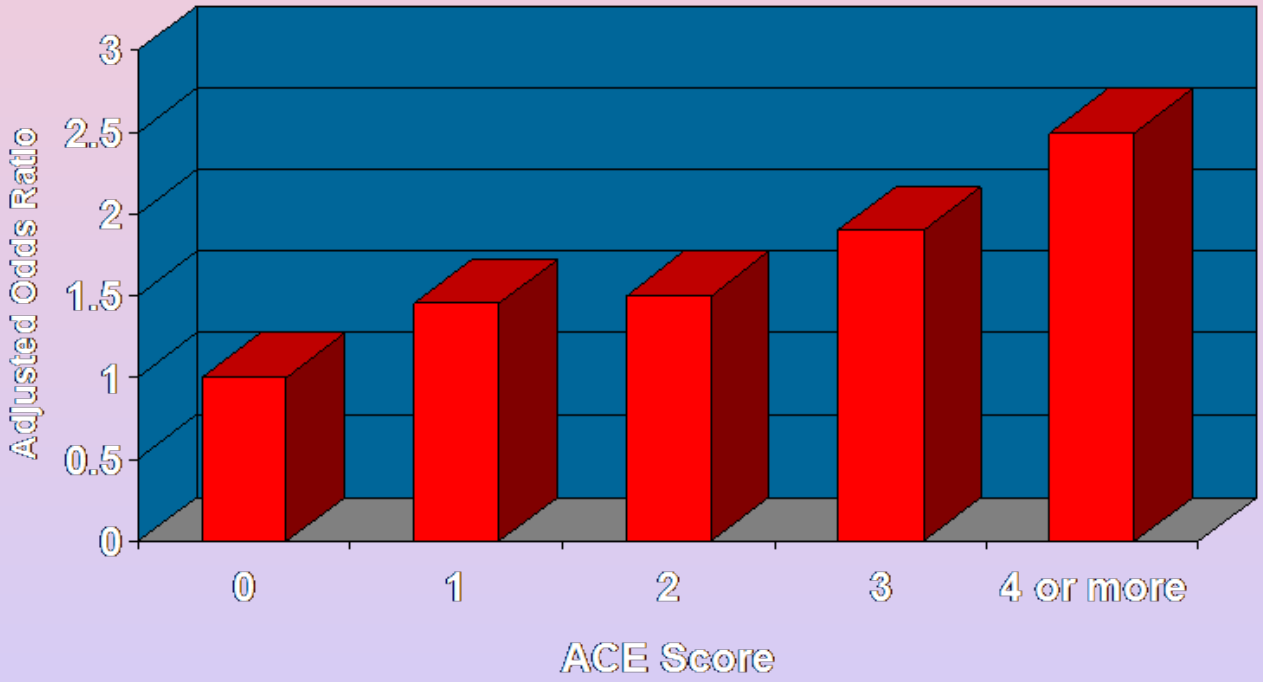

ACE Score vs Intravenous Drug Use
% Have Injected Drugs
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4 or more
ACE Score

ACE Score and Rates of Antidepressant Prescriptions



Disease

Adverse Childhood Experiences vs. History of STD



Neglect

- Lack of a specific sensory input during development results in abnormal development of the brain.

`www.ChildTraumaAcademy.org`

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- The abnormal development is in those brain systems which sense, perceive, process, "interpret", and "act on" information related to that specific sensory deprivation.

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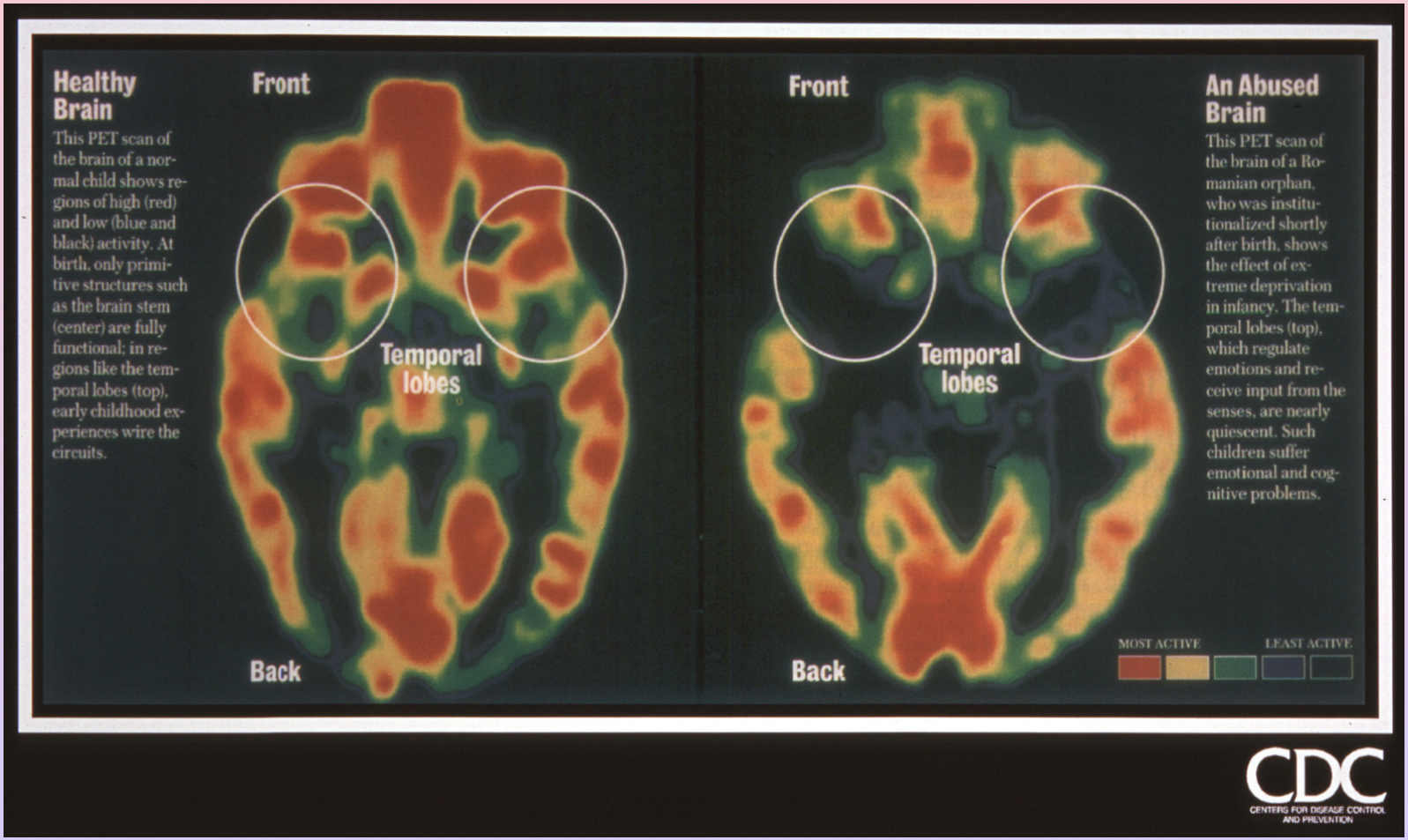
Healthy Brain
This PET scan of the brain of a normal child shows regions of high (red) and low (blue and black) activity. At birth, only primitive structures such as the brain stem (center) are fully functional; in regions like the temporal lobes (top), early childhood experiences wire the circuits.
Front
Temporal lobes
Back
Front
Temporal lobes
Back
An Abused Brain
This PET scan of the brain of a Romanian orphan, who was institutionalized shortly after birth, shows the effect of extreme deprivation in infancy. The temporal lobes (top), which regulate emotions and receive input from the senses, are nearly quiescent. Such children suffer emotional and cognitive problems.
MOST ACTIVE
LEAST ACTIVE
CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION

Sensory Deprivation

- Absence of sight, sound, touch, taste, smell -and meaningful combinations of these sensations

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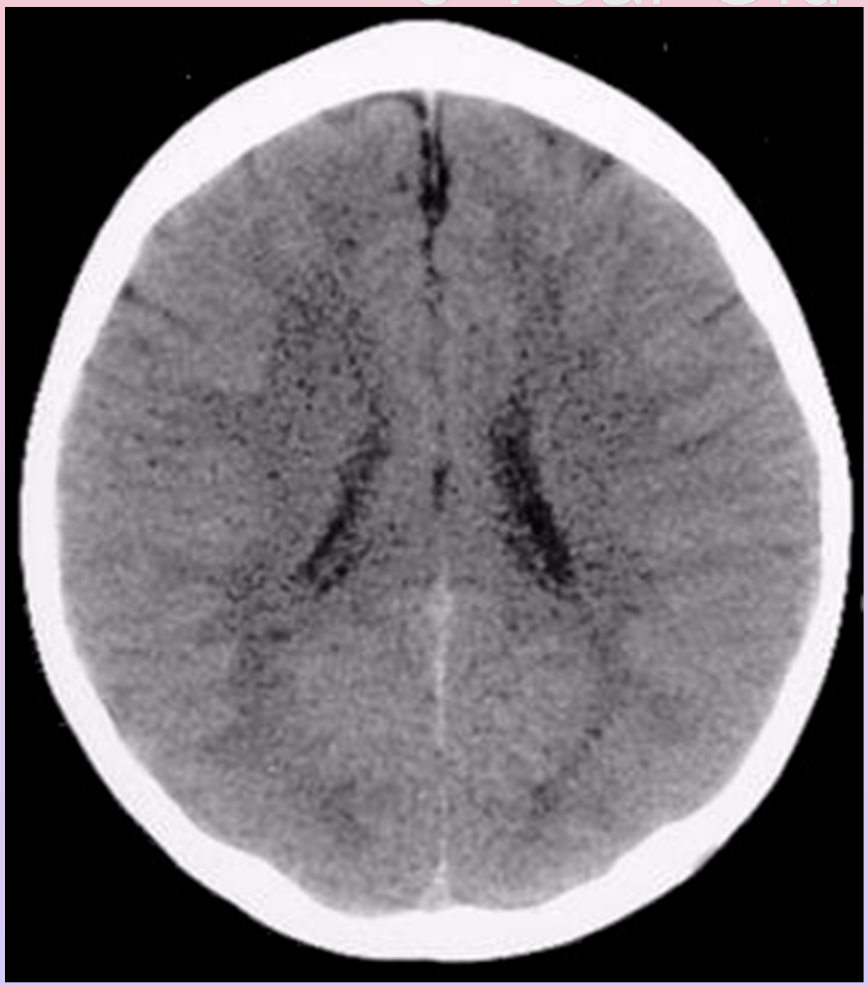
- The somatosensory bath of early childhood provides the major sensory cues responsible for organizing key areas in the brain
- Absent these sensory experiences, abnormal development results

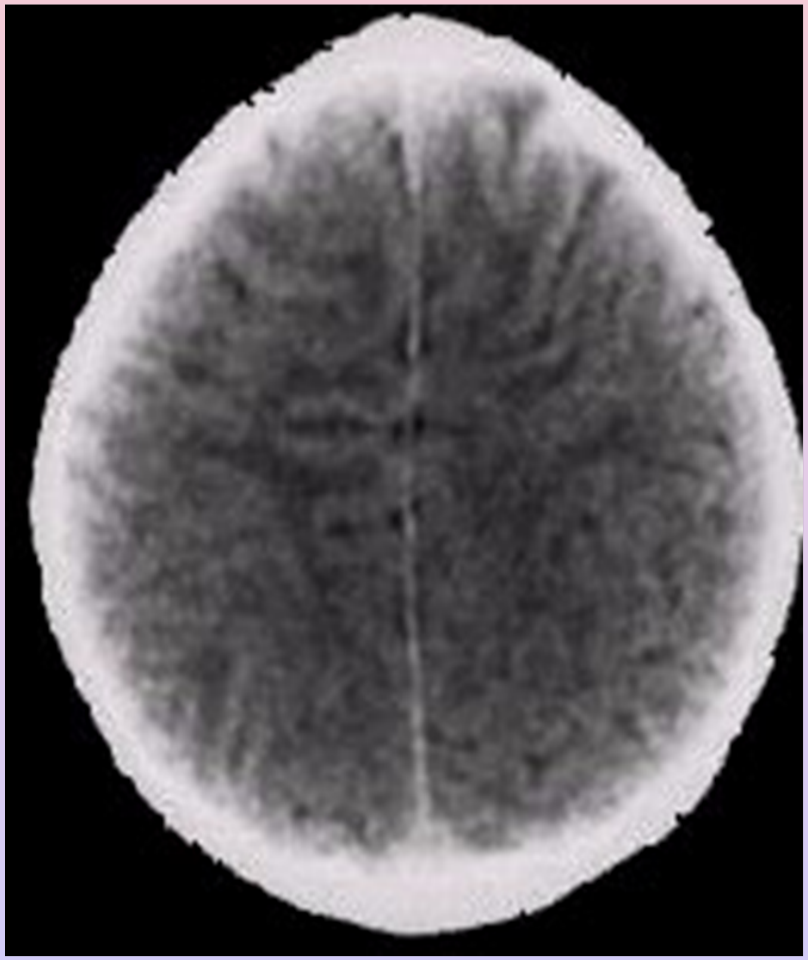
3 Year Old Children



Normal

Extreme Neglect

3 Year Old Children



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- Romanian infants in orphanages received virtually no stimulation (intellectual or otherwise).
- The earlier the remediation, the better.

Romanian adoption study supports this

	Within-UK Adoptees	Romanian Orphans		
Age of Adoption (Months):	6	Before 6	Age 6-24	Age 24-42
Weight at Age 6	0.30 (0.90)	0.02 (0.97)	-0.25 (0.96)	-0.85 (0.98)
Percentage with Denver Developmental Scale at Age 6 Below 70	2 (1)	0 (0)	5 (2)	18 (7)
McCarthy GCI at Age 6	117 (17.8)	114 (18.3)	99 (19.2)	90 (23.8)

See Rutter et al. (1998) and O'Connor et al. (2000) for more details on the analysis.

Enriched Early Environments Can Compensate In Part For Rish Features

- Experiments that enrich the early environments of disadvantaged children show that the effects of early environments on adolescent and adult outcomes are causal. Improvements in family environments enhance outcomes and affect both cognitive and noncognitive skills.

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- Noncognitive skills are an important channel of improvement.

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- Two of these investigations, the Perry Preschool Program and the Abecedarian Program, are the most informative for the purposes of this discussion because they employed a random assignment design and collected long-term follow-up data.

- These longitudinal studies demonstrate substantial, positive effects of early environmental enrichment on a range of cognitive and "non-cognitive" skills, schooling achievement, job performance, and social behaviors, long after the intervention ended.

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- Data from non-controlled assessments of Head Start and the Chicago Child-Parent Centers programs suggest similar conclusions.

Early Intervention Programs for Disadvantaged Children

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- The control and treatment groups have been followed through age 40.

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- The program was a year-round, full-day intervention that continued through age 8. The children were followed up until age 21, and the project is ongoing.

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- Effects stronger for girls than boys.
- In the Chicago Parent-Child program, just the opposite appears to be true.

- Perry did not raise IQ.

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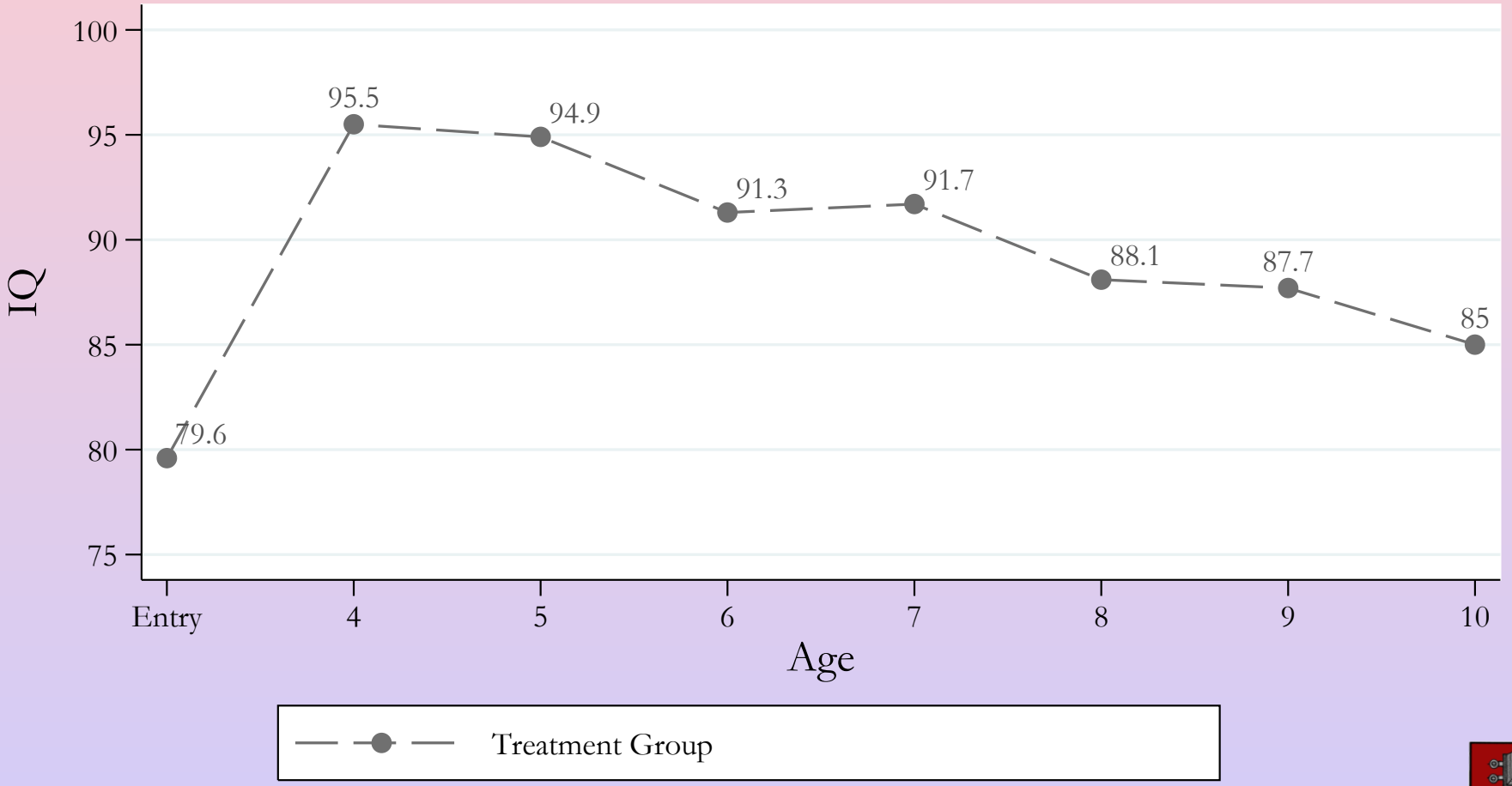
- It raised noncognitive skills.

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.

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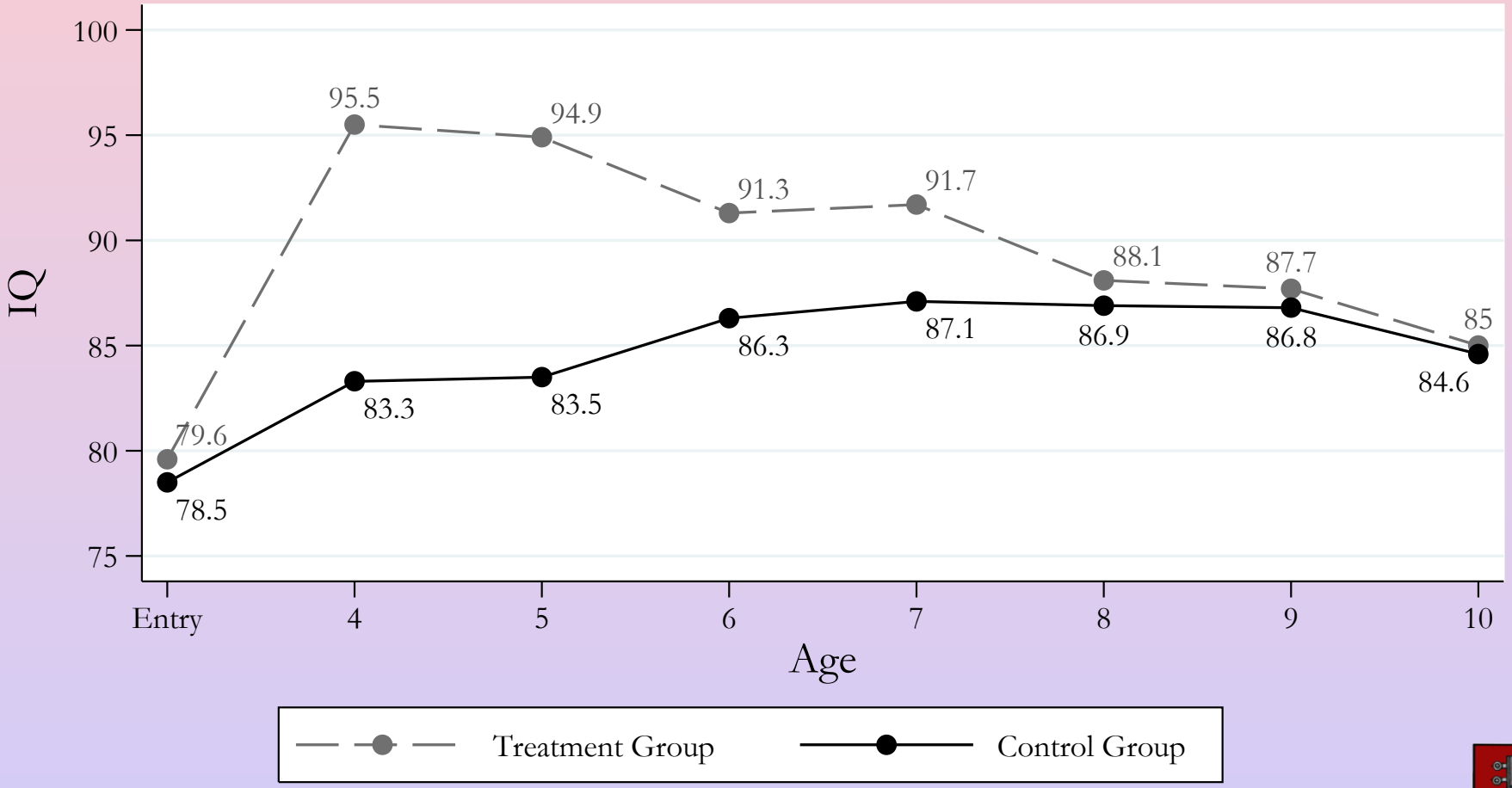

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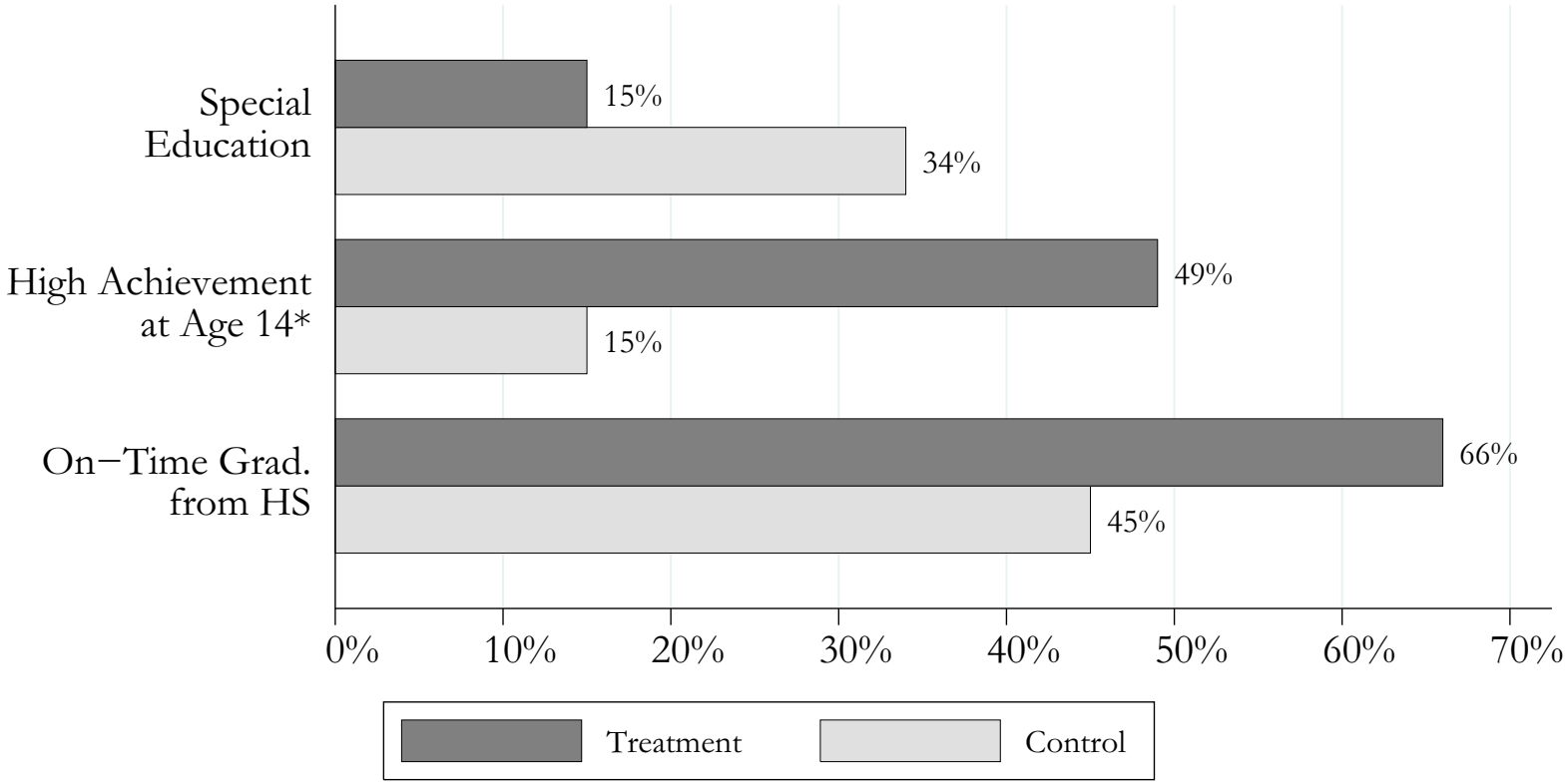
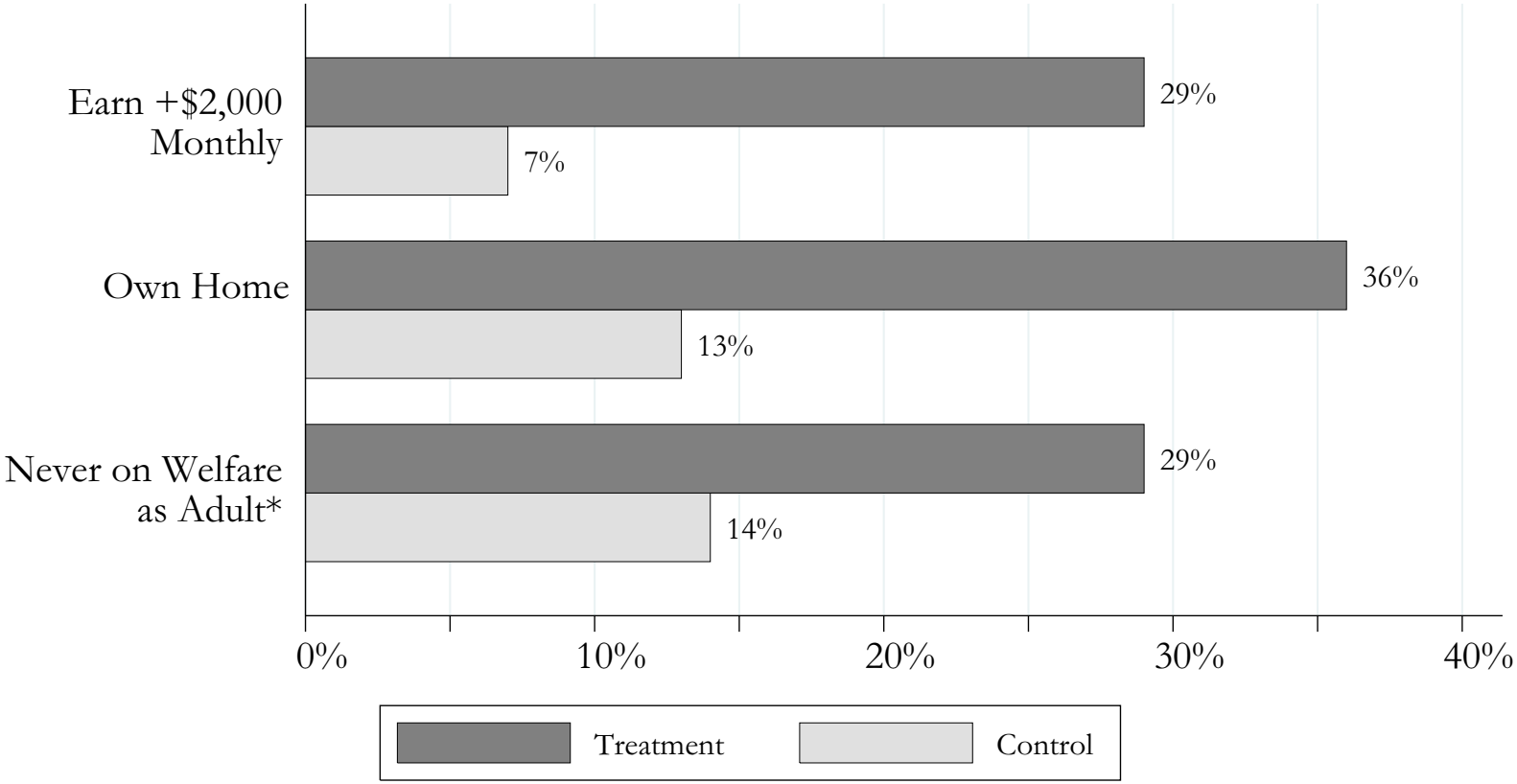
- At the oldest ages tested (Perry: 40 yrs; Abecedarian: 21 yrs), individuals scored higher on achievement tests, reached higher levels of education, required less special education, earned higher wages, were more likely to own a home, and were less likely to go on welfare or be incarcerated than individuals from the control groups.

Perry preschool program: educational effects, by treatment group



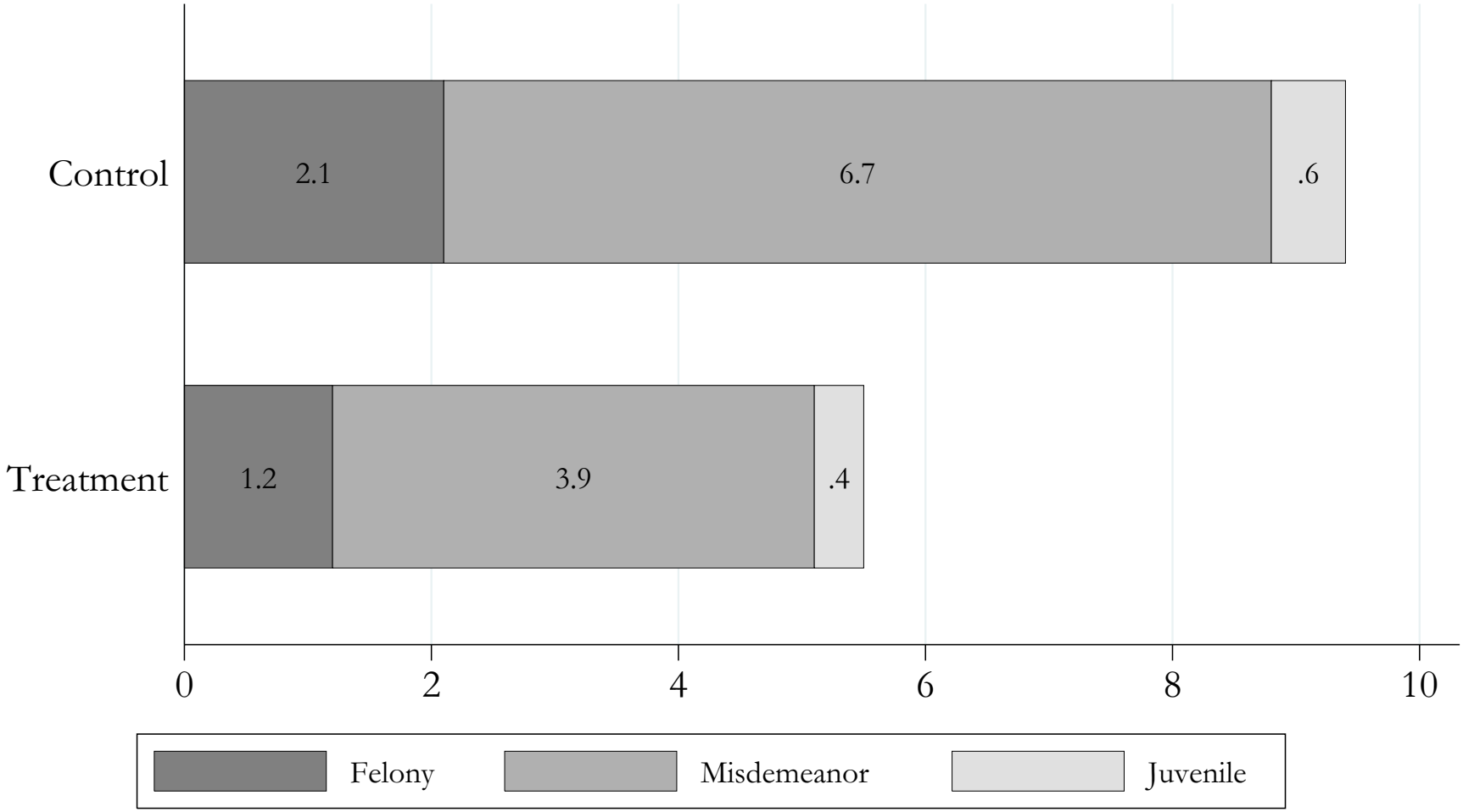
Source: Barnett (2004).
Notes: *High achievement defined as performance at or above the lowest 10th percentile on the California Achievement Test (1970).

Perry preschool program: economic effects at age 27, by treatment group



Source: Barnett (2004). *Updated through Age 40 using recent Perry Preschool Program data, derived from self−report and all available state records.

Perry preschool program: arrests per person before age 40, by treatment group



Source: Perry Preschool Program. Juvenile arrests are defined as arrests prior to age 19.

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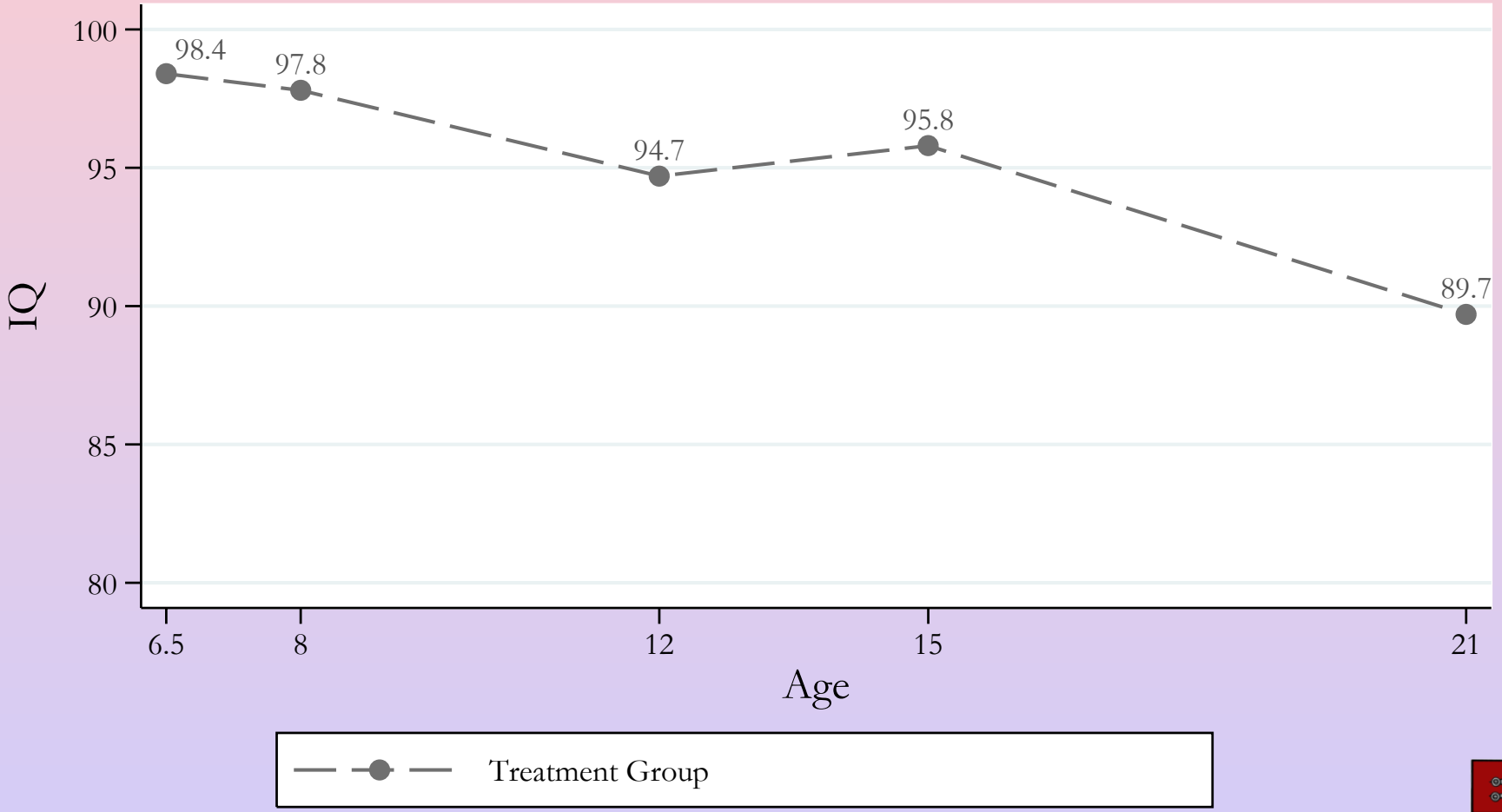
- In the more intensive, earlier starting, Abecedarian program, IQ gains were found.

Abecedarian program: IQ, by age and treatment group



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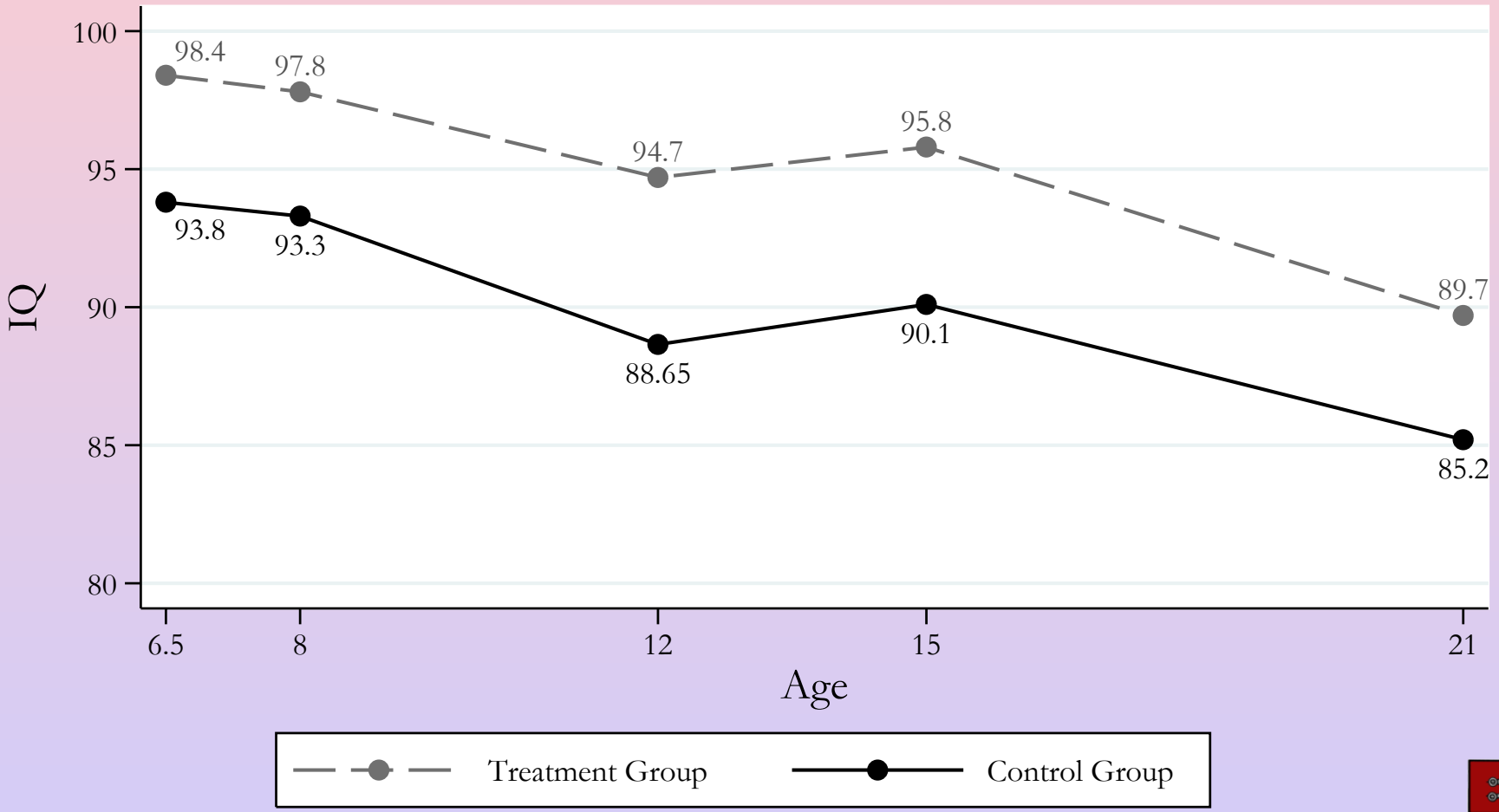

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- These are underestimates of the rate of return because they ignore health and mental health.

Evidence from Early Interventions with Long Term Follow-up

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Evidence from Early Interventions with Long Term Follow-up

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- First, skills beget skills. All capabilities are built on a foundation of capacities that are developed earlier.

Evidence from Early Interventions with Long Term Follow-up

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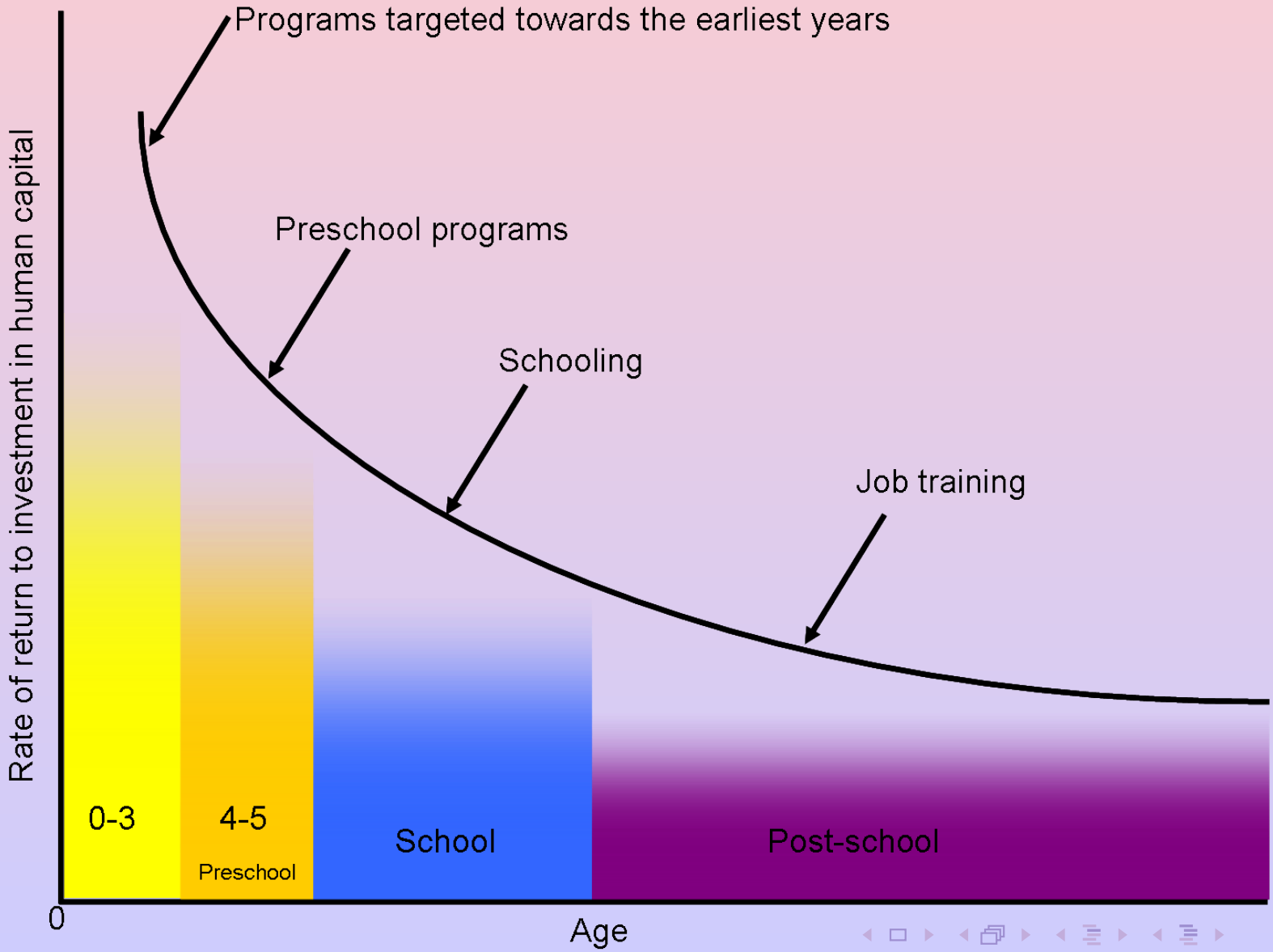
- Moreover, for several studies in which later intervention showed benefits, the performance of these children was still behind the performances of children who experienced earlier interventions in the preschool years.
- If the base is weak, the return to later investment is low.

Returns to a unit dollar invested



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- Indeed, the advantages gained from effective early interventions are sustained best when they are followed by continued high quality learning experiences.
- The technology of skill formation shows that the returns on school investment are higher for persons with higher ability, where ability is formed in the early years.
- Due to dynamic complementarity, early investments must be followed by later investments if maximum value is to be realized.

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- There is a lot of evidence for critical and sensitive periods in child development.

Language

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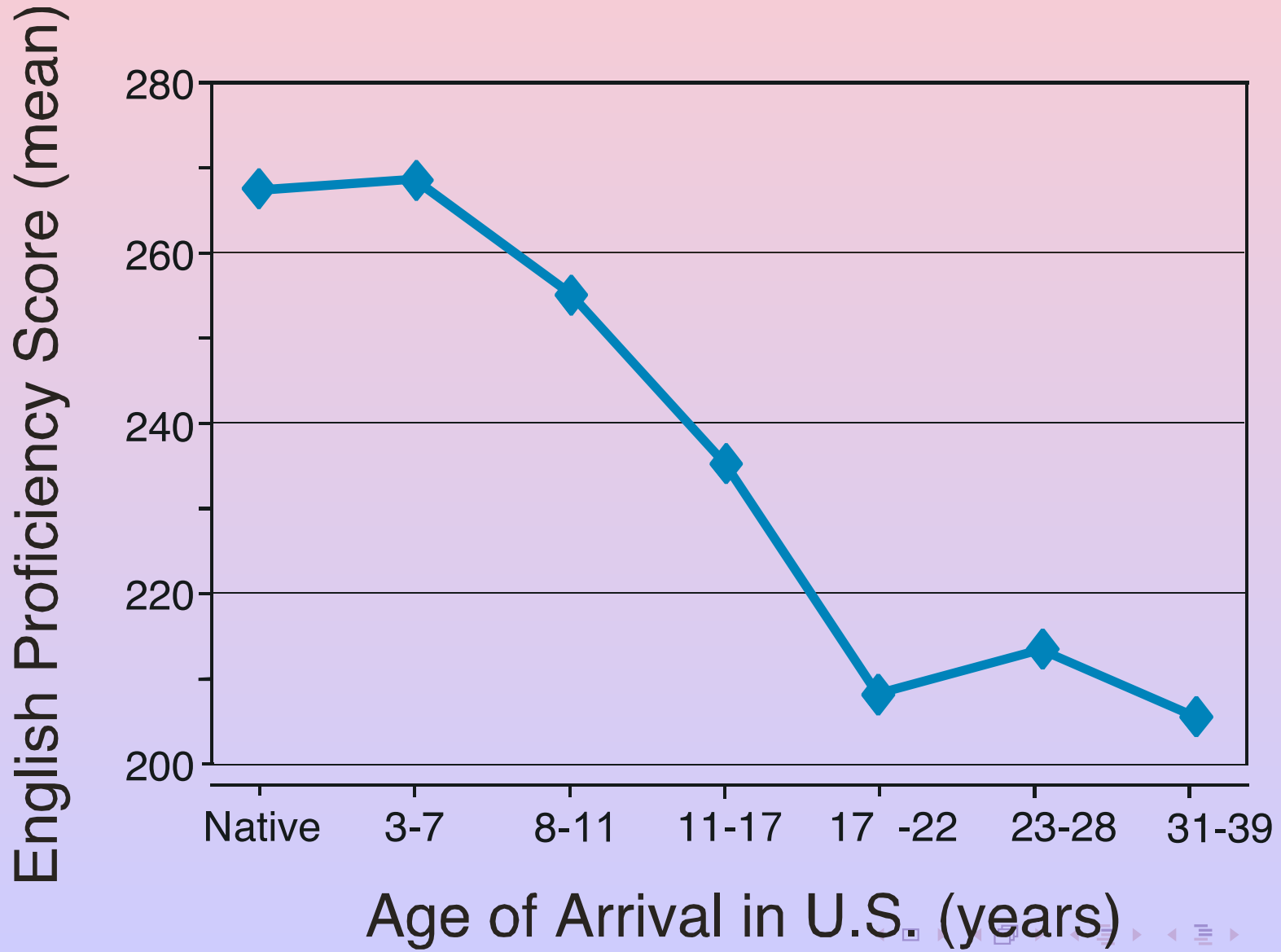
- Language is an example of a cognitive skill that is acquired readily in early life, but with great effort and never as thoroughly as an adult.
- The dependence of language learning on age holds for first languages and second languages, and for spoken languages as well as sign languages.

Second language learning



Legend

Sensitive period for second language acquisition. English language proficiency scores as a function of age of arrival in the United States for a group of Chinese and Korean adult immigrants ($n = 46$). All subjects were students or faculty at the University of Illinois and had been in the U.S. for at least 10 years prior to testing. The test measured a variety of grammatic judgements. From Johnson and Newport (1989).

Formulating and Estimating the Technology of Skill Formation

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- Need a framework to incorporate these insights.
- Basis for unifying the literature and conducting policy analysis.

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- Abilities are not just genetically determined but are the outcomes of parental investment, broadly defined.

Experience During Circuit Maturation Is Effective

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Experience During Circuit Maturation Is Effective

- We estimate nonlinear technologies to capture substitution and remediation.
- We anchor test scores on outcomes: earnings and/or schooling choices. Test scores *per se* are arbitrary scales.

A Simple Introduction to The Technology of Skill Formation

Assume childhood lasts two periods "1" and "2". This is contrary to a huge body of literature in economics and social policy that collapses childhood into a single period. Relaxing this assumption has important policy implications.

- Skills S are both cognitive and noncognitive.
- I_1 is investment in period "1".
- I_2 is investment in period "2".
- θ are environmental/genetic factors determined at birth.

A Simple Introduction to The Technology of Skill Formation

S_1 is the skill produced in period "1" according to:

$$S_1 = g\left(I_1; \theta\right)$$

S_2 is the skill produced in period "2" according to:

$$S_2 = k\left(S_1, I_2; \theta\right)$$

h is adult human capital,

$$h = S_2, \text{ a vector.}$$

Investments may be qualitatively different at different stages.

Self-Productivity and Complementarity

Universal Complementarity:

$$\frac{\partial^2 S_2}{\partial I_2 \partial S_1'} > 0$$

(Early Investment facilitates later investment.)
Can be true componentwise.

Example. Attainment of noncognitive skills through mother's warmth and encouragement raises effectiveness of both cognitive and noncognitive investments.

Self-Productivity and Complementarity

Self-Productivity:

$$\frac{\partial h}{\partial I_1} = \frac{\partial S_2}{\partial I_1} = \frac{\partial k}{\partial S_1}\frac{\partial S_1}{\partial I_1} > 0$$

(Early investment raises the stock of second period skills.)

Example. Those who attain higher first period skills are better able to progress to period two and produce skills more effectively.

- This explains the higher returns to education for more able individuals that is found in the literature.

Self-Productivity and Complementarity

To fix ideas, assume that we have one investment in each period.

Two skills $S_2 = (S_2^C, S_2^N)$, cognitive and noncognitive.

We form the human capital that consists of cognitive and noncognitive components

$$h = h(S_1, S_2).$$

More generally, we can think of different tasks $T(S_1, S_2)$ using skills in different proportions.

Self-Productivity and Complementarity

We establish conditions under which we can express this as:

$$h = \left\{ \gamma I_1^{\phi} + (1-\gamma) I_2^{\phi} \right\}^{\frac{1}{\phi}}$$

- γ is a skill multiplier.
- γ is higher the greater the complementarity effect and the greater the self-productivity.
- ϕ is a measure of how well we can substitute late for early investments.

Simple Examples

- Example 1: Assume $\phi = 1$:

$$h = \gamma I_1 + (1 - \gamma) I_2$$

- This extreme case states that remediation is always possible. (However, it may not be cost effective.)
- This is at odds with the evidence from Neuroscience, Developmental Psychology and Economics.

Simple Examples (cont.)

- Example 2: Assume $\phi \rightarrow -\infty$:

$$h = \min\{I_1, I_2\}$$

- In this case, if investments in period one are very low, no remediation is possible.
- Adult human capital (and consequently adult success) is defined in the first periods of the life of an individual.

Critical and Sensitive Periods

- We have seen how early experience modifies the biochemistry and architecture of the brain.
- When this modification occurs during a limited time frame, it is called a sensitive period.
- When the modification occurs during a limited time frame and it is crucial for normal development, it is called a critical period.

Critical and Sensitive Periods (cont.)

- This technology is rich enough to capture the notions of Sensitive and Critical Periods in neuroscience.
- Period one is critical if $\gamma = 1$.
- Period one is sensitive if $0.5 < \gamma < 1$.

The Technology in an Intuitive Framework

- In the simplest set up, suppose that parents have \$1 to invest in human capital.
- The problem is how to allocate this amount between early and late investments.
- This depends crucially on the parameters of the technology of skill formation.
- Let the price of the investment good be 1.
- Let r denote the interest rate.
- Suppose the parents seek to maximize the child's human capital.

The Technology in an Intuitive Framework

Case 1: I_1 and I_2 are perfect substitutes ($\phi = 1$) $\Rightarrow$

$$S_2 = \gamma I_1 + (1 - \gamma) I_2$$

"corner solution."

Concentrate investments early if and only if:

$$\gamma \geq (1 - \gamma)(1 + r)$$

The Technology in an Intuitive Framework

- This technology, which is widely held to be true, suggests that the timing of investment is not an important issue. As a consequence, remediation is possible.
- However, even though it may be feasible to remediate, it may be very costly (especially if γ is close to 1).
- Even if it is technologically feasible to remediate, it is not necessarily economically feasible.
- May be more efficient to give the child a bank account to finance its schooling.

The Technology in an Intuitive Framework

Case 2: I_1 and I_2 are perfect complements ($\phi \to -\infty$) $\Rightarrow$

$$S_2 = [\min\{I_1, I_2\}]^{\rho}$$

Then:

$$I_1 = I_2 = \frac{1+r}{2+r}$$

Complementarity has a dual face:

1. Early investments increase returns to late investments.
2. Late investments are needed to make early investments pay off.

In this case, timing of investments matter. In particular, no remediation is possible.

A poor initial environment cannot be offset.

The Technology in an Intuitive Framework

Case 3: $-\infty < \phi < 1$. A consequence of this model is:

$$\log\left(\frac{I_1}{I_2}\right) = \left(\frac{1}{1-\phi}\right)\log\left(\frac{\gamma}{1-\gamma}\right) - \left(\frac{1}{1-\phi}\right)\log\left(1+r\right).$$

- r increases $\Rightarrow \left(\frac{I_1}{I_2}\right)$ decreases;

  γ increases $\Rightarrow \left(\frac{I_1}{I_2}\right)$ increases
- The goal of our research is to understand the technology of skill formation and what the optimal profile of investments in skills are over time.

The Technology in an Intuitive Framework

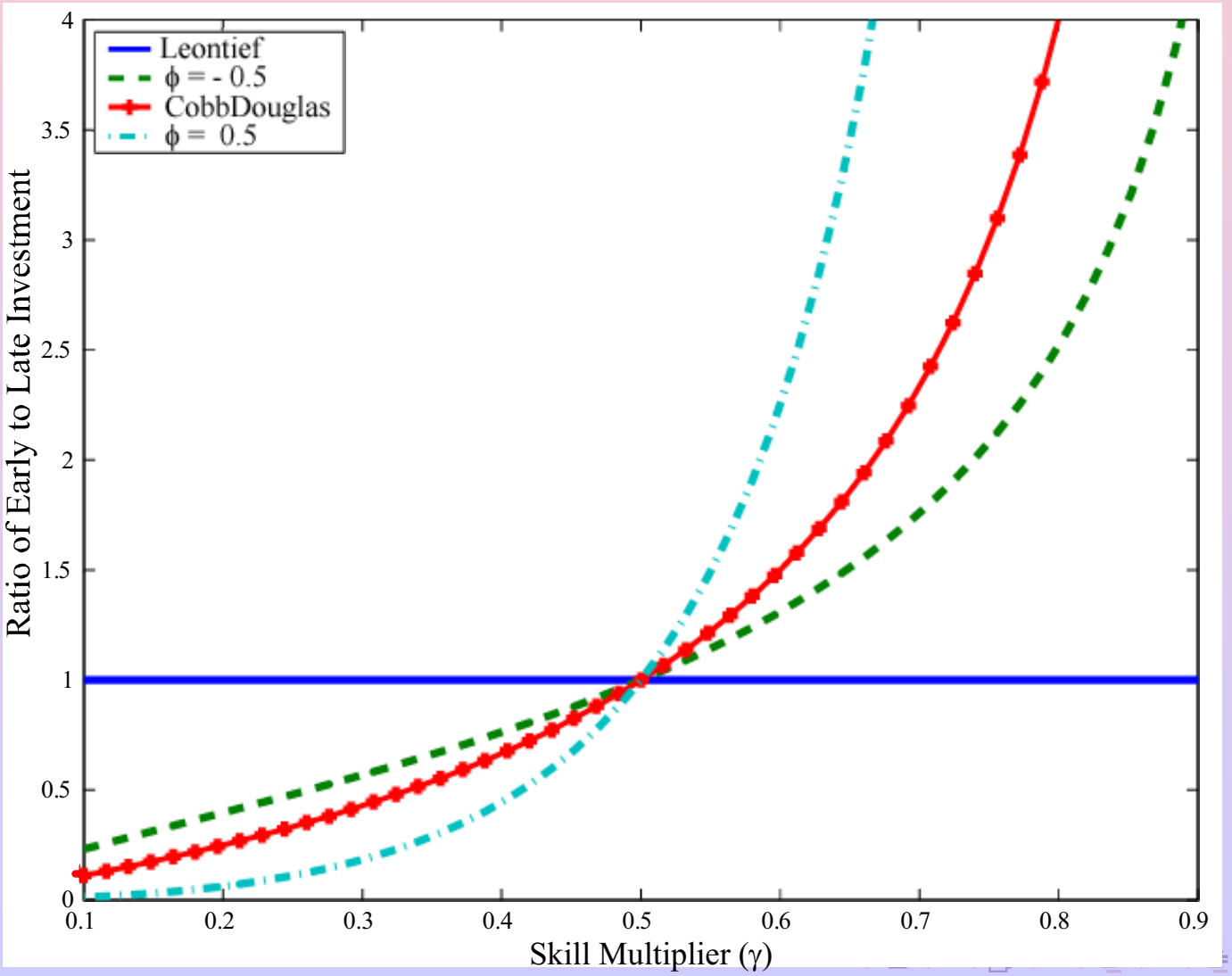
- This technology is rich enough to capture the notions of Sensitive and Critical Periods in neuroscience.

$$h = \left[\gamma \left(I_1\right)^{\phi} + \left(1-\gamma\right)\left(I_2\right)^{\phi}\right]^{\frac{\rho}{\phi}}$$

- Period "1" is critical if $\gamma = 1$. Period "2" is critical if $\gamma = 0$.
- Period "1" is sensitive if $\gamma \geq 1-\gamma \Longrightarrow \gamma \geq \frac{1}{2}$.
- We develop more general models in Cunha, Heckman and Schennach (2006).

Intuitive

Ratio of early to late investment in human capital as a function of the skill multiplier for different values of complementarity



Our Approach

- We want to understand how the skills of the children evolve in response to:
  1. The stock of skills children have already accumulated.
  2. The investments made by the parents.
  3. The stock of skills accumulated by the parents themselves.

Our Approach

- C_t is the stock of cognitive skill of the child at age t.
- N_t is the stock of noncognitive skill of the child at age t.
- It is the parental investment at age t.
- C_M is mother's cognitive skill.
- N_M is mother's non-cognitive skill.

Our Approach

We estimate two equations:

- One technology for the production of cognitive skills:

$$C_{t+1} = F_{C,t}(N_t, C_t, I_t, C_M, N_M)$$

- One technology for the production of non-cognitive skills:

$$N_{t+1} = F_{N,t}(N_t, C_t, I_t, C_M, N_M)$$

Our Approach

- All of the variables are unobserved.
- However, from a rich array of panel data sets on child development and family resources, we have numerous proxies for each variable.

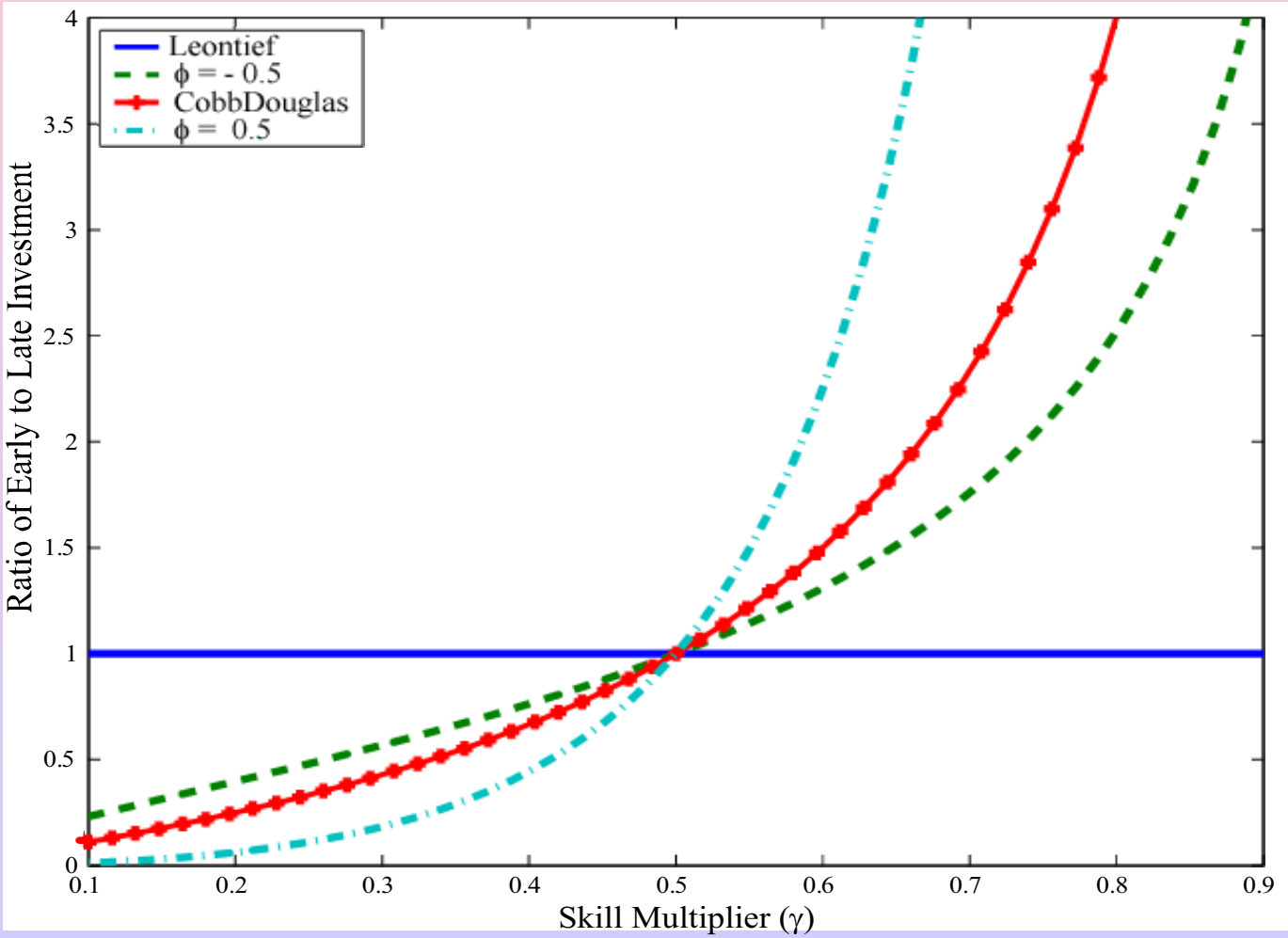
Our Approach

- We develop dynamic factor models that allow for nonlinearities (Cunha, Heckman, Schennach, 2006).
- This recognizes the proxy nature of the measurements and this turns out to be empirically important as there is a lot of measurement error.
- Allows us to combine numerous measurements into low dimensional indices.
- We anchor test scores so our estimates are based on an interpretable metric (e.g., earnings and schooling).

Econometric Work

- In a series of papers, we have estimated the technology of skill formation.
- We develop a dynamic factor model that allows us to use multiple inputs in a technology.
- Technology has elasticities of substitution below 1 (Cobb-Douglas).
- We are especially interested in the elasticity of intertemporal substitution parameters.
- It governs the early-late trade-off of investment.

The ratio of early to late investment in human capital as a function of the skill multiplier for different values of complementarity



- We find much stronger yields of investment in the early years.

Anchored Stage Specific Technology Equations, Anchor: Log Earnings of the Child Between Ages 23-28, Measurement Error is Classical, No Omitted Inputs Correlated with θ_t, White Males, CNLSY/79

Dependent Variable	Noncognitive Skill			Cognitive Skill		
	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
Lagged Noncognitive Skill, θ_t^N	0.9849	0.9383	0.7570	0.0216	0.0076	0.0005
	(0.014)	(0.015)	(0.010)	(0.0043)	(0.0029)	(0.0029)
Lagged Cognitive Skill, θ_t^C	0.1442	−0.1259	0.1171	0.9197	0.8845	0.9099
	(0.1204)	(0.1148)	(0.1148)	(0.023)	(0.021)	(0.019)
Parental Investment, θ_t^I	0.0075	0.0149	0.0064	0.0056	0.0018	0.0019
	(0.0018)	(0.0031)	(0.0027)	(0.0016)	(0.0007)	(0.0007)
Maternal Education, S	0.0005	−0.0004	0.0019	−0.0003	0.0007	0.0001
	(0.0010)	(0.0010)	(0.0011)	(0.0005)	(0.0006)	(0.0006)
Maternal Cognitive Skill, A	0.0001	−0.0011	−0.0019	0.0025	0.0002	0.0010
	(0.0001)	(0.0001)	(0.0003)	(0.0007)	(0.0004)	(0.0004)

Different stages of the life cycle are sensitive periods for different outcomes.

The Percentage Impact on Log Earnings at Age 23 of an Exogenous Increase by 10% in Investments at Different Periods (This technology omits health impacts).

Total Percentage Impact, Percentage Impact Through Cognitive Skill Only, and Percentage Impact Through Noncognitive Skill Only
White Males, CNLSY/1979

Total Percentage Impact on Earnings	% Impact on Log Earnings Exclusively Through Cognitive Skills	% Impact on Log Earnings Exclusively Throug Noncognitive Skills

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		Total Percentage Impact on Earnings	% Impact on Log Earnings Exclusively Through Cognitive Skills	% Impact on Log Earnings Exclusively Throug Noncognitive Skills
Period 1	Mean	0.2487%	0.1247%	0.1240%
	Standard Error	0.0302%	0.0151%	0.0150%

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Period 2	Mean	0.3065%	0.0445%	0.2620%
	Standard Error	0.0358%	0.0052%	0.0306%

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Period 2	Mean	0.3065%	0.0445%	0.2620%
	Standard Error	0.0358%	0.0052%	0.0306%
Period 3	Mean	0.2090%	0.0540%	0.1550%
	Standard Error	0.0230%	0.0059%	0.0170%

The Percentage Impact on the Probability of Graduating from High School of an Exogenous Increase by 10% in Investments at Different Periods

Total Percentage Impact, Percentage Impact Through Cognitive Skill Only, and Percentage Impact Through Noncognitive Skill Only
White Males, CNLSY/1979

Total Percentage Impact on HS Graduation	% Impact on HS Graduation Exclusively Through Cognitive Skills	% Impact on HS Graduation Exclusively Through Noncognitive Skills

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		Total Percentage Impact on HS Graduation	% Impact on HS Graduation Exclusively Through Cognitive Skills	% Impact on HS Graduation Exclusively Through Noncognitive Skills
Period 1	Mean	0.6441%	0.5480%	0.0961%
	Standard Error	0.0789%	0.0672%	0.0118%

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	Standard Error	0.0789%	0.0672%	0.0118%
Period 2	Mean	0.3980%	0.1951%	0.2029%
	Standard Error	0.0466%	0.0229%	0.0238%

The Percentage Impact on the Probability of Graduating from High School of an Exogenous Increase by 10% in Investments at Different Periods

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	Standard Error	0.0789%	0.0672%	0.0118%
Period 2	Mean	0.3980%	0.1951%	0.2029%
	Standard Error	0.0466%	0.0229%	0.0238%
Period 3	Mean	0.3565%	0.2366%	0.1198%
	Standard Error	0.0389%	0.0258%	0.0131%

Illustration of the Results of Our Empirical Analysis

- Consider the following target group.

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- Children who are 6 years old, who come from a very disadvantaged background.

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Illustration of the Results of Our Empirical Analysis

- Consider the following target group.
- Children who are 6 years old, who come from a very disadvantaged background.
- They are at the bottom 10th percentile in the distribution of skills.
- They receive investments that are at the bottom 10th percentile in the distribution of investments.
- Mothers are also at 10th percentile in the distribution of skills.

Comparison of Different Investment Strategies

Disadvantaged Children: First Decile in the Distribution of Cognitive and Non-Cognitive Skills at Age 6

Mothers are in First Decile in the Distribution of Cognitive and Non-Cognitive Skills at Ages 14-21

	Baseline
High School Graduation	0.4109
Enrollment in College	0.0448
Conviction	0.2276
Probation	0.2152
Welfare	0.1767

Source: Cunha and Heckman (2006)

Comparison of Different Investment Strategies

Disadvantaged Children: First Decile in the Distribution of Cognitive and Non-Cognitive Skills at Age 6

Mothers are in First Decile in the Distribution of Cognitive and Non-Cognitive Skills at Ages 14-21

	Baseline	Changing initial conditions: moving children to the 4 th decile of distribution of skills only through early Investment
High School Graduation	0.4109	0.6579
Enrollment in College	0.0448	0.1264
Conviction	0.2276	0.1710
Probation	0.2152	0.1487
Welfare	0.1767	0.0905

Source: Cunha and Heckman (2006)

Comparison of Different Investment Strategies

Disadvantaged Children: First Decile in the Distribution of Cognitive and Non-Cognitive Skills at Age 6

Mothers are in First Decile in the Distribution of Cognitive and Non-Cognitive Skills at Ages 14-21

	Baseline	Changing initial conditions: moving children to the 4 th decile of distribution of skills only through early Investment	Adolescent intervention: moving investments at last transition from 1st to 9th decile
High School Graduation	0.4109	0.6579	0.6391
Enrollment in College	0.0448	0.1264	0.1165
Conviction	0.2276	0.1710	0.1773
Probation	0.2152	0.1487	0.1562
Welfare	0.1767	0.0905	0.0968

Source: Cunha and Heckman (2006)

Comparison of Different Investment Strategies

Disadvantaged Children: First Decile in the Distribution of Cognitive and Non-Cognitive Skills at Age 6

Mothers are in First Decile in the Distribution of Cognitive and Non-Cognitive Skills at Ages 14-21

	Baseline	Changing initial conditions: moving children to the 4 th decile of distribution of skills only through early Investment	Adolescent intervention: moving investments at last transition from 1st to 9th decile	Changing initial conditions and performing a balanced intervention
High School Graduation	0.4109	0.6579	0.6391	0.9135
Enrollment in College	0.0448	0.1264	0.1165	0.3755
Conviction	0.2276	0.1710	0.1773	0.1083
Probation	0.2152	0.1487	0.1562	0.0815
Welfare	0.1767	0.0905	0.0968	0.0259

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- If we start at too low a level, later skill investment is economically inefficient.

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- Late remediation not very effective.
- Remediation can work, but is costly.
- Social policy should be directed toward the malleable early years, if we want to address the problem.