SCHOOLS, SKILLS, AND SYNAPSES

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This paper discusses (a) the role of cognitive and noncognitive ability in shaping adult outcomes, (b) the early emergence of differentials in abilities between children of advantaged families and children of disadvantaged families, (c) the role of families in creating these abilities, (d) adverse trends in American families, and (e) the effectiveness of early interventions in offsetting these trends. Practical issues in the design and implementation of early childhood programs are discussed. (*JEL* A12)

I. INTRODUCTION

American society is polarizing. Proportionately more American youth are graduating from college than ever before. At the same time, American-born youth are graduating from high school at lower rates than 40 years ago.

This paper reviews and interprets these trends. The origins of inequality are examined and policies to alleviate it are analyzed. Families play a powerful role in shaping adult outcomes. The accident of birth is a major source of inequality. Recent research by Cunha and Heckman (2007a, 2008b) shows that about half of the inequality in the present value of lifetime earnings is due to factors determined by age 18. Compared to 50 years ago, relatively more American children are being born into disadvantaged families where investments in children are smaller than in advantaged families. Policies that supplement the child rearing resources available to disadvantaged families reduce inequality and raise productivity.

The argument of this paper is summarized by the following 15 points:

1. Many major economic and social problems such as crime, teenage pregnancy, dropping out of high school, and adverse health conditions are linked to low levels of skill and ability in society.

2. In analyzing policies that foster skills and abilities, society should recognize the multiplicity of human abilities.

3. Currently, public policy in the U.S. focuses on promoting and measuring cognitive ability through IQ and achievement tests. The accountability standards in the No Child Left Behind Act concentrate attention on

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ABBREVIATIONS

ACE: Adverse Childhood Experiences
AFQT: Armed Forces Qualification Test
CES: Constant Elasticity of Substitution
GED: General Education Development
NCES: National Center for Educational Statistics
PIAT: Peabody Individual Achievement Test

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achievement test scores and do not evaluate important noncognitive factors that promote success in school and life.

4. Cognitive abilities are important determinants of socioeconomic success.

5. So are socioemotional skills, physical and mental health, perseverance, attention, motivation, and self confidence. They contribute to performance in society at large and even help determine scores on the very tests that are commonly used to measure cognitive achievement.

6. Ability gaps between the advantaged and disadvantaged open up early in the lives of children.

7. Family environments of young children are major predictors of cognitive and socioemotional abilities, as well as a variety of outcomes such as crime and health.

8. Family environments in the U.S. and many other countries around the world have deteriorated over the past 40 years. A greater proportion of children is being born into disadvantaged families including minorities and immigrant groups. Disadvantage should be measured by the quality of parenting and not necessarily by the resources available to families.

9. Experimental evidence on the positive effects of early interventions on children in disadvantaged families is consistent with a large body of non-experimental evidence showing that the absence of supportive family environments harms child outcomes.

10. If society intervenes early enough, it can improve cognitive and socioemotional abilities and the health of disadvantaged children.

11. Early interventions promote schooling, reduce crime, foster workforce productivity and reduce teenage pregnancy.

12. These interventions are estimated to have high benefit-cost ratios and rates of return.

13. As programs are currently configured, interventions early in the life cycle of disadvantaged children have much higher economic returns than later interventions such as reduced pupil-teacher ratios, public job training, convict rehabilitation programs, adult literacy programs, tuition subsidies, or expenditure on police.

14. Life cycle skill formation is dynamic in nature. Skill begets skill; motivation begets motivation. Motivation cross-fosters skill and skill cross-fosters motivation. If a child is not motivated to learn and engage early on in life, the more likely it is that when the child becomes an adult, he or she will fail in social and economic life. The longer society waits to intervene in the life cycle of a disadvantaged child, the more costly it is to remediate disadvantage.

15. A major refocus of policy is required to capitalize on knowledge about the importance of the early years in creating inequality in America, and in producing skills for the workforce.

The evidence assembled in this paper substantially amends the analysis of *The Bell Curve* by Herrnstein and Murray (1994). Those authors made an important contribution to academic and policy analysis by showing that cognitive ability, as captured by achievement test scores measured in a child's adolescent years, predicts adult socioeconomic success on a variety of dimensions. Heckman, Stixrud, and Urzua (2006) and Borghans, Duckworth, Heckman, and ter Weel (2008) demonstrate that personality factors are also powerfully predictive of socioeconomic success and are as powerful as cognitive abilities in producing many adult outcomes. Achievement tests of the sort used by Herrnstein and Murray reflect both cognitive and noncognitive factors.

The Bell Curve assigned a primary role to genetics in explaining the origins of differences in human cognitive ability and a primary role to cognitive ability in shaping adult outcomes. If cognitive ability is genetically determined and is primary in shaping adult outcomes, public policy towards disadvantaged populations is limited to transfer payments to the less able. Recent research, summarized in this paper, establishes the power of socioemotional abilities and an important role for environment and intervention in creating abilities. The field of epigenetics surveyed in Rutter (2006) demonstrates how genetic expression is strongly influenced by environmental influences and that environmental effects on gene expression can be inherited. Evidence is presented in this paper that high quality early childhood interventions foster abilities and that inequality can be attacked at its source. Early interventions also boost the productivity of the economy.

The plan of this paper is as follows. Section II reviews some evidence on growing polarization in American society. Section III reviews evidence on the importance of cognitive and noncognitive abilities in producing a variety of socioeconomic outcomes. Section IV shows how the abilities that are so powerfully predictive of adult success and failure emerge early in the life of a child. This evidence has important implications for policies designed to alleviate poverty. Section V summarizes the evidence that a greater fraction of American youth is being born and reared in disadvantaged families compared to 50 years ago. It also discusses the question of the best way to measure disadvantage. Section VI reviews evidence on the role of families in producing abilities. Section VII shows the evidence that enriching early environments can partially compensate for the effects of early adversity, and draws general lessons from the recent literature on the optimal timing of investment in disadvantaged children. Section VIII discusses practical issues that arise in designing and implementing early childhood interventions. Section IX concludes. An Appendix presents a more technical and comprehensive version of the discussion about the optimal timing of investment and some additional evidence.

II. GROWING POLARIZATION OF AMERICAN SOCIETY AND ITS IMPLICATIONS FOR PRODUCTIVITY

The high school graduation rate is one barometer of the performance of American society and the skill level of its future workforce. Throughout the first half of the 20th century, each new cohort of Americans was more likely to graduate high school than the preceding one. This upward trend in secondary education increased worker productivity and fueled American economic growth (see Aaronson and Sullivan, 2001, and Delong, Katz, and Goldin 2003).

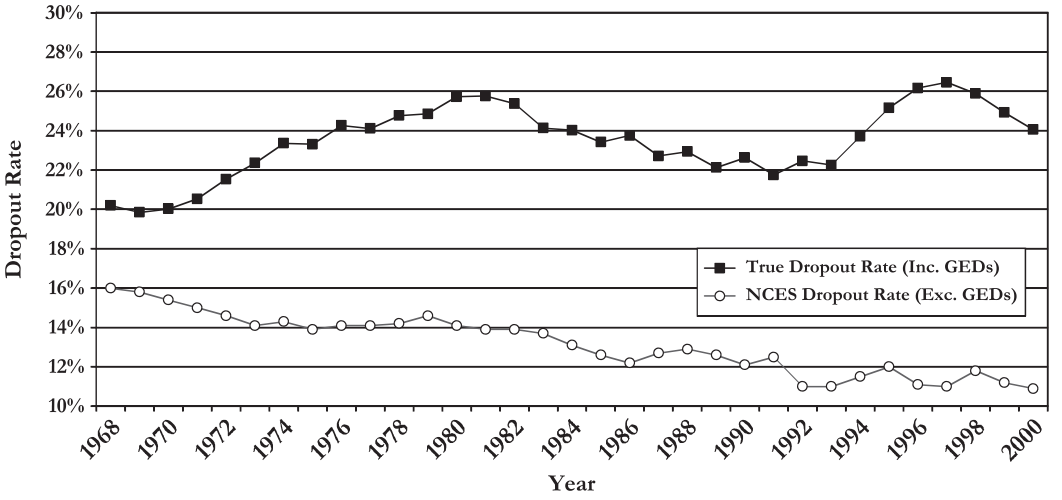
In the past 30 years, growing wage differentials between high school graduates and high school dropouts have increased the economic incentive to graduate from high school. The real wages of high school dropouts have declined since the late 1970s while those of more skilled workers have risen (see Autor, Katz, and Kearney, 2005). Heckman, Lochner, and Todd (2008) show that in recent decades, the internal rate of return to graduating high school compared to dropping out has greatly increased and is now over 50 percent per year.

It is thus surprising and disturbing that, at a time when the premium for skills has increased and the return to graduating high school has risen, the high school dropout rate in America is increasing. This trend is rarely noted in academic or policy discussions. The principal graduation rate issued by the National Center for Educational Statistics (NCES) – widely regarded as the official rate – would suggest that U.S. students responded to the increasing demand for skill by completing high school at increasing rates and that a greater fraction of high school graduates go to college and complete it. According to what many regard as the official high school graduation rate, U.S. schools now graduate nearly 88 percent of students and black graduation rates have converged to those of non-Hispanic whites over the past four decades.

The evidence in Heckman and LaFontaine (2008a) challenges these claims and establishes that the high school dropout rate has *increased* among native-born American children. Using a wide variety of data sources, they estimate U.S. graduation rates. They establish that (1) the U.S. high school graduation rate peaked at around 80 percent in the late 1960s and then declined by 4–5 percentage points. (2) About 65 percent of blacks and Hispanics leave school with a high school diploma. Minority graduation rates are substantially below the rates for non-Hispanic whites. Contrary to claims based on the official statistics, they find no evidence of convergence in minority-majority graduation rates for males over the past 35 years. (3) Exclusion of incarcerated populations from the official statistics substantially biases upward the reported high school graduation rate for black males.

The contrast between the ''official'' rate and the true rate is demonstrated in Figure 1. The official rate is plotted as the line with circles in Figure 1. The official dropout rate has steadily declined since 1968. However, the dropout rate adjusted for high school dropouts who are exam certified as high school equivalents, but who perform in the labor market at or near the level of high

FIGURE 1
True Dropout Rate vs. NCES Status Dropout Rate, Males and Females 1968–2000



Source: Heckman and LaFontaine (2008a).

school dropouts who do not certify, is very different.[1] The adjusted rate, plotted in the line with dark rectangles, has risen.

The slowdown in the rate of growth of college attendance that has been noted by many scholars is not primarily due to a slowdown in the rate of growth of college attendance among high school graduates.[2] The curve marked "Δ" in Figure 2 shows that the college attendance rate among high school graduates has not slowed down as much as the rate for college attendance. The primary source of the slowdown is the growth in the high school dropout rate (see the curve with the light rectangles). This pattern is mainly due to males. (Compare Figures 3 and 4 which are in a format comparable to Figure 2.) A gap has emerged in the education of men and women. This is another source of the growth of inequality in America. Black female college enrollment is converging to that of white male enrollment. Across all ethnic groups, women are doing better than men.[3] For recent birth cohorts, the gap in college attendance between males and females is roughly ten percent. However, the gap in college attendance given high school graduation is only five percent. Half of the growing gender gap in college attendance documented by Goldin, Katz, and Kuziemko (2006) can be explained by the declining rate of male high school graduation (Heckman and LaFontaine, 2008a).

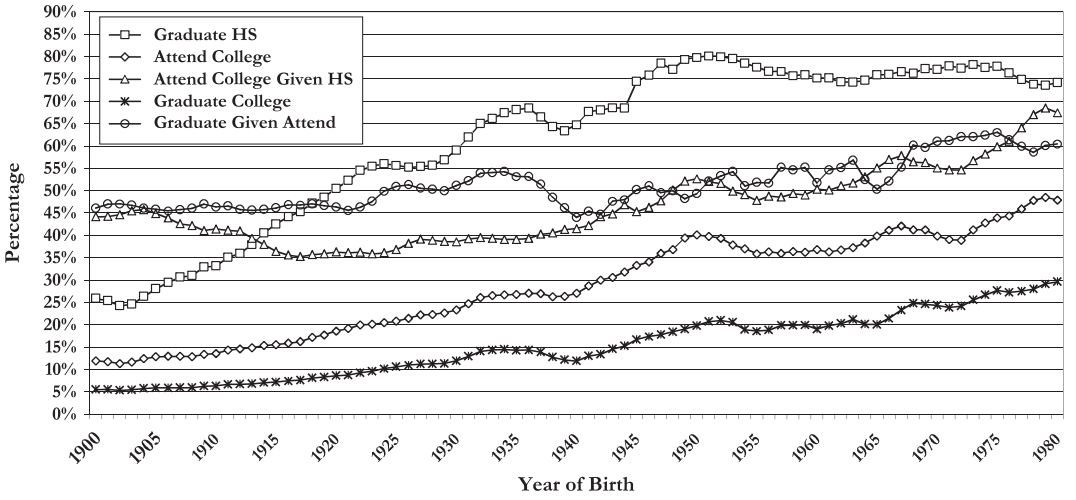
Table 1 performs standard growth accounting, decomposing the change in college graduation into the change due to high school graduation, the change in college attendance given high school graduation, and the change in college graduation given college attendance.

1. The most significant source of bias in the official statistics comes from including GED recipients as high school graduates. "GED" refers to General Education Development. GEDs are high school dropouts who certify as the equivalents of ordinary graduates through passing an exam. Currently 14 percent of all new high school credentials issued each year are to GEDs. In recent years, inclusion of GEDs as high school graduates has biased graduation rates upwards of 7–8 percentage points. A substantial body of scholarship shows that the GED program does not benefit most participants, and that GEDs perform at the level of dropouts in the U.S. labor market (see Cameron and Heckman, 1993; Heckman and LaFontaine, 2006). The GED program conceals major problems in American society. See Heckman and LaFontaine (2008b). For example, a significant portion of the racial convergence in education reported in the official statistics is due to black males obtaining GED credentials in prison. Research by Tyler and Kling (2007) and Tyler and Lofstrom (2008) shows that, when released, prison GEDs earn at the same rate as non-GED prisoners, and the GED does not reduce recidivism.

2. Card and Lemieux (2001) and Ellwood (2001) discuss the slowdown in the rate of growth of college attendance.

3. See Heckman and LaFontaine (2008a).

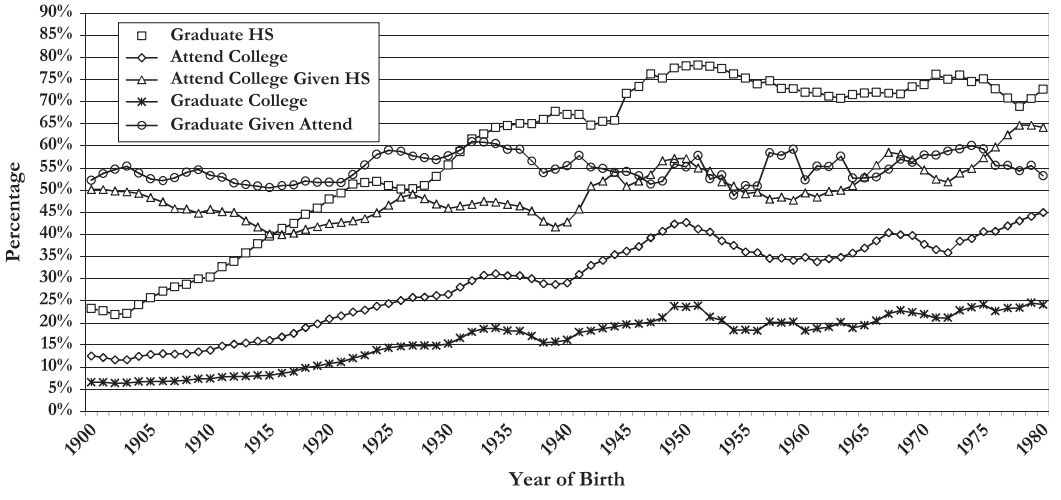
FIGURE 2
Educational Attainment Decompositions, Males and Females 1900–1980 Birth Cohorts



Source: Heckman and LaFontaine (2008a).

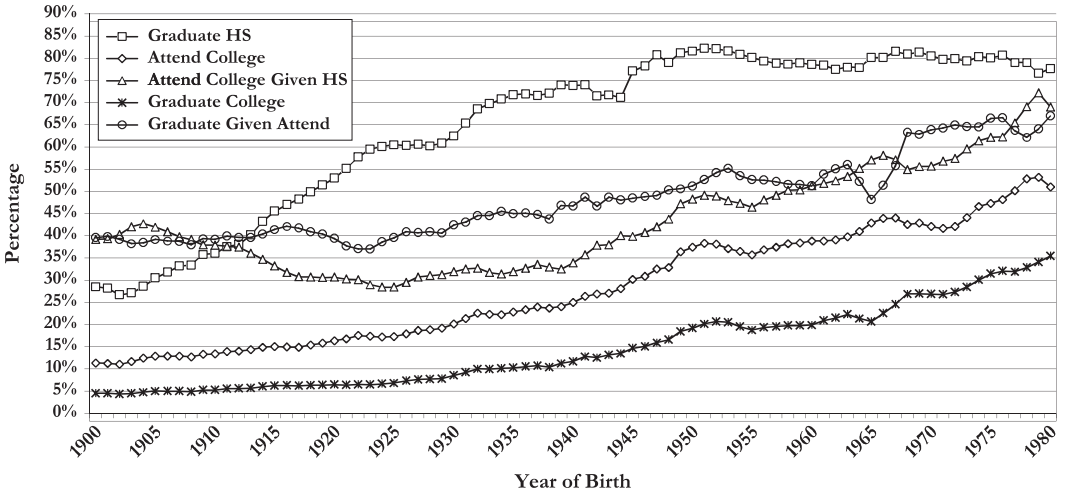
The table shows that in the first half of the 20th century, growth in high school graduation was the driving force behind increased college enrollments. Growth in high school graduation no longer contributes to growth in college attainment for cohorts born after 1950, especially for men. High school graduation as a source of growth in educational attainment diminishes and turns negative for more recent cohorts of Americans. The decline in high school graduation rates since 1970 (for cohorts born after 1950) has flattened college attendance and completion rates and has slowed growth in the skill level of the U.S. workforce

FIGURE 3
Educational Attainment Decompositions, Males 1900–1980 Birth Cohorts



Source: Heckman and LaFontaine (2008a).

FIGURE 4
Educational Attainment Decompositions, Females 1900–1980 Birth Cohorts



Source: Heckman and LaFontaine (2008a).

at a time when the economic return to skill has increased. (See Figure 5.)

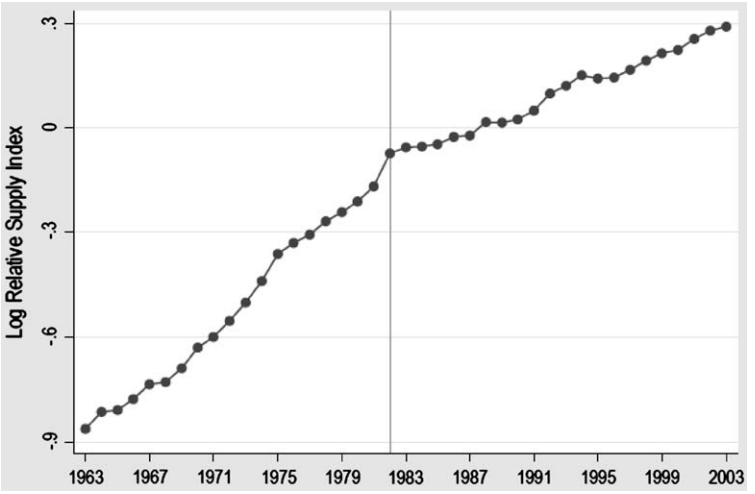
The trends in high school graduation rates reported in Figures 2–4 are for persons born in the United States and exclude immigrants. The recent growth in unskilled migration to the U.S. increases the proportion of unskilled Americans in the workforce apart from the

TABLE 1
Decomposition of the Sources of Change in College Graduation in the Cohorts Born Between 1900 and 1980. Broken Down by Birth Cohorts 1900–1949 vs. Birth Cohorts 1950–1980

Totals Pre- and Post-1950 Cohort	Change in College Graduation Rate Due to Change in High School Graduation Rate	Change in College Graduation Rate Due to Change in College Attendance Given High School Graduation	Change in College Graduation Rate Due to Change in Finishing College Given Enrollment in College	Change Due to Interaction
Overall				
Birth Years 1900–1949	8.99%	3.17%	0.81%	0.92%
% of Total Change	64.71%	22.86%	5.80%	6.63%
Birth Years 1950–1980	−1.47%	6.70%	5.20%	0.03%
% of Total Change	−14.05%	64.02%	49.75%	0.28%
Males				
Birth Years 1900–1949	12.38%	3.81%	0.40%	0.35%
% of Total Change	73.10%	22.49%	2.36%	2.06%
Birth Years 1950–1980	−1.59%	2.90%	0.86%	0.08%
% of Total Change	−70.02%	128.26%	38.14%	3.63%
Females				
Birth Years 1900–1949	7.06%	3.69%	2.19%	0.78%
% of Total Change	51.44%	26.89%	15.98%	5.68%
Birth Years 1950–1980	−0.94%	9.50%	6.20%	0.65%
% of Total Change	−6.13%	61.70%	40.23%	4.20%

Source: Heckman and LaFontaine (2008a).

FIGURE 5
Relative Supply of College Equivalent Labor, 1963–2003 (March CPS)



Source: Autor, Katz, and Kearney (2005).

decline in skills due to a rising high school dropout rate. This trend further reduces the growth in workforce productivity, and promotes inequality in society at large. Estimates by Aaronson and Sullivan (2001) and Delong, Katz, and Goldin (2003) suggest that annual growth in labor productivity has slowed by 0.17 to 0.35 percent per year due to trends that reduce the growth of labor force quality.

A greater percentage of the workforce of tomorrow will come from traditional minority populations where the levels of educational attainment are lower and the rate of growth in the supply of skills for males is smaller. Table 2 taken from Ellwood (2001) shows that in the period 2000–2020, American society will generate less than half of the number of college graduates that it produced in the previous 20 years despite growth in the size of the total population.

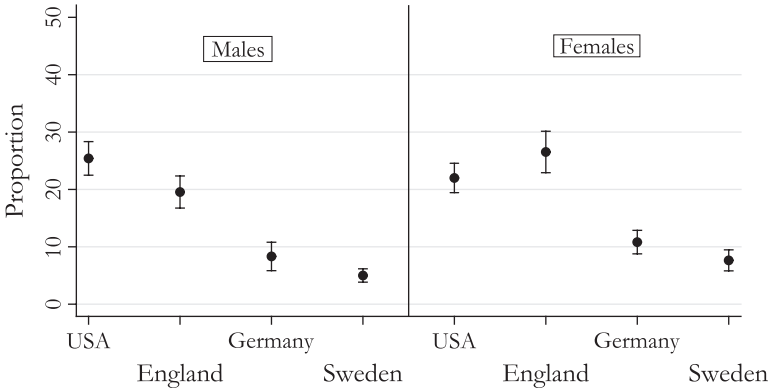
Trends in the production of skills from American high schools coupled with a growing influx of unskilled immigrants have produced more people with low skills in the U.S. Consider the performance of the American workforce on a basic level of literacy. (See

TABLE 2
Educational Characteristics of the Labor Force Aged 25 and Over (1980, 2000, 2020)

Education	Labor Force in 1980	Growth 1980–2000	Labor Force in 2000	Growth 2000–2020	Labor Force in 2020
Less than High School	17.3	−5.3	12.0	0.9	12.9
High School Only	31.5	6.3	37.8	3.8	41.6
Some Schooling					
Beyond High School	13.8	19.1	32.9	6.2	39.1
College Degree or More	17.3	18.5	35.8	7.7	43.5
Total	*79.8*	*38.7*	*118.5*	*18.6*	*137.1*
Precent with College Degree	21.6%		30.2%		31.7%

Source: Ellwood (2001).

FIGURE 6
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. The sample is restricted to adults who are between 16 and 65 years of age at the time of the survey (1994 for the U.S. and Germany, 1996 for the U.K., and 1994–1995 for Sweden). Standard errors are calculated using the methodology described in International Adult Literacy Survey (2002).

Figure 6.) At level 1, depicted in the figure, a person cannot understand the instructions written in a medical prescription. American (and UK) workers perform poorly by this measure both absolutely and in comparison with counterparts in Germany and Sweden. More than 20 percent of American workers do not possess this basic competence.

What forces have produced these low levels and adverse trends? Are the public schools responsible? Can we look to school reform to fix the problem? Are higher college tuition costs to blame? Contrary to widely held views, accounting for the ability of a child at the age college decisions are made, tuition costs and schooling quality explain trivial fractions of the gaps in educational attainment by socioeconomic status.

III. THE IMPORTANCE OF COGNITIVE AND NONCOGNITIVE ABILITIES

Cognitive and noncognitive abilities are important determinants of schooling and socioeconomic success. In the U.S. and many countries around the world, schooling gaps across ethnic and income groups have more to do with ability deficits than family finances in the school-going years. A substantial body of research shows that earnings, employment, labor force experience, college attendance, teenage pregnancy, participation in risky activities, compliance with health protocols, and participation in crime are strongly affected by cognitive and noncognitive abilities.[4] By noncognitive abilities I mean motivation, socioemotional regulation, time preference, personality factors, and the ability to work with others.

American public policy currently focuses on cognitive test scores or "smarts." The No Child Left Behind Act in the U.S. focuses on achievement test scores to measure success or failure in schools. Yet an emerging literature shows that, as is intuitively obvious and commonsensical, much more than smarts is required for success in life. Motivation, sociability (the ability to work with others), the ability to focus on tasks, self-regulation, self esteem, time preference, health and mental health all matter.

The importance of noncognitive skills tends to be underrated in contemporary policy discussions. Only recently have such traits been measured and there are competing measurement systems.[5] Recent evidence shows that the workplace is increasingly oriented towards a greater valuation of the skills

4. See the summary of the evidence in Heckman, Stixrud, and Urzua (2006) and in Borghans, Duckworth, Heckman, and ter Weel (2008).

5. See the discussion in Borghans, Duckworth, Heckman, and ter Weel (2008).

required for social interaction and for sociability.[6,7]

Compelling evidence on the importance of noncognitive skills comes from the GED program (Heckman and LaFontaine, 2008b; Heckman and Rubinstein, 2001). GEDs are dropouts who pass a test to certify that they are equivalent to high school graduates. Participation in the GED program is growing. Currently 14 percent of U.S. high school certificates issued are to GEDs. The GED is successful in terms of measuring performance on tests of scholastic ability.

Heckman, Hsee, and Rubinstein (2001) and Heckman and Rubinstein (2001) show that GED test scores and the test scores of persons who graduate high school but do not go on to college are comparable. Figure 7 displays the distribution of achievement test scores for regular high school graduates who do not go on college (the graph with dark rectangles) and GEDs (the circles). The two distributions are very similar for all ethnic and gender groups. Yet GEDs earn at the rate of high school dropouts (see Heckman and LaFontaine, 2006, 2008b). GEDs are as "smart" as ordinary high school graduates, yet they lack noncognitive skills.[8] The GEDs are the wise guys who cannot finish anything. They quit their jobs and marriages they start at much greater rates than ordinary high school graduates. Most branches of the U.S. military recognize this in their recruiting strategies. Until the recent war in Iraq, the armed forces did not generally accept GEDs because of their poor performance in the military (Laurence, 2008). This and other evidence shows that both cognitive and noncognitive skills matter in a variety of aspects of life.

It is useful to summarize additional evidence on the power of noncognitive skills.[9] Consider the effects of both cognitive and noncognitive skills on many measures of social performance. Heckman, Stixrud, and Urzua (2006) examine the effects of a core set of cognitive and noncognitive factors on a variety of outcomes. Figures 8 and 9, excerpted from their paper, show how the outcome measure written at the base of each figure varies with cognitive and noncognitive skills.[10] For many social outcomes, both cognitive and noncognitive skills are equally predictive in the sense that a one percent increase in either type of ability has roughly equal effects on outcomes across the full distribution of abilities. Figure 8(a) shows that those with low levels of cognitive and noncognitive skills are much more likely to be incarcerated and that an increase in both cognitive and noncognitive skills reduces the probability of teenage pregnancy. For the lowest deciles, the drop off in incarceration with increasing noncognitive ability is greater than it is for cognitive ability. For teenage pregnancy, the drop off in the rate is about the same for both types of skills. Figure 9 shows similar patterns for high schooling dropping out, four year college graduation, daily smoking, and log wages.

Cameron and Heckman (2001) and the papers they cite show that tuition costs explain little of the gap in college going between the affluent and less affluent, between rich and poor, and between majorities and minorities. Controlling for cognitive ability measured at the age college decisions and high school dropout decisions are made, minorities are *more* likely than whites to be at normal grade level in high school. See Table 3. The top row in each panel shows the raw gap in educational attainment for the indicated schooling level. The bottom row shows the gap, adjusting for cognitive ability. The gaps become negative. Tuition costs and family income in the school-going years explain little of the dramatic gaps in high school dropping out across minority and majority groups.[11]

6. See Borghans, ter Weel, and Weinberg (2007).

7. It is plausible that the change in patterns of sectoral output away from manufacturing has harmed males more than females. Females appear to be better endowed with noncognitive skills — especially self-control, motivation, agreeableness and the like. The assembly line is a powerful monitoring device that polices expression of unproductive traits such as aggression and noncooperation. As employment on the assembly line declines and employment in the service sector rises, there is less restraint on the unfavorable traits of males and a growth in demand for the favorable traits of females.

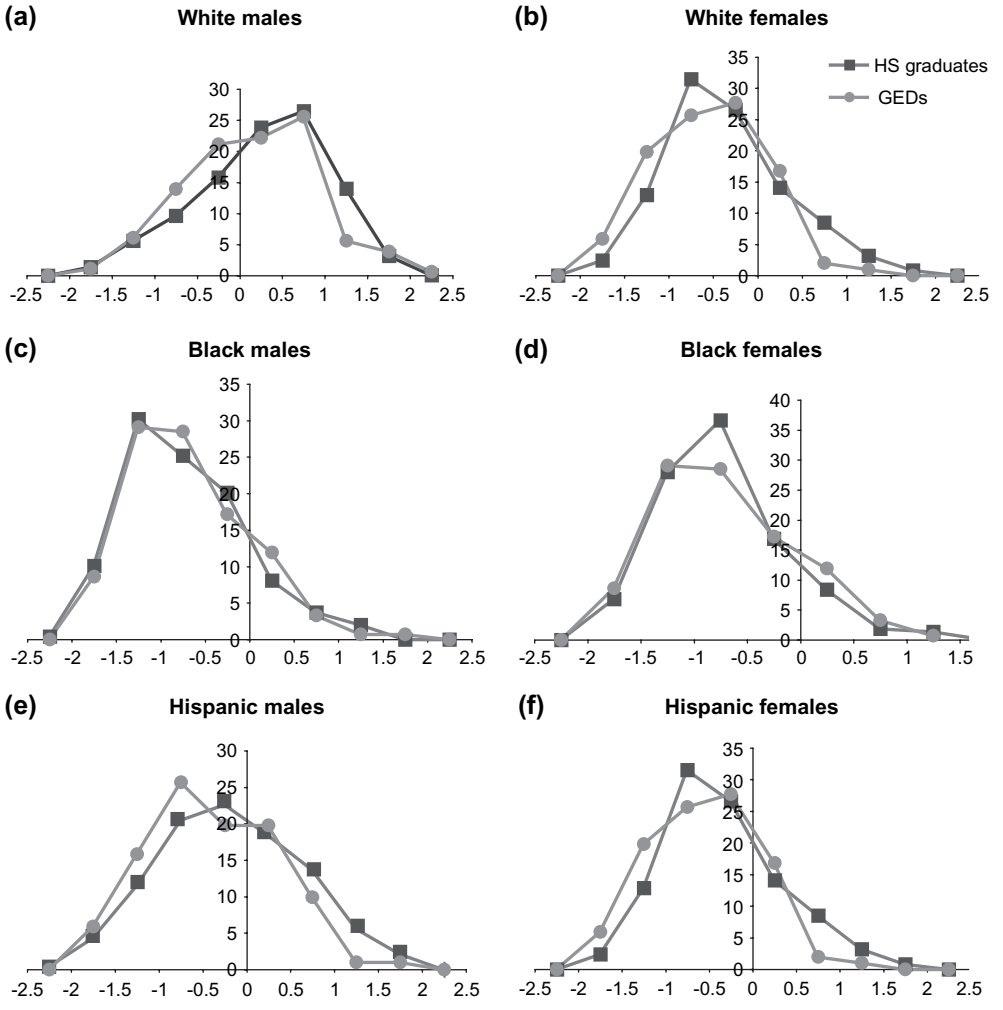
8. Heckman, Stixrud, and Urzua (2006) show that, for males, GEDs have *worse* noncognitive skills than high school dropouts, although they have the cognitive ability of high school graduates who do not go on to college. For females, GED recipients have the same low level of noncognitive skills as dropouts who do not exam certify.

9. Borghans, Duckworth, Heckman, and ter Weel (2008) present an extensive summary of the literature.

10. Heckman, Stixrud, and Urzua (2006) correct for measurement error and reverse causality. In particular, they correct for the effect of schooling on measured cognitive and noncognitive traits.

11. Belley and Lochner (2007) show that family income in the college going years and tuition have become more important in explaining college enrollment in recent years but cognitive ability still plays a dominant role in explaining ethnic and racial gaps. Their sample is younger than samples previously used in the literature.

FIGURE 7
Density of Age Adjusted AFQT Scores for GED Recipients and High School Graduates with Twelve Years of Schooling



Source: Heckman, Hsee, and Rubinstein (2001).

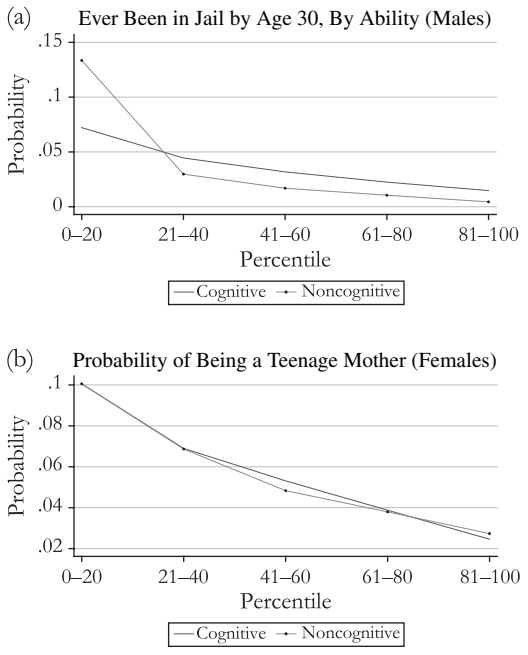
IV. ABILITY GAPS OPEN UP EARLY IN LIFE

Gaps in the abilities that play an important role in determining diverse outcomes open up very early across socioeconomic groups. Consider the evolution of both cognitive and noncognitive scores over the life of children, stratifying by social background.

Figure 10 shows the gap in cognitive test scores by age of low birth weight children stratified by the mother's education. Gaps in ability emerge early and persist. Most of the gaps at age 18 that help to explain gaps in adult outcomes are present at age five. Schooling plays a minor role in creating or perpetuating gaps. Even though American children go to very different schools, depending on their family backgrounds, test scores are remarkably parallel.

Figure 11(a) plots ranks of math scores by age by income class. The salient feature of this figure, as for Figure 10, is that the gaps in achievement at age 12 are mostly present at age 6, when children enter school. Again, schooling after the second grade plays only

FIGURE 8
Effects of Cognitive and Noncognitive Skills on the Outcomes Indicated in the Table, Measured from Lowest Level to Highest in Percentiles of Skills



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 ability. For example, the lines with markers show the effect of increasing noncognitive ability after integrating cognitive ability. Source: Heckman, Stixrud, and Urzua (2006).

a minor role in alleviating or creating test score gaps.

A similar pattern appears for socioemotional skills. Figure 12(a) plots ranks on an anti-social score — a measure of behavior problems. In this figure, a high score is an indicator of behavior problems. Gaps by socioeconomic status open up early and persist. High scores (worse behavior problems) are associated with lower socioeconomic status. Again, schools do not account for much of this pattern.

How do these early and persistent differences in abilities arise? Is the difference due to genes as Herrnstein and Murray claimed in *The Bell Curve*? Recall that they used an achievement test score measured in the adolescent years to claim that genes are important determinants of ability. They implicitly claim that compensation for early deficits is not possible. The test score they use has been shown to be caused in part by schooling and family environments (Hansen, Heckman, and Mullen, 2004; Neal and Johnson, 1996). In Section VII, I summarize the experimental evidence that test scores and adult achievement can be improved by high quality interventions.

Evidence from epigenetics suggests that the genes vs. environment distinction that is so much in vogue in popular discussions of the origins of inequality is obsolete, as is the practice of additively partitioning outcomes due to "nature" and "nurture" that is common in many papers in economics. An extensive recent literature suggests that gene-environment interactions are central to explaining human and animal development. Rutter (2006) provides an accessible introduction to this literature.[12]

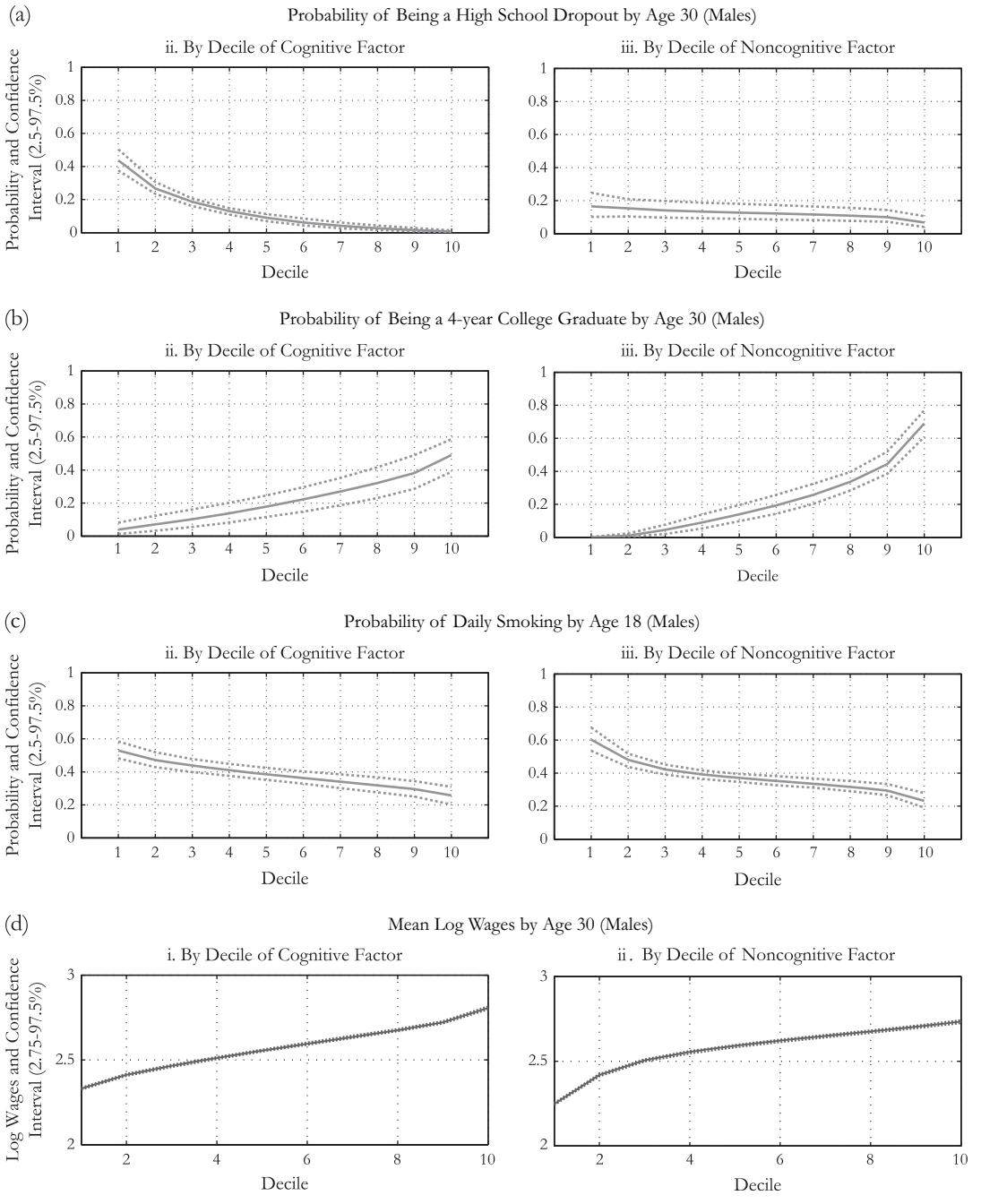
For example, recent work by Caspi, Williams, Kim-Cohen et al. (2007) shows that children's intellectual development is influenced by both genetic and environmental factors. Breast-fed children attain higher IQ scores than non-breast fed children. This relationship is moderated by a gene (FADS2) that controls fatty acid pathways. Fraga, Ballestar, Paz et al. (2005) show how monozygotic (identical) twins are affected by life experience that substantially differentiates the genetic expression of adult twins.[13] Caspi, Sugden, Moffitt et al. (2003) show that one gene (a serotonin transporter 5-HTT) moderates the influence of stressful life events on depression. Caspi, McClay, Moffitt et al. (2002) show that the impact of growing up in a harsh or abusive environment on adult antisocial behavior depends on the absence of a particular variant of the MAOA gene. Cole, Hawkley, Arevalo et al. (2007) show the effect of social environments (isolation) on gene expression that moderates adverse health outcomes. Turkheimer, Haley, Waldron et al. (2003) find a powerful role of environment in determining heritability of IQ.

12. A special issue of *Twin Research and Human Genetics* (2007) edited by Jennifer Harris provides numerous concrete examples.

13. See Champagne, Weaver, Diorio et al.(2006).

FIGURE 9

Effects of Cognitive and Noncognitive Skills on the Outcomes Indicated in the Table, Measured from Lowest Level to Highest in Percentiles of the Skills



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

TABLE 3
Ability Explains Schooling Gaps. (The gap is the difference in the fraction attaining the indicated schooling status)

	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)
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). Standard errors are in parentheses.

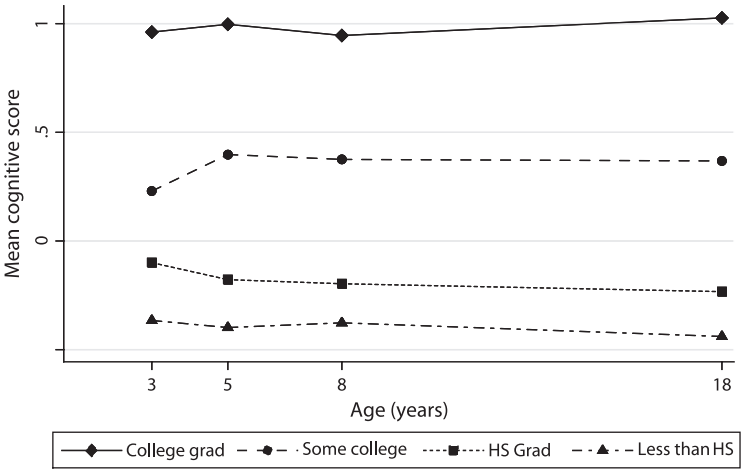
Research on animals by Champagne and Curley (2005) and Champagne, Weaver, Diorio et al. (2006) shows that environmental effects are inherited across generations, and that early environmental influences are especially important. Suomi (1999, 2003) reports parallel findings on genetic moderation of environmental influences for rhesus monkeys that have 95 percent of human genes.

When one controls for early family background factors (mother's education and ability) using regression analysis, the gaps shown in Figures 11(a) and 12(a) greatly diminish. See Figures 11(b) and 12(b), respectively. While such regression adjustments cannot establish causality, a causal interpretation of this evidence is supported by the experimental evidence discussed in Section VII.

V. THE DECLINE OF THE AMERICAN FAMILY AND THE RISE OF SOCIAL PROBLEMS

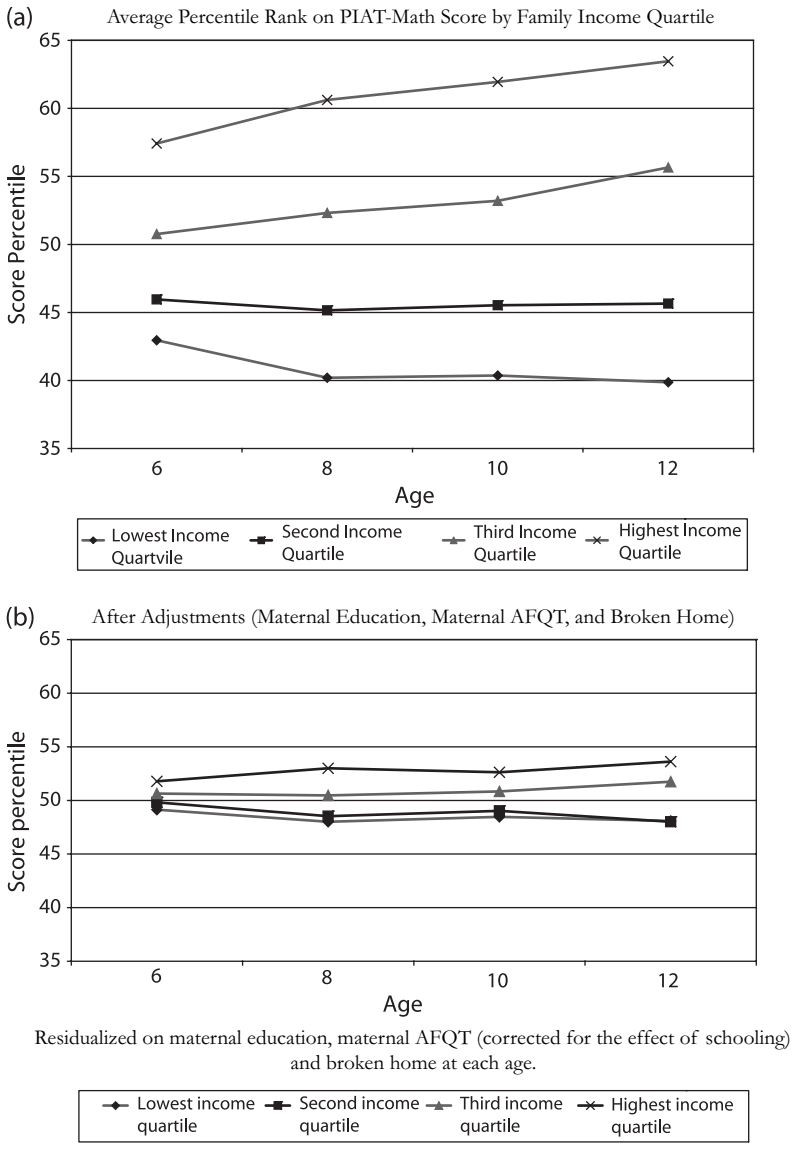
The evidence on the importance of family factors in explaining ability gaps is a source of concern because a greater proportion of American children is being born into disadvantaged families. A divide is opening up in American society. Those born into disadvantaged environments are receiving relatively less stimulation and fewer resources to promote child development than those born into more advantaged families. Figure 13(a) shows the dramatic rise in the proportion of children living in single parent families. The greatest

FIGURE 10
Trend in Mean Cognitive Score by Maternal Education. IHDP Study



Note: Using all observations and assuming that data are missing at random.
Source: Brooks-Gunn, Cunha, Duncan, Heckman, and Sojourner (2006).

FIGURE 11
Evolution by Age of Average Percentile Ranks on the PIAT Math Score by Family Income Status: Adjusted and Unadjusted

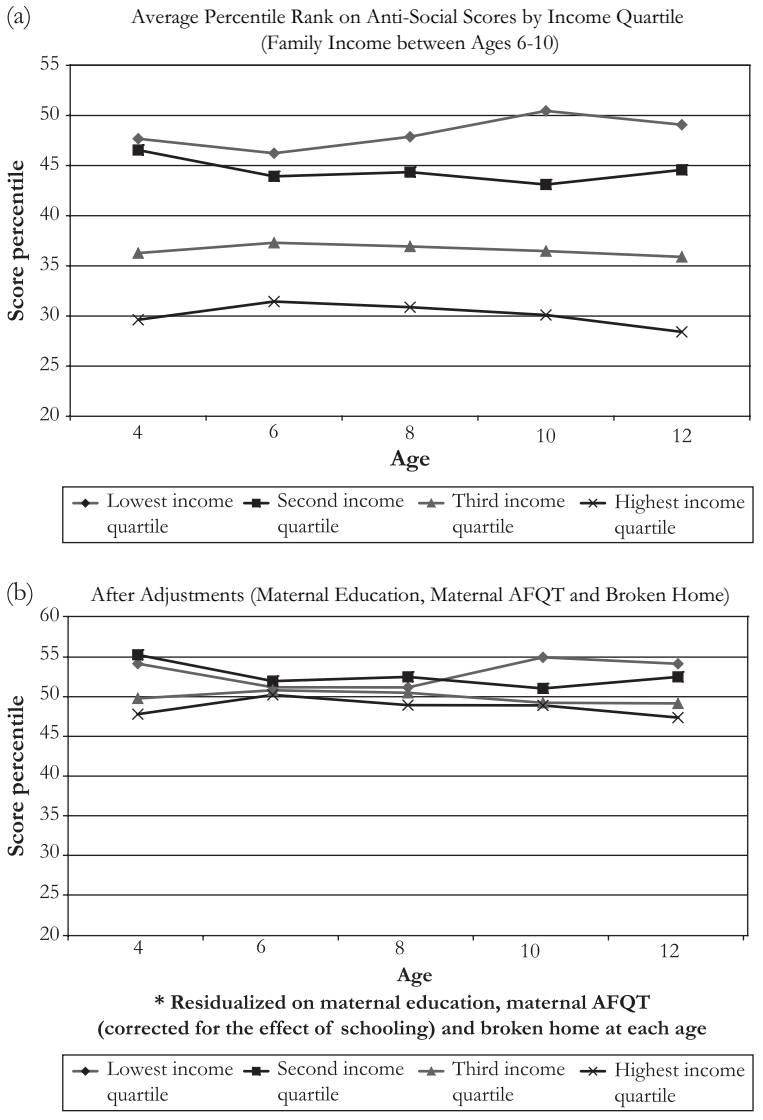


Source: Carneiro and Heckman (2003), but reformatted.

contributor to this growth is the percent living in families with never married mothers. (See the top category.) Such families are much less likely to invest in their children (Moon, 2008). Figure 13(b) shows that the percentage of all children less than age 5 with a never married mother is over 25% for children born into families with dropout mothers. Figure 13(c) shows that this phenomenon is especially pronounced for African-American families.

A gap has emerged between the environments of children of more educated women and the environments of children of less educated women. More educated women are

FIGURE 12
Evolution by Age of Average Percentile Rank on Behavioral Problems Index (BPI) by Family Income Status: Adjusted and Unadjusted



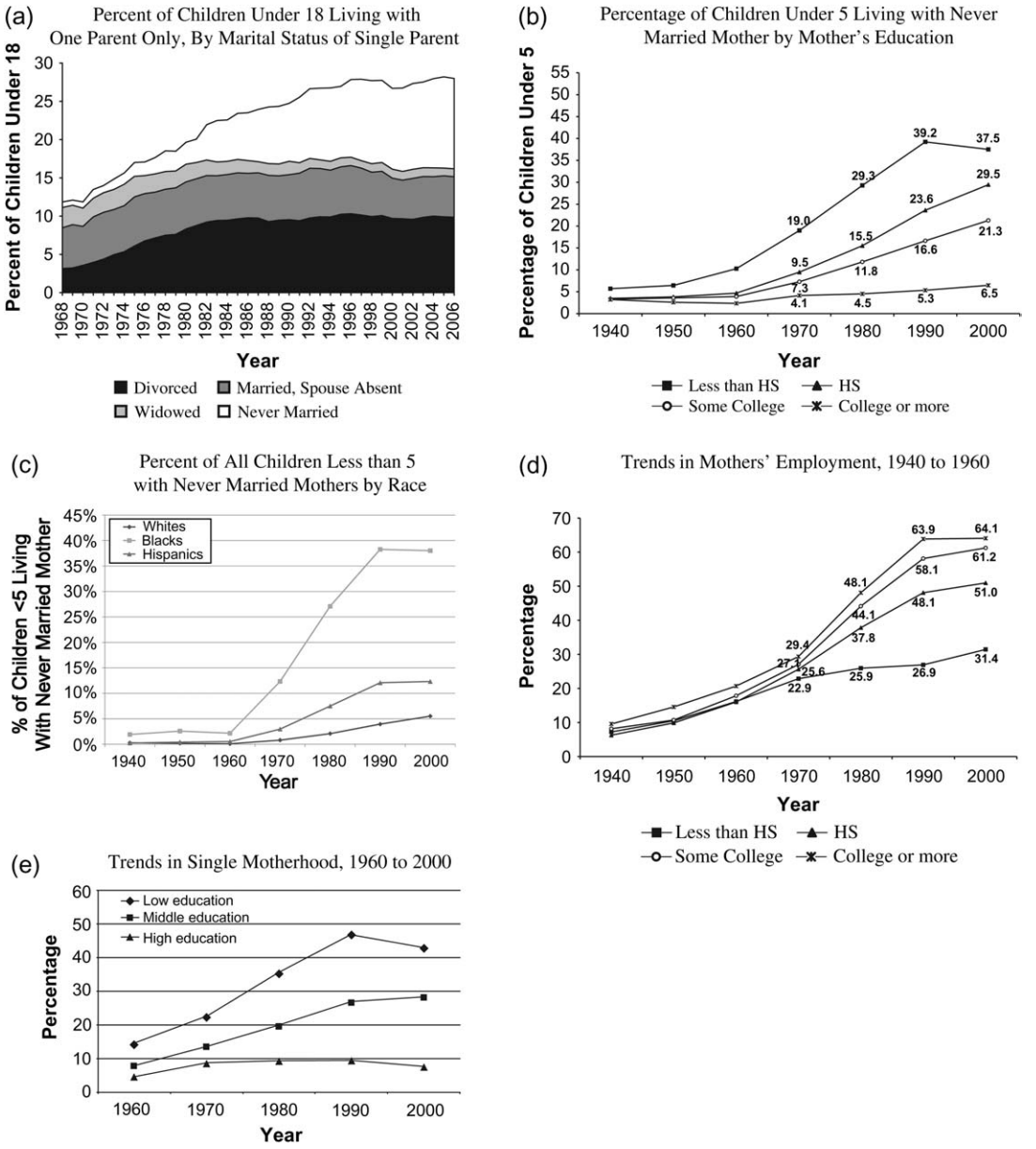
Source: Carneiro and Heckman (2003), reformatted.

having their children later after they have completed their education and have a steady flow of resources from their own income and that of their spouses (McLanahan, 2004).

More educated women are working disproportionately more than less educated women.[14] Fewer than ten percent of the more educated women bear children out of wedlock. (See Figures 13(d) and 13(e), respectively.) In educated families, fathers' involvement with children has increased over the past 30 years (McLanahan, 2004). More educated women marry later, have more resources, fewer children, and provide much richer child rearing environments that produce dramatic

14. See McLanahan (2004).

FIGURE 13
Alternative Measures of the Percentage of Children at Risk and a Measure of Trends in Single Motherhood



Source: Figure 13(a) is from Heckman and LaFontaine (2008b). Figures 13(b) and 13(c) are from Heckman and LaFontaine (2008b). 13(d) Employment is defined as working at least 27 weeks per year for 15 hours per week. PUMS (1960–2000). 13(e) Single motherhood is defined as not being married or not living with a spouse. PUMS (1960–2000).

differences in child vocabulary and intellectual performance. (See Huttenlocher, Haight, Bryk et al., 1991, Huttenlocher, Vasilyeva, Waterfall et al., 2007 and Hart and Risley, 1992, 1995.) These advantages are especially pronounced for children of two parent stable

marriages.[15] Children of such marriages appear to be at a major advantage compared to children from other unions.

A comprehensive survey by Bianchi, Robinson, and Milkie (2006) of the evidence from time diary studies shows that college-educated mothers devote more time to child rearing than less-educated mothers, especially in child enrichment activities. They spend more time reading to children and less time watching television with their children. College-educated mothers spend more time in child care.[16]

In the words of McLanahan (2004), children from different family backgrounds face "diverging destinies." While more educated women are working more, their families are more stable and the mothers in these families are also devoting more time to child development activities than less educated women. Children in affluent homes are bathed in financial and cognitive resources. Those in less advantaged circumstances are much less likely to receive cognitive and socioemotional stimulation and other family resources. The family environments of single parent homes compared to intact families are much less favorable for investment in children. See Table 4, taken from McLanahan (2004). The patterns of single motherhood, employment, and age at first birth of the child by mother's educational status are found in many countries around the world (see McLanahan, 2004).

Adverse backgrounds produce much greater risk for the persons involved and their children (Felitti and Anda, 2005; Krein and Beller, 1988; McLanahan and Sandefur, 1994). An emerging literature establishes the lower quality of the early environments of children born to less educated mothers and especially teenage mothers and their consequences for adult outcomes.[17] Both family structure and age of the mother appear to play a role (Francesconi, 2007). Fetal alcohol ingestion alone, which is more frequent with teenage and less educated mothers, appears to have substantial deleterious consequences on adult outcomes. (See Nilsson, 2008; Streissguth, 2007; Zhang, Sliwowska, and Weinberg, 2005.)[18]

TABLE 4
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 smoking	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: McLanahan (2004). 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 $p < .05$.

The available evidence from psychology and sociology suggests that the conventional measures of family disadvantage used by many social scientists to study child outcomes, such as "broken home" or family income, are very crude proxies for the real determinants of child outcomes (Harris, Brown, and Bifulco, 1986; Mayer, 1997;

15. See McLanahan (2008).

16. The evidence for *growing* differentials of child investment by education and social class of the parent is less clear.

17. See Francesconi (2007); Hunt (2006); Levine, Pollack, and Comfort (2001).

18. Some evidence (e.g., Krein and Beller, 1988) suggests that adverse early childhood environments differentially harm boys. Given the growth in the percentage of all births to children in adverse environments, this is one possible channel that explains emerging educational gaps between men and women. Much further research is required to confirm this conjecture. In evolutionary biology (see, e.g., Wells, 2000, and Trivers and Willard, 1973), a theory has been developed that explains the greater vulnerability of males to adverse early environments.

Rutter, 1971). Presence of a father can be a negative factor if he shows antisocial tendencies (Jaffee, Caspi, Moffitt et al., 2005). A substantial body of evidence suggests that a major determinant of child disadvantage is the quality of the nurturing environment rather than just financial resources available or presence or absence of parents (see Rutter, 2006). This evidence is supported by the evidence on the effects of early parenting enrichment programs summarized in Section VII.

Strengthening the observation that conventional measures of childhood adversity are inaccurate is a study by Costello, Compton, Keeler et al. (2003). An American Indian population enriched by the opening of a casino showed substantial improvements in baseline measures of disruptive behavior of their children. The beneficial effects of the intervention were mediated by changes within the family. Parental supervision of children improved and there was greater parental engagement. In this natural experiment, income improved parenting, but it was parenting that reduced disruptive behavior. A proper measure of disadvantage would account for parenting inputs. However, time series data on parenting are limited. This evidence raises a serious policy question. Should one target income or should one target parenting? The successful early intervention programs discussed in Section VII target parenting. However, targeting parenting raises difficult political and cultural issues that are discussed in Section IX.

Adverse trends in family environments raise an environmental version of concerns about the quality of the future population analogous to the concerns expressed by the eugenics movement a century ago. Then the concern was expressed that ''genetically inferior'' populations were breeding at a higher rate and diluting population quality. Since genetics was assumed to be beyond the control of intervention, the eugenicists forecast a dim future for the human race.

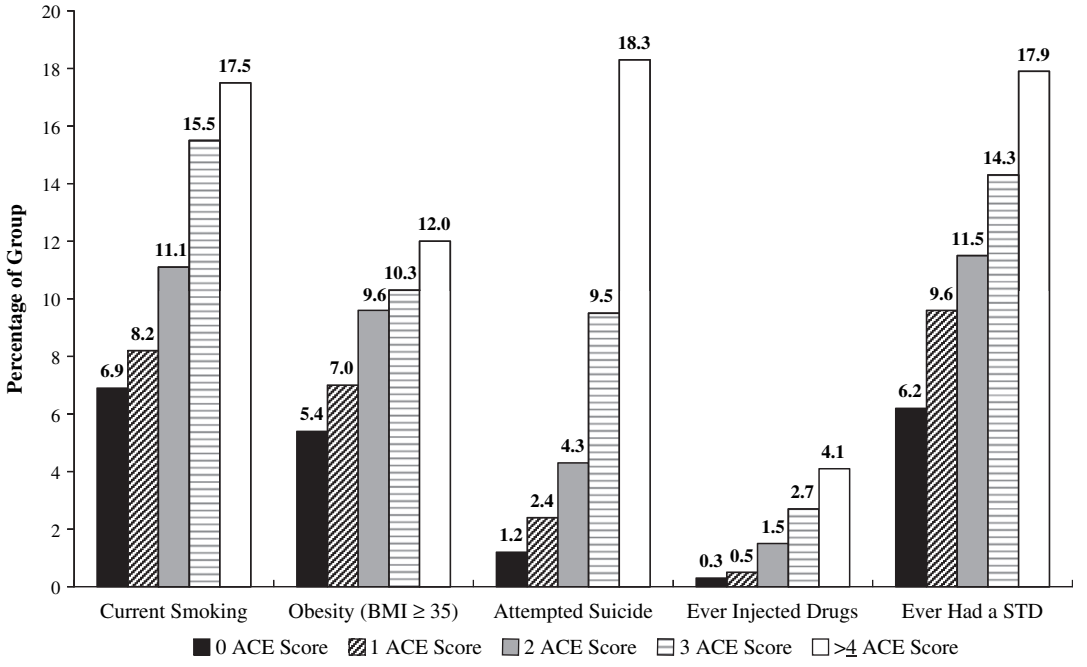
Recent evidence suggests that early *environments* play a powerful role in shaping adult outcomes. Disproportionately more American children are growing up in adverse environments and this will have adverse consequences for American society. The good news in all of this is that environments can be enhanced to promote the quality of children in ways that were thought impossible under the traditional view of genetic determination. The recent literature suggests that early environments powerfully affect genetic expression, and that society need not passively watch its own decline. Policy can matter. Before turning to the evidence, I bolster the case made in this section.

VI. ADDITIONAL EVIDENCE ON THE CONSEQUENCES OF ADVERSE EARLY CIRCUMSTANCES ON CHILD AND ADULT OUTCOMES

Many scholars, including Plato (1991, reprinted) and Freud (1935, reprinted), have discussed the importance of early childhood environments on adult outcomes. Felitti and Anda (2005) and Anda (2006) present some empirical support for Freud, Plato, and the numerous thinkers who have stressed the importance of the early years. They use retrospective data to examine the effects of adverse childhood experiences on health and human development over the lifespans of 17,337 participants. The cohorts they analyze are born as early as the 1900s. Their studies show the long-term effects of adverse early childhood environments. They have not yet established exact neural or genetic mechanisms, nor do they demonstrate what aspects of early trauma or adverse environments affect child outcomes. Their use of recall data on adversity in childhood is potentially very problematic. Nonetheless, their evidence is strongly suggestive of an important role for early family factors in determining child outcomes that is consistent with a large body of evidence from a variety of literatures.

Felitti and Anda (2005) and Anda (2006) define Adverse Childhood Experiences (ACE) as experiences in childhood or adolescence such as abuse and neglect, and growing up with domestic violence. Their studies based on ACE show that adverse childhood life experiences are correlated with adult disease burden and medical care costs; reduced well-being; increased depression and suicide rates; alcoholism and drug use; poor job performance and disability; social function; and impaired performance of subsequent generations. They compute a score (the ACE score) based on the extent of adverse childhood circumstances. The higher the score, the worse the childhood environment. Two out of three adults experience at least one category of ACE and 11% experience five or more. Their results are striking. Figure 14 shows the adult consequences of adverse childhood experiences.

FIGURE 14
Adult Health Risks by Adverse Childhood Experience (ACE) Score



Source: Anda (2006).

This evidence is bolstered by a large body of research in developmental psychology (Watt, Ayoub, Bradley et al., 2008). Lack of input during early child development results in abnormal development of the brain. The abnormal development is in those brain systems which sense, perceive, process, "interpret" and "act on" information related to that specific sensory deprivation.

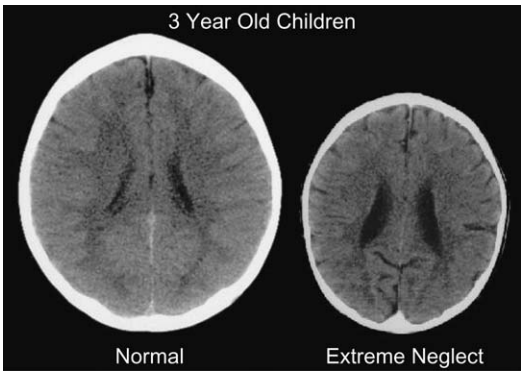
Studies of Romanian infants show the importance of the early years. A perverse natural experiment, described in detail in Cunha, Heckman, Lochner et al. (2006), placed many Romanian children in state run orphanages at birth. Conditions in the orphanages were atrocious. Children received minimal social and intellectual stimulation. They were adopted out at different ages (length of exposure).[19] Children raised in these institutions demonstrated cognitive delays, serious impairments in social behavior, and abnormal sensitivity to stress. Young children adopted out of institutional care often have persisting cognitive, socioemotional, and health problems.[20]

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. This is vividly illustrated in the smaller head size compared to normal children, enlarged ventricles and cortical atrophy found in neglected three-year-olds. (See Figure 15.) The later the Romanian orphans were adopted out, the poorer their recovery on average, although there are important variations among the children which are related to the quality of orphanages and adopted home environments. See Smyke, Koga, Johnson et al. (2007) for comprehensive discussions of these issues.

19. See Rutter and the English and Romanian Adoptees Study Team (1998) and Smyke, Koga, Johnson et al. (2007).

20. Rutter, Kreppner, Connor, and English and Romanian Adoptees Study Team (2001) discuss the wide variability in the recovery rates among infants. The general rule is that the longer the exposure to adverse environments, the harder it is to remediate through adoption, at least on average. The more adverse the early environment, the worse the outcome.

FIGURE 15
Abnormal Brain Development Following Sensory Neglect in Early Childhood



Note: These images illustrate the negative impact of neglect on the developing brain. The scan on the left is an image from a healthy three-year-old with an average head size (50^{th}percentile). The image on the right is from a three-year-old child suffering from severe sensory-deprivation neglect. This child's brain is significantly smaller than average (3^{rd} percentile) and has enlarged ventricles and cortical atrophy. Source: Perry (2004).

VII. ENRICHING EARLY ENVIRONMENTS CAN PARTIALLY COMPENSATE FOR EARLY ADVERSITY

Experiments that enrich the early environments of disadvantaged children demonstrate causal effects of early environments on adolescent and adult outcomes and provide powerful evidence against the genetic determinism of Herrnstein and Murray (1994). Enhancements of family environments improve child outcomes and affect both cognitive and noncognitive skills. Noncognitive skills — personality factors, motivation and the like — are an important channel of improvement.

The most reliable data come from experiments that substantially enrich the early environments of children living in low-income families. Two of these investigations, the Perry Preschool Program and the Abecedarian Program, are very informative for the purposes of this discussion because they use a random assignment design and collect long-term follow-up data.

These longitudinal studies demonstrate substantial positive effects of early environmental enrichment on a range of cognitive and noncognitive skills, schooling achievement, job performance, and social behaviors, long after the interventions ended. Data from Olds' Nurse Family Partnership Program (2008) and from non-controlled assessments of Head Start and the Chicago Child-Parent Centers programs confirm these findings.[21]

The Perry Program was an intensive preschool program that was administered to 58 disadvantaged black children in Ypsilanti, Michigan between 1962 and 1967. The treatment consisted of a daily 2.5-hour classroom session on weekday mornings and a weekly 90-minute home visit by the teacher on weekday afternoons. The length of each preschool year was 30 weeks. The control and treatment groups have been followed through age 40.

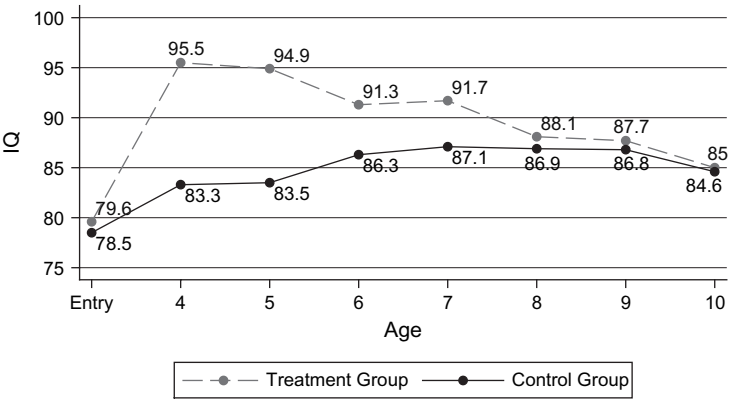
The Abecedarian Program studied 111 disadvantaged children, born between 1972 and 1977, whose families scored high on a risk index. The mean age at entry was 4.4 months. The program was a year-round, full-day intervention that continued through age 8. The children were followed through age 21, and an age 30 follow-up study is in preparation.

In both the Perry and Abecedarian Programs there was a consistent pattern of successful outcomes for treatment group members compared with control group members.[22] For the Perry Program, an initial increase in IQ disappeared gradually over 4 years following the intervention. Such IQ fadeouts have been observed in other studies. Figure 16 shows that the initial surge in IQ for treatment group members fades out by age ten. Heckman, Malofeeva, Pinto, and Savelyev (2008) establish that Perry operates primarily through improving noncognitive traits. These improvements explain the treatment effects graphed in Figure 17. Even though their IQs are not higher, the Perry treatment group does better on achievement tests at age 14 than the controls. (See the second set of bar charts in Figure 17(a).)

Positive effects of these interventions were also documented for a wide range of social behaviors, even though IQ is not any higher. At the oldest ages tested (Perry: 40 yrs; Abecedarian: 21 yrs), individuals scored higher on achievement tests, attained 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 controls. Intervening at an early enough age might even raise the IQ of participants. In the more intensive, earlier starting,

21. See Cunha, Heckman, Lochner et al. (2006) for a detailed discussion of these programs.
22. See Cunha, Heckman, Lochner et al. (2006).

FIGURE 16
Perry Preschool Program: IQ, by Age and Treatment Group



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

Abecedarian program, IQ gains were found that last into early adulthood.

An estimated rate of return (the return per dollar of cost) to the Perry Program is around 10%.[23] This high rate of return is higher than standard returns on stock market equity (5.8%) and suggests that society at large can benefit substantially from such interventions. These are underestimates of the rate of return because they ignore the economic returns to health and mental health. Cunha, Heckman, Lochner, and Masterov (2006) present a comprehensive survey of the early intervention programs.

Several observations about the evidence from the intervention studies and nonexperimental longitudinal studies are relevant. Skills beget skills and capabilities foster future capabilities. All capabilities are built on a foundation of capacities that are developed earlier. Early mastery of a range of cognitive, social, and emotional competencies makes learning at later ages more efficient and therefore easier and more likely to continue.

As currently configured, public job training programs, adult literacy services, prisoner rehabilitation programs, and education programs for disadvantaged adults produce low economic returns.[24] Moreover, for studies in which later intervention showed some benefits, the performance of disadvantaged children was still behind the performance of children who experienced earlier interventions in the preschool years. If the base is weak, the return to later investment is low.

The advantages gained from effective early interventions are best sustained when they are followed by continued high quality learning experiences. The technology of skill formation developed in Cunha and Heckman (2007b) and Heckman (2007) shows that the returns on school investment are higher for persons with higher ability, where ability is formed in the early years. Figure 18(a) shows the return to a marginal increase in investment at different stages of the life cycle starting from a position of low but equal initial investment at all ages.[25] Figure 18(b) is explained below.

Due to dynamic complementarity, or synergy, early investments must be followed by later investments if maximum value is to be realized. The Appendix to this paper presents a formal derivation of this curve and the associated optimal investment strategy. It draws on the analyses of Cunha and Heckman (2007b), Heckman (2007) and Cunha, Heckman, Lochner et al. (2006). One unusual feature of early interventions that is stressed in Cunha and Heckman (2007b) and Heckman

23. See Heckman, Moon, Pinto, and Yavitz (2007).

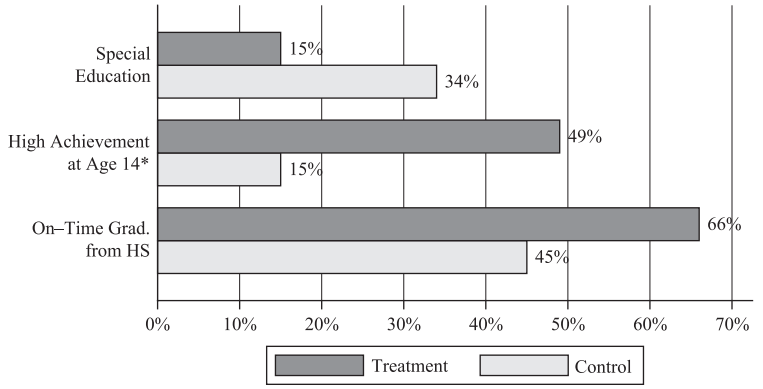
24. See Cunha, Heckman, Lochner, and Masterov (2006) and Heckman and Lochner (2000) for evidence on the returns to adolescent interventions for disadvantaged youth.

25. The curve is not an equilibrium schedule. It is a return to a unit of investment at each age assuming an initial low and equal investment at all ages that is below the final equilibrium level at each age. The equilibrium investment policy would allocate more resources to the early years and less to later years.

FIGURE 17
Perry Preschool Program

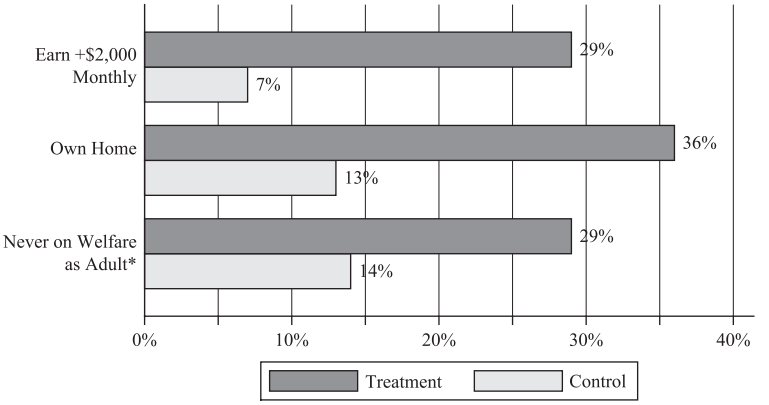
(a)

Educational Effects, by Treatment Group. *High Achievement Defined as Performance at or above the Lowest 10th Percentile on the California Achievement Test (1970). Source: Barnett (2004)



(b)

Economic Effects through Age 40, by Treatment Group. Source: Barnett (2004)



(c)

Arrests Per Person before Age 40, by Treatment Group. Juvenile arrestas are defined as arrests prior to age 19. Source: Barnett (2004)

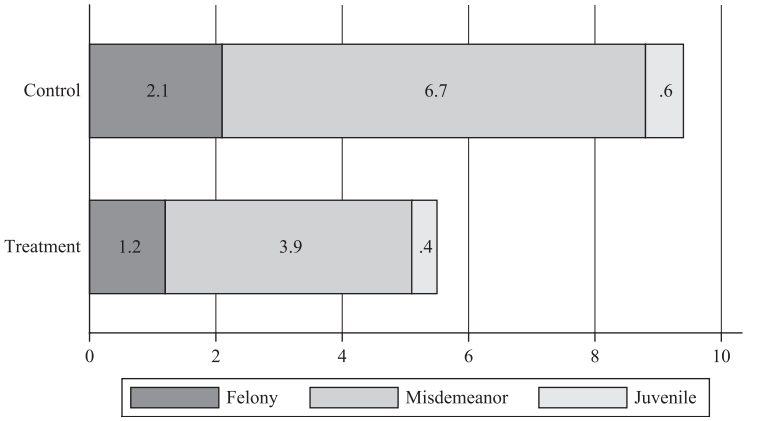
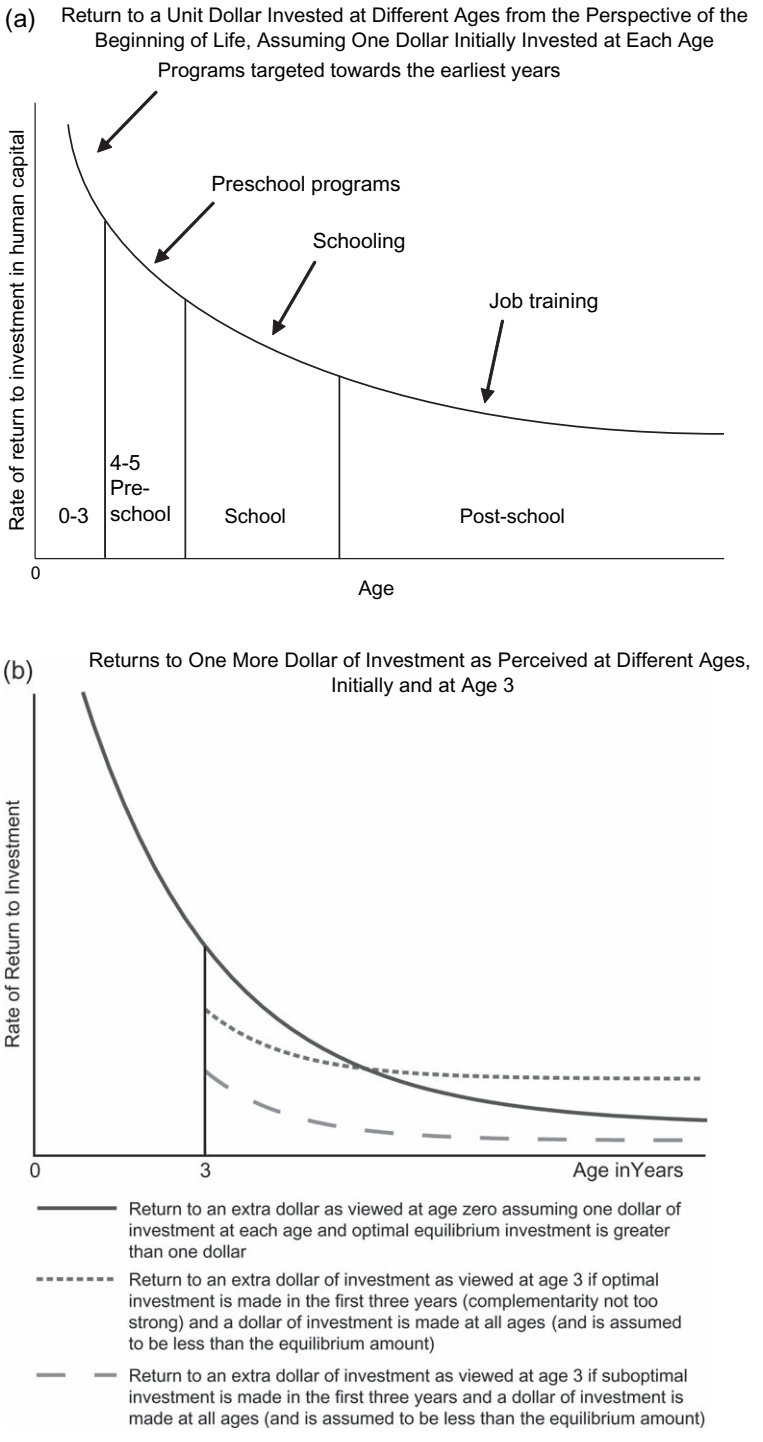


FIGURE 18
Returns to a Unit Dollar Invested



and Masterov (2007) is that the traditional equity-efficiency tradeoff that plagues most policies is absent. Early interventions promote economic efficiency and reduce lifetime inequality. Remedial interventions for disadvantaged adolescents who do not receive a strong initial foundation of skills face an equity-efficiency tradeoff. They are difficult to justify on the grounds of economic efficiency and generally have low rates of return.

Cunha and Heckman (2008a) and Cunha, Heckman, and Schennach (2007) estimate technologies of skill formation to understand how the skills of children evolve in response to (1) the stock of skills children have already accumulated; (2) the investments made by their parents; and (3) the stock of skills accumulated by the parents themselves. In the text, I sketch the framework. It is formally developed in the Appendix.

Let C_t be 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. I_t is the parental investment at age t. C_M is mother's cognitive skill. N_M is mother's noncognitive skill.

Cunha, Heckman, and Schennach (2007) and Cunha and Heckman (2008a) estimate two equations. One is a technology for the production of cognitive skills:

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

Another equation is a technology for the production of noncognitive skills:

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

The framework developed in the Appendix includes health as a third output of the developmental process.

Cunha, Heckman, and Schennach (2007) estimate the elasticity of substitution parameters for inputs at different periods that govern the trade-off of investment between the early years and the later years. They find much stronger yields of investment in the early years, supporting the shape of the curve displayed in Figure 18(a). Different stages of the life cycle are sensitive periods for different outcomes. Sensitive periods for cognitive skills come early in life. Sensitive periods for noncognitive skills come later in the life of the child.[26]

26. See Cunha and Heckman (2008a).

Figure 18(b) repeats the curve of Figure 18(a) on a different scale and shows the return to an extra dollar of investment at *age three* under two different scenarios. In the first scenario (depicted by the tightly-spaced dashed line), optimal investment up to age three is assumed to have been made. An additional dollar is invested at each age after age three and the return to the next dollar after that is computed. At age three, the curve starts below the curve 18(a) that is determined at age zero because substantial investment is assumed to have been made at age three. This is a manifestation of diminishing returns. After age three, the return eventually is greater than the initial curve for Figure 18(a) because of dynamic complementarity. The higher skill base at three enhances the productivity of later investment.[27]

The third curve (the curve with wider dashes) depicts a case with suboptimal investment in the years zero to three. Assuming that a dollar is initially invested in each year after age three, the return to the next dollar is less than the return viewed prospectively. When the initial base is substantially compromised, so are the returns to later investment.[28]

Table 5 presents a simulation of the model of Cunha, Heckman, and Schennach (2007), developed in Cunha and Heckman (2006). It considers a population of disadvantaged children with low levels of skills as measured at ages four to six. The investments they receive place them at the bottom decile of the overall population ability distribution. Their mothers are also at the bottom decile of the distribution of maternal endowments. For the outcomes listed in the first column, the baseline (no treatment) performance is presented in the second column "Baseline." These outcomes are those of the Perry control group.

Using an empirically determined technology, Cunha and Heckman (2006) simulate an intervention that moves children from the bottom decile of family resources to the seventh decile (from the bottom) in terms of their family environments. This produces the outcomes displayed in the third column of the table. This intervention essentially

27. The curve is drawn assuming moderate dynamic complementarity. In principle, the interval between age three and the crossing age could be made arbitrarily small.

28. Many different configurations of the age 3 investment curve are possible depending on the extent of diminishing returns within a period and the strength of dynamic complementarity of investments over time.

TABLE 5

Comparison of Different Investment Strategies. Disadvantaged Children are in first decile in the distribution of cognitive and noncognitive skills at age 6. Mothers are in first decile in the distribution of cognitive and noncognitive skills at ages 14–21

Outcome	Baseline	Changing early conditions: changing investment from the 1st to 7th decile of the overall distribution of early investment	Adolescent intervention: moving investments at last transition from 1st to 9th decile of overall investment	Changing initial conditions and performing a balanced intervention using the resources of the adolescent 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 35 – 50% more costly*	0.0259

Source: Cunha and Heckman (2006). *This is the range produced from a two standard deviation confidence interval.

produces the outcomes for the Perry treatment group (see Schweinhart, Montie, Xiang, Barnett, Belfield, and Nores 2005). The fourth column of Table 5 is a later adolescent intervention that also causes children to achieve Perry outcomes. To achieve Perry results in this fashion requires 35–50 percent *more* investment costs in present value terms discounted back to ages three to six (the age of the initial intervention). Family resources must be moved from the bottom decile to the ninth decile to achieve with later interventions what can be achieved with earlier interventions.

It is possible to remediate rather than to intervene early, but it is also much more costly. The outcomes displayed in the final column of the table result from allocating the resources spent in the adolescent intervention more smoothly over the life cycle of the child. Such interventions front load investment in the early years, following the logic of Figure 18(a) and the model developed in the Appendix. Relatively more investment is spent in the early years, but early investments are supported by later investments. Suppose that the resources required to produce Perry outcomes solely from adolescent interventions are spread more smoothly over the life cycle using an optimal investment strategy. This causes Perry-like children to attain middle class outcomes as is shown in the final column of numbers.

The evidence summarized in this paper supports the economic efficiency of early initial investment that is sustained. The optimal policy is to invest relatively more in the early years. But early investment must be followed up to be effective. This is a consequence of dynamic complementarity. See Cunha and Heckman (2007b) and the Appendix. Later remediation for early disadvantage is possible but to attain what is accomplished by early investment is much more costly. If society intervenes too late and individuals are at too low a level of skill, later investment can be economically inefficient. Middle class children receive massive doses of early enriched environments. Children from disadvantaged environments do not.

VIII. PRACTICAL ISSUES IN IMPLEMENTING EARLY CHILDHOOD PROGRAMS

A variety of practical issues arise in implementing early childhood programs. I discuss them in turn.

• *Who should be targeted?* The returns to early childhood programs are the highest for disadvantaged children who do not receive substantial amounts of parental investment in the early years. The proper measure of disadvantage is not necessarily family poverty or parental education. The available evidence suggests that the quality of *parenting* is the

important scarce resource. The quality of parenting is not always closely linked to family income or parental education. Measures of risky family environments should be developed that facilitate efficient targeting.

- *With what programs?* Programs that target the early years seem to have the greatest promise. The Nurse Family Partnership Program (Olds, 2002), the Abecedarian Program and the Perry Program have been evaluated and show high returns. Programs with home visits affect the lives of the parents and create a permanent change in the home environment that supports the child after center-based interventions end. Programs that build character and motivation that do not focus exclusively on cognition appear to be the most effective.
- *Who should provide the programs?* In designing any early childhood program that aims to improve the cognitive and socioemotional skills of disadvantaged children, it is important to respect the sanctity of early family life and to respect cultural diversity. The goal of early childhood programs is to create a base of productive skills and traits for disadvantaged children living in culturally diverse settings. By engaging private industry and other social groups that draw in private resources, create community support, and represent diverse points of view, effective and culturally sensitive programs can be created.
- *Who should pay for them?* One could make the programs universal to avoid stigmatization. Universal programs would be much more expensive and create the possibility of deadweight losses whereby public programs displace private investments by families. One solution to these problems is to make the programs universal but to offer a sliding fee schedule by family income to avoid deadweight losses.
- *Will the programs achieve high levels of compliance?* It is important to recognize potential problems with program compliance. Many successful programs change the values and motivations of the child. Some of these changes may run counter to the values of parents. There may be serious tension between the needs of the child and the acceptance of interventions by the parent. Developing culturally diverse programs will help avoid such tension. One cannot assume that there will be no conflict between the values of society as it seeks to develop the potential of the child and the values of the family, although the extent of such conflict is not yet known.

IX. SUMMARY

America has a growing skills problem. One consequence of this skills problem is rising inequality and polarization of society. A greater fraction of young Americans is graduating from college. At the same time, a greater fraction is dropping out of high school. Another consequence of the skills problem is the slowdown in growth of the productivity of the workplace. In designing policies to combat inequality, it is important to recognize that about 50% of the variance in inequality in lifetime earnings is determined by age 18. The family plays a powerful role in shaping adult outcomes that is not fully appreciated by current American policies.

Current social policy directed toward children focuses on improving cognition. Yet more than smarts is required for success in life. Gaps in both cognitive and noncognitive skills between the advantaged and the disadvantaged emerge early and can be traced in part to adverse early environments. A greater percentage of U.S. children is being born into adverse environments.

The problems of rising inequality and diminished productivity growth are not due mainly to defects in public schools or to high college tuition rates. Late remediation strategies designed to compensate for early disadvantage such as job training programs, high school classroom size reductions, GED programs, convict rehabilitation programs, and adult literacy programs are not effective, at least as currently constituted. Remediation in the adolescent years can repair the damage of adverse early environments, but it is costly. There is no equity-efficiency tradeoff for programs targeted toward the early years of the lives of disadvantaged children. There is a substantial equity-efficiency tradeoff for programs targeted toward the adolescent years of disadvantaged youth. Social policy should be directed toward the malleable early years.

A proper measure of disadvantage would be based on the quality of the parenting environment. Any proposed programs should respect the primacy of the family. Policy proposals should be culturally sensitive and recognize the diversity of values in American society. Effective strategies would engage the private

sector to mobilize resources and produce a menu of programs from which parents can choose.

APPENDIX: SOME FACTS ABOUT HUMAN DEVELOPMENT AND A SIMPLE MODEL THAT SUMMARIZES THE EVIDENCE

Any analysis of human development must reckon with nine facts. The first fact is that *ability matters*. Many empirical studies document that cognitive ability is a powerful determinant of wages, schooling, participation in crime and success in many aspects of social and economic life (Heckman, 1995; Heckman, Stixrud, and Urzua, 2006; Murnane, Willett, and Levy, 1995) including health (Auld and Sidhu, 2005).

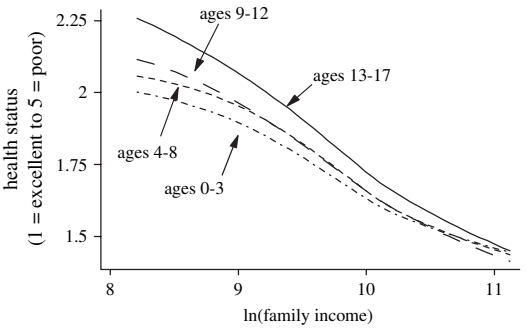
Second, *abilities are multiple in nature*. Noncognitive abilities (perseverance, motivation, time preference, risk aversion, self-esteem, self-control, preference for leisure) have direct effects on wages (controlling for schooling), schooling, teenage pregnancy, smoking, crime, performance on achievement tests, and many other aspects of social and economic life (Borghans, Duckworth, Heckman, and ter Weel, 2008; Bowles, Gintis, and Osborne, 2001; Heckman, Stixrud, and Urzua, 2006). They affect health choices (see the evidence on time preference and health in Grossman, 2000). Social and emotional factors affect adult health (Ryff and Singer, 2005).

Third, *the nature versus nurture distinction, while traditional, is obsolete*. The modern literature on epigenetic expression and gene-environment interactions teaches us that the sharp distinction between acquired skills and ability featured in the early human capital literature is not tenable (Gluckman and Hanson, 2005; Pray, 2004; Rutter, 2006). Additive "nature" and "nurture" models, while traditional and still used in many studies of heritability and family influence in economics, mischaracterize gene-environment interactions. Recent analyses in economics that break the "causes" of birthweight into environmental and genetic components ignore the lessons of the recent literature. Genes and environment cannot be meaningfully parsed by traditional linear models that assign unique variances to each component. Abilities are produced, and gene expression is governed by environmental conditions (Rutter, 2006; Rutter, Moffitt, and Caspi, 2006). Behaviors and abilities have both a genetic and an acquired character. Measured abilities are the outcome of environmental influences, including *in utero* experiences, and also have genetic components.

The literature on fetal programming emphasizes the importance of the environment in causing gene expression that gives rise to susceptibility to different diseases, abilities, and personality characteristics. See Gluckman and Hanson (2005) for evidence on gene expression for disease and Rutter (2006) and Rutter, Moffitt, and Caspi (2006) for evidence on environmental determinants of psychopathology and cognition. Some adverse early effects are more easily compensated than other effects. The concepts of remediation and resilience play prominent roles in economic and psychological analyses but are not featured in current discussions in health economics.[29]

29. See, however, Curtis and Cicchetti (2003) and Charney (2004) for analyses of biological and psychobiological mechanisms for resilience.

FIGURE A.1
Health and Income for Children and Adults, U.S. National Health Interview Survey 1986–1995



Source: Case, Lubotsky, and Paxson (2002).

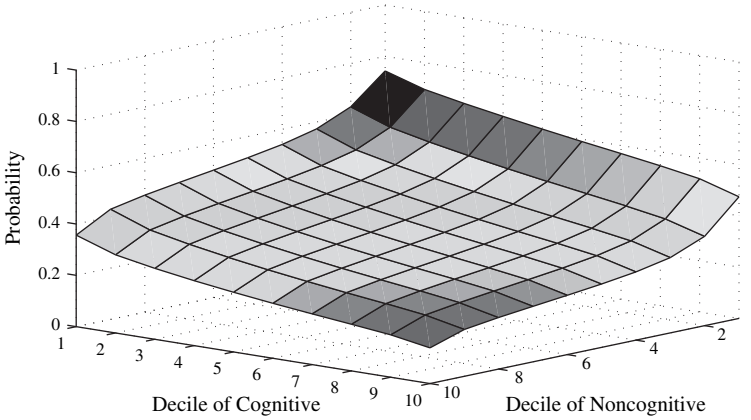
Fourth, *ability gaps between individuals and across socioeconomic groups open up at early ages, for both cognitive and noncognitive skills. So do gaps in health status.* We have illustrated this in the text of the paper. See Cunha and Heckman (2007b) and their appendices for much further evidence on this point. Cunha, Heckman, Lochner, and Masterov (2006) present numerous graphs showing the early divergence of child cognitive and noncognitive skills by age across children of parents with different socioeconomic status which supplement Figures 10, 11 and 12 in the text. Levels of child cognitive and noncognitive skills are highly correlated with family background factors like parental education and maternal ability, which, when statistically controlled for, largely eliminate these gaps (Carneiro and Heckman, 2003; Cunha, Heckman, Lochner, and Masterov, 2006). Currie (2006) presents parallel evidence on child health. Case, Lubotsky, and Paxson (2002) show that family income gradients in child health status emerge early and widen with age (see Figure A.1).[30] Experimental interventions with long-term follow-up confirm that changing the resources available to disadvantaged children improves adult outcomes on a number of dimensions. See the studies surveyed in Cunha, Heckman, Lochner, and Masterov (2006) and Blau and Currie (2006).

Fifth, *for both animal and human species, there is compelling evidence of critical and sensitive periods in development*. Some skills or traits are more readily acquired at certain stages of childhood than other traits (Knudsen, Heckman, Cameron, and Shonkoff (2006). For example, on average, if a second language is learned before age 12, the child speaks it without an accent (Newport, 1990). If syntax and grammar are not acquired early on, they appear to be very difficult to learn later on in life (Pinker, 1994). A child born with a cataract on the eye will be blind for life if the cataract is not removed within the first year of life.

Different types of abilities appear to be manipulable at different ages. See the evidence summarized in Borghans, Duckworth, Heckman et al. (2008). IQ scores become stable by age 10 or so, suggesting a sensitive period for their formation below age 10. There is evidence that adolescent interven-

30. Notice that a high "*y*" value is associated with *lower* health status on their graph.

FIGURE A.2
Probability of Daily Smoking by Age 18, Males by Decile of Cognitive and Noncognitive Factor



Note: The highest decile of cognitive and noncognitive ability is "10." "1" is the lowest decile.
Source: Heckman, Stixrud, and Urzua (2006).

tions can affect noncognitive skills (Cunha, Heckman, Lochner,and Masterov, 2006). This evidence is supported by the neuroscience that establishes the malleability of the prefrontal cortex into the early 20s (Dahl, 2004). This is the region of the brain that governs emotion and self-regulation. Rutter (2006) and Rutter, Moffitt, and Caspi (2006) present comprehensive summaries of age-dependent epigenetic and other gene-environment interactions for psychopathology — including aggression. Nagin and Tremblay (1999) show that early aggression predicts adult levels of criminality and violence. Barker and his coauthors show the powerful influence of the mother's health, as determined by her lifetime experiences on child outcomes.

On average, the later remediation is given to a disadvantaged child, the less effective it is. A study by O'Connor, Rutter, Beckett, et al. (2000) and their coauthors examined adopted Romanian infants reared in severely deprived orphanage environments before their adoption. As noted in the text, the later an orphan was rescued from the social and emotional isolation of the orphanage, the lower was his or her later cognitive performance. Secondary school classroom remediation programs designed to combat early cognitive deficits have a poor track record.

At historically funded levels, public job training programs and adult literacy and educational programs, like the GED, that attempt to remediate years of educational and emotional neglect among disadvantaged individuals, have a low economic return and produce meager effects for most persons. Much evidence suggests that returns to adolescent education for the most disadvantaged and less able are lower than the returns for the more advantaged (Carneiro and Heckman, 2003; Carneiro, Heckman, and Vytlacil, 2006; Meghir and Palme, 2001).

The available evidence suggests that, for many skills and human capabilities, later intervention for disadvantage may be possible, but that it is much more costly than early remediation to achieve a given level of adult performance (Cunha and Heckman, 2006). Barker and coauthors document that if intervention is administered in the first year of birth after the fetal stage, compensation for undernutrition can produce *greater* risk for later diabetes and heart disease (Eriksson, Forsen, Tuomilehto et al., 2001).[31,32]

Sixth, *despite the low returns to interventions targeted toward disadvantaged adolescents, the empirical literature shows high economic returns for remedial investments in young disadvantaged children.* See Barnett (2004), the evidence in Cunha, Heckman, Lochner, and Masterov (2006) and the papers they cite. This finding is a consequence of dynamic complementarity and self-productivity captured by the technology described in the next section. The evidence for interventions in low birth weight children suggests that early intervention can be effective (Brooks-Gunn, Cunha, Duncan et al., 2006). Olds (2002) documents that perinatal interventions that reduce fetal exposure to alcohol and nicotine have substantial long-term effects on cognition, socioemotional skills and on health and have high economic returns.

Seventh, *if early investment in disadvantaged children is not followed up by later investment, its effect at later ages is lessened.* Investments at different stages of the life cycle are complementary and require follow-up to be effective (Cunha and Heckman, 2006; 2007b).

Eighth, *the effects of credit constraints on a child's adult outcomes depend on the age at which they bind for the child's family*. Recent research summarized in Carneiro and Heckman (2002; 2003); Cunha, Heckman, Lochner, and Masterov (2006) demonstrates the quantitative insignificance of family credit constraints in a child's college-going years in explaining a child's enrollment in college. Controlling for cognitive ability, under policies currently in place in American society, family income during a child's

31. Barker and coauthors only investigate compensation in the first year after birth.

32. To date, the health economics literature has not systematically studied the effectiveness of remediation for adverse early environments, although it evaluates the efficacy of treatments of diseases that may be influenced by adverse early environments.

college-going years plays only a minor role in determining socioeconomic differences in college participation, although much public policy is predicated on precisely the opposite point of view. As noted in the text, controlling for ability, minorities are *more likely* to attend college than others despite their lower family incomes (see Cameron and Heckman, 2001, and the references they cite). Augmenting family income or reducing college tuition at the stage of the life cycle when a child goes to college does not go far in compensating for low levels of early investment. It is the shortfall in adolescent abilities and motivations that account for minority college enrollment gaps. The gaps in health status by income evident in Figure A.1 likely diminish once early environmental factors are controlled for, but this remains to be rigorously established.

Credit constraints operating in the *early* years have lasting effects on adult ability and schooling outcomes (Dahl and Lochner, 2005; Duncan, Kalil, and Ziol-Guest, 2007; Duncan and Brooks-Gunn, 1997; Morris, Duncan, and Clark-Kauffman, 2005). Evidence on the persistent effects of early malnutrition *in utero* and in the early years on adult health is consistent with this evidence (Fogel, 1997; 2004; Gluckman and Hanson, 2005).

Ninth, *socioemotional (noncognitive) skills foster cognitive skills and are an important product of successful families and successful interventions in disadvantaged families. They also promote healthy behaviors*. Emotionally nurturing environments produce more capable learners. The Perry Preschool Program, which was evaluated by random assignment, did not boost participant adult IQ but enhanced the performance of participants on a number of dimensions, including scores on achievement tests, employment, and reduced participation in a variety of social pathologies. See Schweinhart, Montie, Xiang, et al. (2005) and the figures and tables on the Perry program posted at the website for Cunha and Heckman (2007b).

Perseverance and motivation are also important factors in explaining compliance with medical protocols. A large body of evidence suggests that a person's mood and attitudes as well as his social environment account, in part, for the ability of persons to ward off and overcome various diseases and to age gracefully (Ryff and Singer, 2005). The evidence that personality traits affect educational attainment (Heckman, Stixrud, and Urzua, 2006) helps to explain how education, as a proxy, helps reduce disease gradients by socioeconomic class, as reported by Smith (2007). Figure A.2 shows how greater cognitive and noncognitive skills reduce participation in smoking, a major health hazard (Heckman, Stixrud, and Urzua, 2006).

A Model of Investment in Human Capabilities

A model of capability formation unifies this evidence. Agents are assumed to possess a vector of capabilities at each age including pure cognitive abilities (e.g. IQ), noncognitive abilities (patience, self control, temperament, risk aversion, time preference), and health stocks. Health stocks include propensities for mortality and morbidity, including infant mortality. All capabilities are produced by investment, environment, and genes. These capabilities are used with different weights in different tasks in the labor market and in social life more generally.[33]

33. Cunha, Heckman, Lochner, and Masterov (2006) propose a model of comparative advantage in occupational choice to supplement their model of skill formation.

The capability formation process is governed by a multistage technology. Each stage corresponds to a period in the life cycle of a child. While the recent child development literature in economics recognizes stages of development (Cunha and Heckman, 2007b; Cunha, Heckman, Lochner, and Masterov, 2006), the early literature on the economics of child development and the current literature on the economics of health do not (Becker and Tomes, 1986; Grossman, 2000). In the developmental approach, inputs or investments at each stage produce outputs at the next stage. Qualitatively different inputs can be used at different stages and the technologies can be different at different stages of child development.

The investment model used by Grossman (1972; 2000) focuses on adult investments in health where time and its opportunity cost play important roles. For investments in childhood health, parents make decisions and child opportunity costs are less relevant (Cunha and Heckman, 2007b). The outputs at each stage in our technology are the changes in capability at that stage. Some stages of the technology may be more productive in producing some capabilities than other stages, and some inputs may be more productive at some stages than at other stages. The stages that are more effective in producing certain capabilities are called "sensitive periods" for the acquisition of those capabilities. If one stage alone is effective in producing a capability, it is called a "critical period" for that capability. See Cunha and Heckman (2007b).

The capabilities produced at one stage augment the capabilities attained at later stages. This effect is termed *self-productivity*. It embodies the ideas that capabilities are self-reinforcing and cross-fertilizing and that the effects of investment persist. For example, emotional security fosters child exploration and more vigorous learning of cognitive skills. This has been found in animal species (Cameron, 2004; Meaney, 2001; Suomi, 1999) and in humans (see Duncan, Dowsett, Claessens et al, 2007; Raver, Garner, and Smith-Donald, 2007), interpreting the ability of a child to pay attention as a socioemotional skill. A higher stock of cognitive skill in one period raises the stock of next period cognitive skills. Higher levels of self-regulation and conscientiousness reduce health risks and avoid accidents. Higher levels of health promote learning. A second key feature of capability formation is *dynamic complementarity*. Capabilities produced at one stage of the life cycle raise the productivity of investment at subsequent stages. In a multistage technology, complementarity implies that levels of investments in capabilities at different ages bolster each other. They are synergistic. Complementarity also implies that early investment should be followed up by later investment in order for the early investment to be productive. Together, dynamic complementarity and self-productivity produce multiplier effects which are the mechanisms through which capabilities beget capabilities. This dynamic process can account for the emergence of socioeconomic differentials in health documented by Smith (2007) and Case, Lubotsky, and Paxson (2002).

Dynamic complementarity and self-productivity imply an equity-efficiency trade-off for late child investments but not for early investments (Cunha and Heckman, 2007b). These features of the technology of capability formation have consequences for the design and evaluation of public policies toward families. In particular, they show why the returns to late childhood investment and remediation for young adolescents from disadvantaged backgrounds are so low for many investments, while the returns to early

investment in children from disadvantaged environments are so high.

Cunha and Heckman (2007b) and Carneiro, Cunha, and Heckman (2003) formalize these concepts in an overlapping generations model. There is evidence on intergenerational linkages in health, personality, and skill formation (Bowles, Gintis, and Osborne Groves, 2005; Carneiro, Cunha, and Heckman, 2003; Currie, 2006). Consider a household which consists of an adult parent and his/her child. Take parental stocks of skills as given. In a proper overlapping generations model, as developed in Carneiro, Cunha, and Heckman (2003) and the website for Cunha and Heckman (2007b), investment in parents is modeled, explaining the intergenerational transmission of health, personality, and cognition.

Altruistic parents invest in their children. Let I_t denote parental investments in child capabilities when the child is t years-old, where $t = 1, 2, \ldots, T$. The first stage can be *in utero* investment. The output of the investment process is a skill vector. The parent is assumed to fully control the investments in the skills of the child, whereas in reality, as a child matures, he gains control over the investment process.[34] Thus, children with greater emotional skills and conscientiousness are less likely to be involved in risky teenage activities (see Figure A.2 and the evidence in Heckman, Stixrud, and Urzua, 2006). These capabilities create a platform of adult capabilities and preferences which affect adult choices. Government inputs (e.g., publicly provided schooling) can be modeled as a component of I_t. It would be desirable to merge the model of parental investment with the model of adult investment, but that is beyond the scope of this Appendix.

At conception, the child receives genetic and environmental initial conditions θ_1. As documented by Gluckman and Hanson (2005) and Rutter (2006), gene expression is triggered by environmental conditions. Let h denote parental capabilities (e.g., IQ, genes, education, income, etc.). These are products of their own parents' investments and genes. At each stage t, let θ_t denote the vector of capabilities. The technology of capability production when the child is t years old is

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

for $t = 1, 2, \ldots, T$.[35] More investment produces more capability $\left(\dfrac{\partial f_t(h, \theta_t, I_t)}{\partial I_t} > 0\right)$.

Substituting in (1) for θ_t, θ_{t-1},..., repeatedly, one can rewrite the stock of capabilities at stage $t + 1$, θ_{t+1}, as a function of all past investments:

$$\theta_{t+1} = m_t(h, \theta_1, I_1, \ldots, I_t), t = 1, \ldots, T. \tag{2}$$

Dynamic complementarity arises when $\partial^2 f_t(h, \theta_t, I_t)/\partial \theta_t \partial I_t' > 0$, i.e., when stocks of capabilities acquired by period $t-1$ (θ_t) make investment in period t (I_t) more productive. Such complementarity explains why returns to educational investments are higher at later stages of the child's life cycle for more able, more healthy, and more motivated children (those with higher θ_t). Students with greater early capabilities (cognitive, noncognitive, and health) are more efficient in later learning of both cognitive and noncognitive skills and in acquiring stocks of health capital. The evidence from the early intervention literature suggests that the enriched early preschool environments provided by the Abecedarian, Perry and CPC interventions promote greater efficiency in learning in school and reduce problem behaviors (Blau and Currie, 2006; Cunha, Heckman, Lochner, and Masterov, 2006). Enriched early environments produce healthier babies (Bhargava, 2008; Gluckman and Hanson, 2005).

Self-productivity arises when $\partial f_t(h, \theta_t, I_t)/\partial \theta_t > 0$, i.e., when higher levels of capabilities in one period create higher levels of capabilities in the next period. For capability vectors, this includes own and cross effects. The joint effects of self-productivity and dynamic complementarity help to explain the high productivity of investment in disadvantaged young children but the lower return to investment in disadvantaged adolescent children for whom the stock of capabilities is low and hence the complementarity effect is lower.

This technology explains the evidence that the ability of the child to pay attention affects subsequent academic achievement. Healthier children are better learners (Currie, 2006). This technology also captures the critical and sensitive periods in humans and animals documented for a number of aspects of development (Knudsen, Heckman, Cameron, and Shonkoff, 2006).

Suppose for analytical simplicity that there are two stages of childhood, ($T = 2$). In reality, there are many stages in childhood, including preconception and *in utero* stages. Assume for expositional simplicity that θ_1, I_1, I_2 are scalars.[36] The adult stock of capability, h' ($= \theta_3$), is a function of parental characteristics, initial conditions and investments during childhood I_1 and I_2:

$$h' = m_2(h, \theta_1, I_1, I_2). \tag{3}$$

The conventional literature in economics (Becker and Tomes, 1986) assumes only one period of childhood when it addresses childhood at all. It does not distinguish between early investment and late investment. A general technology that captures a variety of interesting special cases of (3) is a CES production function

$$h' = m_2(h, \theta_1, [\gamma(I_1)^{\phi} + (1-\gamma)(I_2)^{\phi}]^{1/\phi}) \tag{4}$$

for $\phi \leq 1$ and $0 \leq \gamma \leq 1$, where ϕ is a measure of how well late inputs substitute for early inputs. $1/(1-\phi)$ is called an elasticity of substitution. When $\phi = 1$, I_1 and I_2 are perfect substitutes. When $\phi = -\infty$, I_1 and I_2 are perfect complements. The parameter ϕ governs how easy it is to compensate for low levels of stage 1 investment in producing later adult capability. See the analysis of this model in Cunha and Heckman (2007b); Cunha, Heckman, Lochner, and Masterov (2006). The two polar cases of perfect substitutes and perfect complements are worth exploring in greater detail.

Case 1

Assume $\phi = 1$:

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

34. A sketch of such a model is discussed in Carneiro, Cunha, and Heckman (2003).

35. For analytical convenience, f_t is assumed to be strictly increasing in I_t. I further assume strict concavity in I_t and twice continuous differentiability in all of its arguments.

36. Cunha, Heckman, Lochner, and Masterov (2006) analyze the vector case. See also the supporting material on the website for Cunha and Heckman (2007b).

This extreme case states that remediation is always possible. However, it may not be cost effective. This technology is at odds with the evidence from neuroscience, developmental psychology, and economics, summarized in the first section of this Appendix. The polar opposite case is discussed next.

Case 2

Assume $\phi \to -\infty$:

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

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 period of the life of an individual.

More generally, when ϕ is small, low levels of early investment I_1 are not easily remediated by later investment I_2. The other face of CES complementarity is that when ϕ is small, high early investment should be followed with high late investment if the early investment is to be harvested. In the extreme case when $\phi \to -\infty$, (4) converges to a model of perfect complements. This technology explains why returns to education are low in the adolescent years for disadvantaged (low h, low I_1, low θ_2) adolescents but are high in the early years. Without the proper foundation for learning (high levels of θ_2) in technology (1), adolescent interventions have low returns. Bad initial conditions that create physical and mental impairments produce persistently less healthy adults (Barker, 1998; Eriksson, Forsen, Tuomilehto, Osmond, and Barker, 2001; Gluckman and Hanson, 2005).

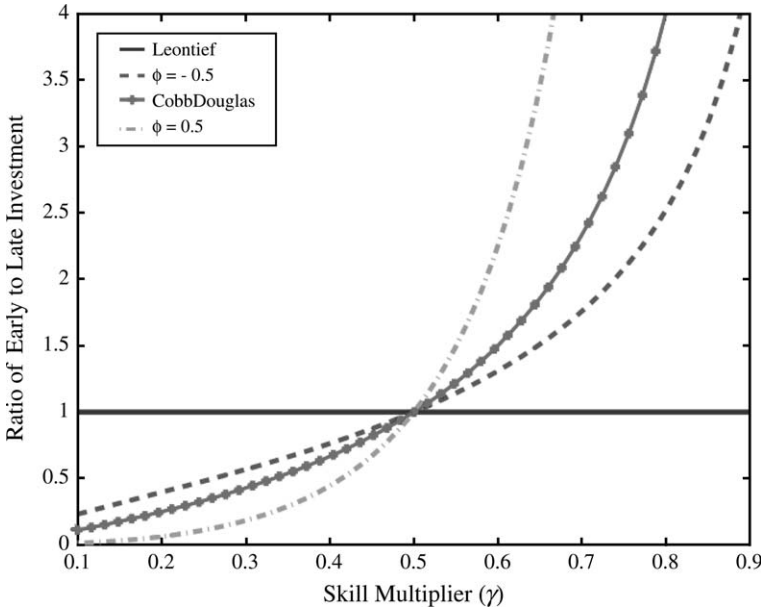
The CES share parameter γ is a *capability multiplier*. It captures the productivity of early investment not only in directly boosting h' (through self-productivity) but also in raising the productivity of I_2 by increasing θ_2 through first-period investments. Thus I_1 directly increases θ_2 which in turn affects the productivity of I_2 in forming h'. γ captures the net effect of I_1 on h' through both self-productivity and direct complementarity. In a multiperiod model, the multiplier could vary across stages. The capability multiplier helps to explain why capabilities foster capabilities.

The Optimal Lifecycle Profile of Capability Investments

Using technology (4), Cunha and Heckman (2007b) determine how the ratio of early to late investments varies as a function of ϕ and γ as a consequence of parental choices under different market arrangements concerning lending and borrowing. It is fruitful to review their analysis of the case without binding credit constraints.

When $\phi = 1$, so early and late investment are perfect CES substitutes, it is always possible to remediate early disadvantage. However, it is not always economically feasible to do so. Assume that the price of early investment is \$1. The price of late investment is $\$1/(1 + r)$, where r is the interest rate and $1/(1 + r)$ is a discount factor. The amount

FIGURE A.3
Ratio of Early to Late Investment in Human Capital as a Function of the Skill Multiplier for Different Values of Complementarity



Note: Assumes $r = 0$. Source: Cunha, Heckman, Lochner et al. (2006).

of human capital (including health capital) produced from one unit of I_1 is γ, while $\$(1+r)$ of I_2 produces $(1+r)(1-\gamma)$ units of human capital. Two forces act in opposite directions. High productivity of initial investment (as captured by the skill multiplier γ) drives the parent toward making early investments. The interest rate drives the parent to invest late. It is optimal to invest early if

$$\gamma > (1-\gamma)(1+r).$$

Epidemiologists are prone to neglect the costs of remediation when they demonstrate its possibilities.

As $\phi \rightarrow -\infty$, the optimal investment strategy sets $I_1 = I_2$. In this case, investment in the young is essential. However, later investment is needed to harvest early investment. On efficiency grounds, early disadvantages should be perpetuated, and compensatory investments at later ages are economically inefficient. In the general case where $-\infty < \phi < 1$, the optimal ratio of early to late investment is

$$\frac{I_1}{I_2} = \left[\frac{\gamma}{(1-\gamma)(1+\gamma)}\right]^{\frac{1}{1-\phi}}. \tag{5}$$

Figure A.3 plots the ratio of early to late investment as a function of the skill multiplier γ under different values of the complementarity parameter ϕ, assuming $r = 0$.

When CES complementarity is high, the skill multiplier γ plays a limited role in shaping the optimal ratio of early to late investment. High early investment should be followed by high late investment. As the degree of CES complementarity decreases, the role of the capability multiplier increases, and the higher the multiplier, the more investment should be concentrated in the early ages. Cunha and Heckman (2007b) analyze the effects of alternative credit market arrangements on optimal investment.

Cognitive, Noncognitive and Health Formation

This framework readily accommodates capability vectors. Child development is not just about cognitive skill formation although a lot of public policy analysis focuses solely on cognitive test scores to the exclusion of physical health and personality factors. Let θ_t denote the vector of capabilities, i.e., cognitive skills, noncognitive skills, and health capabilities: $\theta_t = (\theta_t^C, \theta_t^N, \theta_t^H)$. Let I_t denote the vector of investment in cognitive, noncognitive, and health capabilities: $I_t = (I_t^C, I_t^N, I_t^H)$. Use $h = (h^C, h^N, h^H)$ to denote parental cognitive, noncognitive, and health capabilities. At each stage t, one can define a recursive technology for cognitive skills $(k = C)$, noncognitive skills, $(k = N)$, and health $(k = H)$:

$$\theta_{t+1}^k = f_t^k(\theta_t^C, \theta_t^N, \theta_t^H, I_t^k, h^C, h^N, h^H), k \in \{C, N, H\}. \tag{6}$$

Technology (6) allows for cross-productivity effects: cognitive skills may affect the accumulation of noncognitive skills and vice versa. Health capabilities facilitate the accumulation of cognitive and noncognitive skills. These technologies also allow for critical and sensitive periods to differ across different capability investments. Cognitive and noncognitive skills and health capabilities determine costs of effort, time preference, and risk aversion parameters. By investment choices, parents shape preferences that govern the choices of children in a variety of dimensions.

Accounting for preference formation explains the success of many early childhood programs targeted to disadvantaged children which do not permanently raise IQ, but which permanently boost social performance.[37] Conscientiousness, farsightedness, and persistence, as well as other personality features, affect participation in risky activities, including smoking (Borghans, Duckworth, Heckman, and ter Weel, 2008; Heckman, Stixrud, and Urzua, 2006).

Estimating the Technology: Accounting for the Proxy Nature of Inputs and Outputs

Cunha and Heckman (2008a) and Cunha, Heckman, and Schennach (2007) estimate versions of technology (6) and show that many of the proxies for investment and outcomes that are used in the child development and health literatures are only crude proxies for the true variables they proxy. Systematically accounting for measurement error greatly affects estimates of technologies of skill formation and other behavioral relationships. Smoking is an error-laden proxy for noncognitive skill (Heckman, Stixrud, and Urzua, 2006). Many papers in health economics rely on smoking (and other behaviors) as proxies for time preference (see the survey in Grossman, 2000). The empirical literature on child development suggests that accounting for the proxy nature of smoking and adjusting for measurement error will improve the explanatory power and interpretability of the estimates of time preference on health choices.

Summary of the Appendix

Simple economic models show the importance of accounting for early and late investments and for examining the technological possibilities and economic costs of late remediation for early environmental influence. Frameworks that account for the proxy nature of the measurements of inputs and outputs hold much promise, both in health economics and in the economics of child development.

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