Published in final edited form as:
J Eur Econ Assoc. 2009 ; 7(2): 320–364.

The Economics and Psychology of Inequality and Human Development*

Flavio Cunha and
Department of Economics, University of Pennsylvania, 527 McNeil, 3718 Locust Walk, Philadelphia, PA 19104-6297, Phone: (215) 898-5652, Fax: (215) 573-2057

James J. Heckman
Department of Economics, University of Chicago, 1126 East 59th Street, Chicago, Illinois 60637, Phone: (773) 702-0634, Fax: (773) 702-8490, and Room B005, UCD Geary Institute, University College Dublin, Belfield, Dublin 4, Ireland, Phone: +353 1 716 4615, Fax: +353 1 716 1108

Flavio Cunha: flaviocunha@gmail.com; James J. Heckman: jjh@uchicago.edu

Abstract

Recent research on the economics of human development deepens understanding of the origins of inequality and excellence. It draws on and contributes to personality psychology and the psychology of human development. Inequalities in family environments and investments in children are substantial. They causally affect the development of capabilities. Both cognitive and noncognitive capabilities determine success in life but to varying degrees for different outcomes. An empirically determined technology of capability formation reveals that capabilities are self-productive and cross-fertilizing and can be enhanced by investment. Investments in capabilities are relatively more productive at some stages of a child's life cycle than others. Optimal child investment strategies differ depending on target outcomes of interest and on the nature of adversity in a child's early years. For some configurations of early disadvantage and for some desired outcomes, it is efficient to invest relatively more in the later years of childhood than in the early years.

Keywords

inequality; capabilities; noncognitive traits; human development; technology of capability formation; policy targeting

1 Introduction

This paper examines the origins of inequality in human capabilities and lessons for the design of strategies to reduce it. Preferences and skills determined early in life explain a substantial

*This paper was presented by Heckman as the Marshall Lecture at the European Economics Association, Milan, August 29, 2008. Flavio Cunha is Assistant Professor, Department of Economics, the University of Pennsylvania. James Heckman is Henry Schultz Distinguished Service Professor of Economics at the University of Chicago, Professor of Science and Society, University College Dublin, Senior Research Fellow, American Bar Foundation, and Alfred Cowles Distinguished Visiting Professor, Cowles Foundation, Yale University. We thank the editor and two anonymous referees for very helpful comments on an earlier draft of this paper. We also thank Vince Crawford, Friedhelm Pfeiffer, Seong Hyeok Moon, Rodrigo Pinto, Robert Pollak, Brent Roberts, Peter Savelyev, and Burton Singer for helpful comments and references on various drafts of this paper. This research was supported by the JB & MK Pritzker Family Foundation; The Susan Thompson Buffett Foundation; NIH R01-HD043411; and research grants from the American Bar Foundation. The views expressed in this paper are those of the author and not necessarily those of the funders listed here. A website that posts supplementary technical and empirical material for this paper is http://jenni.uchicago.edu/Marshall_2008.html. The display used in the Milan talk is posted at http://jenni.uchicago.edu/Milan_2008/, and contains supplementary material.

part of lifetime inequality. For example, recent research shows that in American society about 50% of lifetime inequality in the present value of earnings is determined by factors known to agents at age 18.[1] These factors originate in the family, and include genes and the environments that families select and create.

Progress in understanding mechanisms of family influence is facilitated by drawing on an emerging body of research in psychology. Behavioral economics has enriched mainstream economics by absorbing the lessons of cognitive psychology about human preferences and decision making.[2] In studying the *origins* of preferences and abilities and their development, it is also fruitful to draw on personality psychology and the psychology of human development, fields that often do not communicate with each other or to economists. This paper presents the fruits of an initial synthesis and a blueprint for future research.

It is fitting that these topics be addressed in a Marshall lecture. Although Marshall is best known for his work in economic theory, there was another side to him. Throughout his career, he was deeply concerned about the poor.[3] To understand poverty, Marshall analyzed how markets priced skills and studied the role of human capital in creating earnings capacity and inequality. He stressed the role of the family, especially that of the mother, in creating human capabilities:

> *The most valuable of all capital is that invested in human beings; and of that capital the most precious part is the result of the care and influence of the mother.* —Alfred Marshall (1890)[4]

Marshall's conception of human capital was more inclusive than current formulations. Like other Victorians, he thought it was possible to build "character" and "morals" and thereby uplift the poor.[5,6,7]

Since Marshall wrote, we have learned a lot about the pricing of skills in markets and about the formation of skills, abilities and "character" — what are called "capabilities" in this paper. Our understanding of the consequences of what mothers do and how families can be supplemented to improve the outcomes of their children has greatly improved. This paper presents recent developments.

The paper unfolds in the following way. Section 2 reviews recent evidence from economics and psychology that documents the importance of multiple abilities in explaining a diverse array of outcomes. Research on the relationship between psychological measurements and standard economic preference parameters is summarized. This section also examines a number of popular misconceptions about what achievement tests measure, and the role of genes and environments in shaping outcomes. Evidence on the early emergence of gaps in abilities across different socioeconomic groups is reviewed. These gaps are associated with disparities in investments in children across family types. Human and animal evidence on critical and sensitive periods in the development of capabilities is presented. Experimental evidence on the effectiveness of early interventions in remediating disadvantage is summarized. A primary

[1]See Cunha and Heckman (2007a). Notice that this is a lower bound estimate. Forces set in motion in the early years of childhood may play out after age 18 but their consequences may not be fully anticipated at age 18.

[2]See, e.g., Camerer et al. (2004) and Loewenstein (2007).

[3]*I have devoted myself for the last twenty-five years to the problem of poverty, and very little of my work has been devoted to any inquiry which does not bear upon that.* — Alfred Marshall (1893)

[4]Paragraph VI.IV.11.

[5]*The human will, guided by careful thought, can so modify circumstances as largely to modify character; and thus to bring about new conditions of life still more favourable to character; and therefore to the economic, as well as the moral, well-being of the masses of the people.* — Alfred Marshall (1907) as quoted in Whitaker (1977, p. 179)

[6]A worthwhile question is whether part or all of the Victorian program for creating character should be adopted in contemporary society. The relevance of the Victorian program for modern society is discussed in Himmelfarb (1995).

[7]Many societies and organizations have focused on developing traits perceived to be desirable in their children (e.g., ancient Sparta, Communist Russia, and Nazi Germany).

channel through which early interventions operate is enhancement of noncognitive skills. Later remediations that achieve the same adult outcomes are generally more costly, especially if the outcomes require high levels of cognition. Evidence on resilience to early adversity and the possibility of recovery from adversity is presented. Section 3 presents a framework for interpreting the evidence of Section 2 and for designing policies to reduce inequality. It draws on and extends recent research by Cunha and Heckman (2007b) and Heckman (2007). The technology of capability formation rationalizes why early investments in the lives of disadvantaged children are so productive while later investments are often less productive and remediation is often more costly than initial investment. The model is a framework for analyzing resilience and for designing optimal remediation policies. Section 4 summarizes recent empirical evidence on the technology of capability formation and draws new policy lessons from it. For certain configurations of disadvantage, relatively more investment should be allocated to the later years of childhood compared to the early years. A framework for policy analysis based on the technology of capability formation is sketched. Section 5 summarizes and concludes.

2 Genes, Multiple Abilities and Human Development

This section reviews evidence on the importance of multiple abilities in determining socioeconomic success, the relationship between psychological measurements and economic preference parameters, and the emergence of disparities in abilities across socioeconomic groups. Popular misconceptions about genes and the stability and predictive power of psychological traits are critically examined.

2.1 Ability Matters and is Multiple in Nature

Numerous studies document that cognitive ability, usually measured by a scholastic achievement test, is a powerful predictor of wages, schooling, participation in crime, health and success in many other aspects of economic and social life.[8] More recently, noncognitive abilities have been shown to be important predictors of the same outcomes.[9] Noncognitive traits capture Marshall's concept of "character," and include perseverance, motivation, self-esteem, self-control, conscientiousness, and forward-looking behavior.[10] There is substantial heterogeneity in cognitive and noncognitive skills.[11]

An example of the predictive power of noncognitive traits is presented in Figure 1. It displays the relative strength of cognitive and noncognitive capabilities in determining occupational choice. Moving from the bottom of the distribution to the top in either dimension of capability substantially increases the probability that a person is a white collar worker.[12] The same low-dimensional psychological traits that predict occupational choice are also strongly predictive of a variety of diverse behaviors, such as smoking, employment, teenage pregnancy, wages, wages given schooling and many other aspects of economic and social life.[13] Interpreting cognitive and noncognitive traits as generators of, or proxies for, economic preference parameters, this body of evidence is consistent with economic models that predict that a low-dimensional set of economic parameters such as time preference, risk aversion, leisure

[8]See, e.g., Herrnstein and Murray (1994); Murnane et al. (1995); Auld and Sidhu (2005); and Kaestner (2008). Neal and Johnson (1996); Hansen et al. (2004); Carneiro et al. (2005); and Heckman et al. (2006) present estimates of the causal effect of ability on diverse outcomes correcting for the effect of environments on measures of ability.

[9]A causal basis for these predictive relationships is established in Heckman et al. (2006) and Heckman et al. (2009).

[10]Bowles and Gintis (1976); Edwards (1976); Mueser (1979); Bowles et al. (2001); Heckman and Rubinstein (2001); Heckman et al. (2006); Borghans et al. (2008) summarize the evidence to date. Marxist economists (Bowles, Gintis, and Edwards) were the first to establish the importance of noncognitive traits for predicting a variety of labor market outcomes.

[11]See the evidence in Heckman et al. (2006).

[12]These estimates correct for measurement error and the effect of schooling on measured cognitive and noncognitive traits, where schooling itself depends on latent cognitive and noncognitive traits. See Heckman et al. (2006).

[13]See Heckman et al. (2006) for a full description of the outcomes.

preference, social preferences, and altruism, along with prices and endowments, explain diverse economic choices.

Figure 1 oversimplifies matters by assuming that there is one "cognitive" trait and one "noncognitive" trait. At least five dimensions (the Big Five) are required to characterize personality.[14] At least two dimensions of cognition have been isolated.[15]

2.1.1 Controversies Surrounding Psychological Measurements—Some economists dismiss this and other evidence on the predictive power of personality traits. Following Mischel (1968), they claim that psychological traits and economic preference parameters are *solely* situational-specific – that manifest personality traits respond to the incentives in the situation being examined and are not stable across situations.[16]

Borghans et al. (2008) review the substantial body of evidence against the situational-specificity hypothesis.[17] They also discuss the need to standardize measurements of cognition and personality by adjusting for effects of incentives to express traits and effects of the environments in which the measurements are taken. Many measurements reported in psychology and economics do not adjust for the effects of incentives and environments. This induces variation in manifest traits across situations.

For example, scores on IQ tests are substantially affected by rewards for correct answers. IQ can be raised by as much as one standard deviation if proper incentives are provided. The effectiveness of rewards in motivating test performance depends on personality traits.[18]Roberts (2007), Wood (2007) and Wood and Roberts (2006) discuss evidence that the predictive power of personality traits survives after adjustment for the context in which measurements are taken.[19]

Different tests measure different attributes. For example, tests of raw problem-solving ability ("fluid intelligence" as captured by Raven's progressive matrices tests) measure a different collection of traits than the bundle of traits measured by achievement tests, although there is some overlap in their domains. Achievement tests are often interpreted as IQ tests.[20] In fact, achievement test scores (such as the SAT or AFQT) capture both cognitive and personality traits. Borghans et al. (2008),Heckman et al. (2009), and Segal (2008) show that personality traits are powerful predictors of performance on many widely used tests of cognition. A major conclusion from this analysis is that Herrnstein and Murray's evidence on the power of "IQ" in predicting a large array of social and economic outcomes is, in truth, also evidence on the power of personality and preferences in producing test scores.

While personality traits are not solely situational-specific ephemera, neither are they set in stone. Adjusting for context, both cognitive and noncognitive abilities evolve over the life cycle

[14]The Big Five are summarized by the acronym OCEAN: Openness to Experience; Conscientiousness; Extraversion; Agreeableness and Neuroticism. Goldberg (1990) defined this concept and Borghans et al. (2008) review this literature. Including the "facets" of the Big Five, there are over 30 personality traits.

[15]McArdle et al. (2002) discuss fluid intelligence (raw problem-solving ability) and crystallized intelligence (knowledge and wisdom).

[16]The traits used to produce Figure 1 and related figures in the literature are typically measured much earlier than the outcomes that they are used to predict. This is one way to protect against the problem of reverse causality that the outcomes affect the measure of the traits. See Borghans et al. (2008) for a discussion of this issue and other approaches for solving the problems of reverse causality.

[17]Mischel himself has modified his earlier view. See Mischel and Shoda (1995). Shoda et al. (1990) present evidence on the "marshmallow test." The ability of a young child to defer gratification to obtain greater rewards (more marshmallows) predicts adult schooling attainment and other favorable outcomes. The stability of preferences manifested in this experiment contradicts the situational-specificity hypothesis of Mischel (1968). The family backgrounds of the children in the marshmallow study are quite homogeneous. They were children attending the Stanford University preschool. Most were children of faculty.

[18]More conscientious test takers respond only weakly to rewards, presumably because they are already at their peak performance. See Borghans et al. (2008) and Segal (2008).

[19]See also Funder and Ozer (1983); Colvin and Funder (1991); Funder and Colvin (1991); Roberts and DelVecchio (2000).

[20]See, e.g., Herrnstein and Murray (1994).

and are malleable.[21] This malleability creates possibilities for improving the preferences ("character") and endowments of disadvantaged persons that are just beginning to be understood. Recent studies demonstrate that the malleability of personality traits is greater at later stages of childhood than is the malleability of IQ. This has important implications for public policy that we discuss below.

While it is analytically convenient to distinguish cognitive from noncognitive traits, doing so empirically raises serious challenges. Few human activities are devoid of cognition. The capacity to imagine alternative states, a cognitive task, has effects on manifest personality.[22] Thus, an active imagination can cause and reflect personality traits and disorders. Emotional states affect reason.[23] To the extent that personality traits proxy and/or produce emotions, a separation of cognitive and noncognitive traits becomes difficult. Measures of cognition, personality and emotion should be standardized for background levels of other traits and incentives to manifest a behavior.[24] Economic preference parameters are a hybrid of cognitive and noncognitive traits. For example, time preference can be interpreted as arising from the ability of an agent to foresee the future as well as the agent's ability to control impulses to immediately consume.

2.1.2 Relating Psychological Measurements to Economic Preference Parameters—

Research on capability formation in economics uses psychological measurements as indicators of stocks of capabilities. Work relating psychological measurements to more standard economic preference parameters has just begun. Heckman et al. (2006) and Borghans et al. (2008) discuss the relationship between psychological measurements and standard economic preference parameters. A tight link between the two types of measurement systems remains to be established. Concepts and measurements from one field neither encompass nor are encompassed by measurements from the other field.

The available evidence is at best suggestive. Benjamin et al. (2006) show that higher SAT scores are positively correlated with patience and negatively correlated with risk aversion. Since SAT scores are determined by a composite of cognitive and noncognitive traits, it is difficult to parse out the separate contributions of cognition and personality to their estimated correlations. Frederick (2005) presents evidence that his measure of cognitive ability is associated with lower time preference, greater risk taking when lotteries involve gains, and less risk taking when they involve losses. However, Borghans et al. (2008) show that his measure of "cognition" is substantially influenced by personality traits and is not a measure of pure cognition as measured by Raven's progressive matrices. Dohmen et al. (2007) report that people with higher cognitive ability are more patient and more willing to take risks. They link time preference and risk aversion with measures of cognitive and noncognitive traits.

When the evidence is sorted out, this research will enrich economists' and psychologists' understanding of human preferences and motivation. Data are abundant that link psychological measurements to behavior. If a strong link between psychological and economic measurements can be established, a treasure chest of new empirical evidence on the effects of preferences on a variety of behavioral outcomes will become available to economists.

2.2 Early and Persistent Gaps in Cognitive and Noncognitive Capabilities

Gaps in the capabilities that play important roles in determining diverse adult outcomes open up early across socioeconomic groups. The gaps originate before formal schooling begins and

[21] See Borghans et al. (2008).
[22] See Borghans et al. (2008) and the references they cite.
[23] See Damasio (1994), LeDoux (1996), and Phelps (2006, 2009).
[24] Standardization is discussed in Section 3.1 in the analysis surrounding equation (1).

persist through childhood. Figure 2 shows the early emergence of gaps in cognitive ability. It is representative of the evidence from a large literature. Evidence on noncognitive measurements shows the same pattern.

Schooling after the second grade plays only a minor role in creating or reducing gaps. Conventional measures of schooling quality (teacher/pupil ratios and teacher salaries) that receive so much attention in contemporary policy debates have small effects in creating or eliminating gaps after the first few years of schooling (Carneiro and Heckman, 2003; Cunha and Heckman, 2007b). In the context of the U.S., this evidence is surprising given substantial inequality in schooling quality across socioeconomic groups.

Controlling for early family environments using conventional statistical methods substantially narrows the gaps.[25] This is consistent with evidence in the Coleman Report (1966) that family characteristics, and not those of schools, explain the variability in student test scores across schools.[26]

Such evidence leaves open the question of which aspects of families are responsible for producing these gaps. Is it due to genes? Family environments? Family investment decisions? The evidence from the intervention studies, reviewed below, suggests an important role for investments and family environments in determining adult capabilities. Before turning to this evidence, we first review the evidence on differentials in family investments.

2.3 Corresponding Gaps in Family Investments and Environments

There are substantial differences in family environments and investments in children across socioeconomic groups. Moon (2008) demonstrates important differences in the family environments and investments of advantaged and disadvantaged children. Gaps in cognitive stimulation, affection, punishment, and other parental investments for children from families of different socioeconomic status open up early. Intact families invest far greater amounts in their children than do single parent families although the exact mechanisms causing this (e.g., differential resources or family preferences) remain to be established. Figure 3(a) and Figure 3(b) show substantial gaps in cognitive stimulation and affection at early ages. They persist throughout childhood.[27,28] Section 4 reviews evidence on the role of family investments in explaining disparities in test scores and adult achievement.

The evidence on disparities in child-rearing environments and their consequences for adult outcomes is troubling in light of the greater proportion of children being raised in such environments. The proportion of American children under the age of 18 with a never-married mother has grown from less than 2% in 1968 to over 12% in 2006. The fraction of American children under age 18 with only a single parent has grown from 12% to over 27% during this period.[29]

---

[25]Carneiro and Heckman (2003); Cunha et al. (2006); Cunha and Heckman (2007b); and Heckman (2008) present a variety of figures with similar patterns on the early emergence of gaps in both cognitive and noncognitive abilities and how gaps are substantially attenuated when adjusted for family background.

[26]The Coleman Report claimed that peer effects were important in explaining student outcomes. Subsequent reanalyses reported in Mosteller and Moynihan (1972) showed that this finding was due to a coding error and that when the error was corrected, family and individual characteristics eliminate any statistical significance from estimated peer effects on test scores.

[27]The patterns are identical for male and female children. Web Appendix A, based on Moon (2008), shows the disparity in child environments by different measures of family status and the persistence of gaps through childhood.

[28]Ginther and Pollak (2004) show that family adversity may be better measured by the presence or absence of the *biological* parents. Blended families – families where one parent is not biologically related to the children – produce children with more adverse outcomes.

[29]See Ellwood and Jencks (2004) and Heckman (2008). Data on child exposure to different types of family structures is analyzed by Moon (2008).

Recent research suggests that parental income is an inadequate measure of the resources available to a child even though it is the standard basis for measuring child poverty.[30] Parenting is more important than cash. High quality parenting can be available to a child even when the family is in adverse financial circumstances, although higher income facilitates good parenting.[31] This observation accounts in part for the success of children from certain cultural and ethnic groups raised in poverty who nonetheless receive strong encouragement from devoted parents and succeed. Sowell (1994),Charney (2004),Masten (2004), and Masten et al. (2006) discuss the factors that promote resilience to adversity.

2.4 Capabilities are Not Solely Determined by Genes

Gaps in family environments and investments and the relationship between investment and child outcomes might simply be a manifestation of genes. Families with good genes might pick good environments but the main effect of family influence might operate through genes. Recent evidence in genetics belies this claim. Gene expression is governed by environmental conditions. The gene expression of identical (monozygotic) twins has been studied. By age three, and certainly by age 50, the genetic expressions of "identical" twins are very different (See Fraga et al, 2005).

Recent research by Caspi et al. (2002) suggests that gene expression is triggered in part by environmental conditions. A variant of the MAOA gene is a known predictor of male conduct disorder and violence. However, the gene pattern is most strongly expressed when child rearing environments are adverse. Many other gene-environment interactions have been documented.[32]

Virtually every study of "nature" and "nurture" in economics estimates models where outcomes are linear and separable functions of nature and nurture which ignore gene-environment interactions. Genes and environments cannot be meaningfully parsed by traditional linear models that assign unique variances to each component.[33]

Little systematic accounting is available on the relative importance of genes, environments and their interactions in predicting any complex aspect of human behavior, although numerous estimates from linear models are available. Additive models with their strong identifying assumptions show that genes explain up to 50% of most behaviors (Rowe, 1994). Even within this oversimplified framework, genes are not full determinative of life outcomes. Neither are environments. However, extreme statements about genetic determinism are clearly at odds with the evidence. The results from the intervention analyses discussed below strengthen this conclusion.

2.5 Critical and Sensitive Periods

Different abilities are malleable at different ages. IQ scores become stable by age 10 or so, suggesting a sensitive period for their formation below age 10 (Schuerger and Witt, 1989). Noncognitive capabilities are more malleable until later ages. The greater malleability of noncognitive capabilities is associated with the slowly developing prefrontal cortex, which

[30]See Mayer (1997).
[31]See Costello et al. (2003), Rutter (2006), and Heckman (2008).
[32]For some outcomes, gene-environment interactions have been replicated in most, but not all, studies. The field of gene-environment interactions is very new and caution is required in using the emerging evidence uncritically. See Moffitt (2008) and the figures posted on the display website for the Marshall lecture at http://jenni.uchicago.edu/Milan_2008/.
[33]See, e.g., Collins et al. (2000), Turkheimer et al. (2003), and Tucker-Drob (2009).

controls executive function, a known determinant of personality and emotion.[34] In general, the later *cognitive* remediation is given to a disadvantaged child, the less effective it is.

Considerable evidence suggests that the economic returns are low for the education of low-ability adolescents and the returns are higher for the more advantaged high-ability adolescents (Carneiro and Heckman, 2003; Meghir and Palme, 2001; Wößmann, 2008). The available evidence also suggests that for many human capabilities, some interventions in the lives of disadvantaged low-ability adolescents have positive effects, but are generally more costly than early remediation to achieve the same level of adult performance (Cunha and Heckman, 2007b; Cunha, Heckman, Lochner, and Masterov, 2006; Cunha, Heckman, and Schennach, 2008).

Knudsen (2004) shows that early experience can modify the biochemistry and architecture of neural circuits. Periods when the modification is easily accomplished are called *sensitive* periods. When the modification can only occur during a limited time frame and it is crucial for normal development, it is called a *critical* period. Sensitive and critical periods have been extensively documented for binocular vision in the cortex of mammals, filial imprinting in the forebrain of ducks and chickens, and language acquisition in humans. Knudsen et al. (2006) review the evidence on critical and sensitive periods in animals and humans. Much of the evidence is at the neuronal circuit level. Missing in the biological and neurological literatures are measurements of the effectiveness of remediation, and discussion of the possibilities and costs of compensation for early deficits.[35]

There is experimental evidence for animals showing that early environments are powerful determinants of adult behavior. Experiences occurring during an early period of development have long-term effects on gene expression that are stably maintained into adulthood.[36] This is not a purely genetic phenomenon because animal environments are experimentally manipulated in these studies. Social experiences alter the epigenome and thus regulate gene expression. Neural systems regulating stress responsivity and the risk of psychopathology can be affected by these epigenetic mechanisms.[37]

A large literature in developmental epidemiology documents the role of adverse early environments on adult health.[38] Nutritional deficiencies in early life cause lifelong health, cognitive, and personality problems.[39]Danese et al. (2008) show that maltreatment in childhood has powerful negative effects on adult inflammation, a serious health risk.[40]

However, the early years are far from being fully determinative of adult outcomes. Many children reared in environments judged severely adverse by conventional measures, succeed in adult life.[41] There is evidence that the effects of adversity on gene expression can be reversed, at least in part.[42] The ability to overcome adversity plays an important role in shaping adult outcomes. The mechanisms that promote resilience and recovery from initial

[34]The greater malleability of noncognitive capabilities at later ages may be a manifestation of traits that *emerge* at later ages and are susceptible to influence at the age at which they emerge. See Borghans et al. (2008) for a review of the literature on the emergence of personality traits by age.

[35]Evidence on critical periods for early development of certain capabilities suggests that remediation costs for later interventions are high. See Knudsen et al. (2006). Costs of remediation in skill acquisition programs are presented in Cunha et al. (2006). There do not appear to be studies of costs of remediation versus prevention for specific medical conditions.

[36]See Heijmans et al. (2008).

[37]See Suomi (2000), Weaver et al. (2004); Champagne (2008).

[38]See Barker (1998); Gluckman and Hanson (2005); Nilsson (2008); van den Berg et al. (2008).

[39]See Knudsen et al. (2006); Georgieff (2007); Engle et al. (2007); Grantham-McGregor et al. (2007); and Walker et al. (2007).

[40]See also the discussion in McEwen (2007).

[41]See Werner et al. (1971). Most of the severely disadvantaged children in their study live failed lives but some — around 20%–25% — succeed in living normal middle class lives.

[42]Meaney and Szyf (2005), Whitelaw and Whitelaw (2006), Szyf (2007) and Champagne (2008).

disadvantage are just beginning to be understood. The available evidence suggests that socioemotional support — i.e., good parenting — for a child from whatever source is a key ingredient.[43] Recent research shows that personality traits determined early in life are especially important determinants of success in lifetime earnings for people born into disadvantaged environments.[44]

2.6 The Effects of Family Credit Constraints on a Child's Adult Outcomes

In advanced Western societies, family income *during a child's college-going years* plays only a minor role in determining socioeconomic differences in college participation once one controls for achievement test scores, measured at college-going ages.[45] Controlling for ability at the age college-going decisions are made, minorities from low income families are *more likely* to go to college than are majority students even though minority family income is generally lower than majority family income.[46] Credit constraints operating in the *early* years of childhood have lasting effects on child ability and schooling outcomes.[47]

Recent research by Belley and Lochner (2007) shows the growing importance of family income constraints in the college-going decisions of Americans. Nonetheless, their research demonstrates that the primary factor explaining differentials in college attendance among socioeconomic groups is cognitive ability and not family income. For less developed countries, credit market restrictions are likely to be more substantial and relaxing them is likely to be an important policy lever.

2.7 Compensating with Enrichments to Early Family Environments

Experiments that enrich the early environments of disadvantaged children establish causal effects of early environments on adolescent and adult outcomes. Noncognitive skills and personality traits are a main cause of the improvement produced from these interventions.

The Perry Preschool Program is the flagship early childhood intervention program. The Perry Preschool Program enriched the lives of low income African-American children with initial IQs of 85 or below. The intervention was targeted to three-year olds and was relatively modest: 2.5 hours per day of classroom instruction, 5 days per week, and $1\frac{1}{2}$ hours of weekly home visits. Children participate for only two years and no further intervention was given.[48] The program has been extensively analyzed in Heckman et al. (2009);Heckman et al. (2009a); and Heckman, Moon, Pinto, Savelyev, and Yavitz (2009b).

Perry did not produce lasting gains in the IQs of its male participants and produced at best modest gains in IQ for females.[49] Yet the program has a rate of return of around 10% per annum for males and females — well above the post-World War II stock market returns to equity estimated to be 5.5%.[50] This evidence defies a strictly genetic interpretation of the origins of inequality.

Even though their IQs after age 10 are not higher (on average), achievement test scores of participants are higher. This evidence underscores the difference between achievement test

---

[43]See Masten and Coatsworth (1998), Masten (2004), and Masten et al. (2006).

[44]See O'Connell and Sheikh (2008).

[45]See Cunha and Heckman (2007b) and the evidence in Cunha et al. (2006).

[46]See Cameron and Heckman (2001) and the evidence summarized in Cunha et al. (2006). This evidence is consistent with the operation of extensive affirmative action programs for promoting the college attendance of the disadvantaged in American society and may not generalize to other societies.

[47]Cunha (2007) presents an analysis of the family determinants of child ability. See also the discussion in section 4 below.

[48]See Heckman et al. (2009).

[49]See Heckman, Stixrud, and Urzua (2006), Borghans, Duckworth, Heckman, and ter Weel (2008) and Heckman (2008).

[50]Heckman, Moon, Pinto, Savelyev, and Yavitz (2009a). DeLong and Magin (2009) is the source for the post-war return to equity.

scores and IQ, previously discussed. Achievement tests measure crystallized knowledge not captured by tests of fluid intelligence. In addition, they are influenced by personality factors. Heckman, Malofeeva, Pinto, and Savelyev (2009) show that a principal channel of influence of the Perry Program is through its effect on noncognitive skills.

Figure 4, taken from their work, demonstrates this point. Panels (a) and (b) decompose treatment effects of the program for various statistically significant outcomes into components that can be attributed to cognitive, noncognitive and residual factors. For males, improvements in measured noncognitive traits are important, but not exclusive, determinants of treatment effects (Figure 4(a)). For females, there were gains attributable to improvements in cognitive and noncognitive traits (Figure 4(b)).[51] The importance of different psychological traits varies across the outcomes measured, reflecting the differential weighting of cognitive, noncognitive and other capabilities in determining performance in different tasks in social life.

Direct investment in children is only one possible channel for intervening in the lives of disadvantaged children. Many successful programs also work with mothers and improve mothering skills. The two inputs — direct investment in the child's cognition and personality and investment in the mother and the family environment she creates — are distinct. They likely complement each other. Improvements in either input improve child outcomes. The Nurse Family Partnership Act intervenes solely with pregnant teenage mothers and teaches them mothering and infant care. It has substantial effects on the adult success of the children of disadvantaged mothers. Olds (2002) documents that perinatal interventions that reduce fetal exposure to alcohol and nicotine have substantial long-term effects on cognition, socioemotional skills and health, and have high economic returns.

The evidence from a variety of early intervention programs summarized in Reynolds and Temple (2009) shows that enriching the early environments of disadvantaged children has lasting beneficial effects on adolescent and adult outcomes of program participants. This evidence undermines the claims of Harris (1998, 2006) and Rowe (1994) that family environments do not matter in determining child outcomes.[52] Programs like the Perry Program and the Nurse Family Partnership Program supplement family life in the early years and have substantial lasting effects on participants.

3 Modeling Human Capability Formation

Cunha and Heckman (2007b) and Heckman (2007) develop models of capability formation, that interpret and crystallize the body of evidence summarized in Section 2. This section summarizes the main ingredients of their research and relates it to previous work on skill formation.

An agent at age t is characterized by a vector of capabilities $\theta_t=(\theta_t^C, \theta_t^N, \theta_t^H)$, where θ_t^C is a vector of cognitive abilities (e.g., IQ) at age t, θ_t^N is a vector of noncognitive abilities at age t (e.g., patience, self control, temperament, risk aversion, and neuroticism), and θ_t^H is a vector of health stocks for mental and physical health at age t. Capabilities are produced by investment, environments and genes. Capabilities are weighted differently in different tasks in the labor market and in social life more generally. The principle of comparative advantage explains why there is specialization in tasks and roles in life. The model has four main ingredients: (a) outcome functions that show how capabilities, effort and incentives affect outcomes; (b) dynamic technologies for producing capabilities; (c) parental preferences; and (d) constraints

[51]Note that the scales are different for the treatment effects of males and females.

[52]For additional evidence against the Harris-Rowe hypothesis, see Collins, Maccoby, Steinberg, Hethering-ton, and Bornstein (2000).

reflecting access to financial markets. Some ingredients are well researched. Others are not and offer interesting research challenges.

3.1 Formal Models of Child Outcomes and Investment in Children

Outcomes in childhood and adulthood are defined generally. They include, among other things, wages, occupational choices, criminal activity, as well as test scores. One can think of them as behavioral "phenotypes" for a variety of behaviors generated by capability "genotypes." They are all manifestations of θ_t in the context in which they are measured. The *outcome from activity k at age t* is Y_t^k, where

$$Y_t^k=\psi_k(\theta_t^C, \theta_t^N, \theta_t^H, e_t^k), \quad k \in \{1, \ldots, K\} \tag{1}$$

where e_t^k is effort devoted to activity k at time t where the effort supply function depends on rewards and endowments:

$$e_t^k=\delta_k(R_t^k, A_t) \tag{2}$$

where R_t^k is the reward per unit effort in activity k and A_t represents other determinants of effort which might include some or all of the components of θ_t. It is likely that the effort supply function is increasing in R_t^k.

An active body of research investigates the role of capabilities in producing outcomes. (See, e.g., Bowles et al., 2001; Heckman et al., 2006; and Dohmen et al., 2007.) Different outcomes are affected more strongly by some components of θ_t than others. Schooling attainment at age t depends more strongly on θ_t^C than does earnings at age t. Conscientiousness, a component of θ_t^N, promotes health[53] Because the mapping of traits to outputs differs among capabilities, there is comparative advantage in activities. Recall the evidence previously cited on the effects of cognitive and noncognitive factors in determining occupational choice and other activities.

The outcome functions instruct us that there may be many ways to achieve a level of performance on a given task. For example, both cognitive and personality traits determine earnings. One can compensate for a shortfall in one dimension by having greater strength in the other. To get better grades or test scores from students at a point in time, one can pay them to perform well (increase R_t^k), build capabilities such as motivation and cognition or one can give students incentives to acquire capabilities. Approaches that build capabilities are more likely to have lasting effects on student achievement.[54] People paid to do well on one task often do not repeat their performance in subsequent assessments of the task for which they are not compensated.[55]

[53]Hampson, Goldberg, Vogt, and Dubanoski (2007) show how health outcomes are affected by noncognitive traits. See Hampson and Friedman (2008).

[54]The pay-for-grades movement is built on an implicit "learning by doing" assumption — that effort in studying to get good grades in period t raises the stock of skills in future periods. An alternative model is an "on the job training" model in which the effort devoted to getting good grades competes with, rather than fosters, the effort required to produce future capabilities, *i.e.* grade grubbing is a different activity than learning. See Heckman, Lochner, and Cossa (2003) for one discussion of learning by doing vs. on the job training models.

[55]See Deci and Ryan (1985); Ryan, Koestner, and Deci (1999); Gneezy (2004); and Deci, Koestner, and Ryan (2001). There is some evidence that participants do *worse* than baseline—no payment performance after payment is withdrawn. For an extensive discussion of the failure of payment for performance systems in education, see Kohn (1993).

The capability formation process is governed by a multistage technology. Each stage corresponds to a period in the life cycle of a child. Previous research on the family (e.g., Becker and Tomes, 1986; Benabou, 2002) treats childhood as a single period. That approach does not capture the notion of critical and sensitive periods in childhood and the essential early-late distinction that is a central feature of the recent literature on child development.

The *technology of capability formation* (Cunha and Heckman, 2007b; Heckman, 2007) captures essential features of human and animal development. It expresses the stock of period $t + 1$ capabilities (θ_{t+1}) in terms of period t capabilities (θ_t), investments, (I_t), and parental environments (θ_t^P):

$$\theta_{t+1}=f_t(\theta_t, I_t, \theta_t^P). \tag{3}$$

θ_0 is the vector of initial endowments determined at birth or at conception. The technology is assumed to be increasing in each argument, twice differentiable, and concave in I_t.

A crucial feature of the technology that helps to explain many findings in the literature on skill formation is *complementarity of capabilities with investment:*

$$\frac{\partial^2 f_t(\theta_t, I_t, \theta_t^P)}{\partial\theta_t \partial I_t'} \geq 0. \tag{4}$$

Technology (3) is characterized by *static complementarity* between period t capabilities and period t investment. For example, people who are more open to experience, more motivated or healthier acquire more capability (θ_{t+1}) from the same investment input.[56]

There is also *dynamic complementarity* because technology (3) determines period $t + 1$ capabilities (θ_{t+1}). This generates complementarity between investment in period t and investment in period s, $s > t$. Higher investment in period t raises θ_{t+1} because technology (3) is increasing in I_t. This in turn raises θ_s because the technology is increasing in θ_τ, for τ between t and s. This, in turn, raises $\frac{\partial f_s(\cdot)}{\partial I_s}$ because θ_s and I_s are complements, as a consequence of (4). Dynamic complementarity explains the evidence that early nurturing environments affect the ability of animals and humans to learn.[57] It explains why investments in disadvantaged young children are so productive. They enhance the productivity of later investments. Dynamic complementarity also explains why investment in low ability adults often has such low returns —because the stock of θ_t is low.

Using dynamic complementarity, one can define *critical* and *sensitive* periods for investment. If $\frac{\partial f_t(\cdot)}{\partial I_t}=0$ for $t \neq t^*$, t^* is a critical period for that investment. If $\frac{\partial f_t(\cdot)}{\partial I_t}>\frac{\partial f_{t'}(\cdot)}{\partial I_{t'}}$ for all $t \neq t^*$, t^* is a sensitive period.[58] The technology is consistent with the body of evidence on critical and sensitive periods summarized in section 2.5.

Adult choices and outcomes are shaped by *sequences* of investments over the life cycle of the child. The importance of the early years on later life outcomes depends on how easy it is to reverse adverse early effects with later investment. The accumulation of investments over the

56See Currie (2008) for evidence on health.

57See the evidence in Knudsen, Heckman, Cameron, and Shonkoff (2006).

58These ideas are stated formally in Web Appendix B, where two related, but conceptually distinct, definitions of sensitive periods are presented.

life cycle of the child determines adult outcomes and the choices people will make when they become adults.

The technology can be used to formally model what resilience theorists in developmental psychology discuss when they analyze the effectiveness of later investments to remediate early adversity. This framework guides precise thinking about the costs of remediation vs. the costs of initial investment to achieve a given level of performance on adult outcomes. The technology allows analysts to discuss developmental "cascades" — how events (investments) propagate through life.[59]

Special cases of (3) are the bases for entire subfields of social science. For example, influential models in criminology by Nagin (2005) and Nagin and Tremblay (1999) represent the lifecycle evolution of criminal propensities as a special case of (3) that excludes investment: $f_t(\theta_t, I_t, \theta_t^P) = f_t(\theta_0, \theta_0^P)$, for all $t \geq 0$. Initial conditions fully determine adult criminality. Their manifestation differs by age. These studies ignore investment and the phenomenon of resilience.[60]McArdle, Ferrer-Caja, Hamagami, and Woodcock (2002) model fluid and crystallized intelligence and their life cycle evolution as a special case of this model where $f_t(\theta_t, I_t, \theta_t^P) = f_t(\theta_0)$, and $\theta_t = \theta_t^C$, a vector. There is no role in their framework for investment or parental environmental factors. Ability is determined by initial conditions.

A third ingredient of any model of capability formation is *preferences*. Agents have preferences over child outcomes. The investing agent may be a parent or the child itself. Very little is known about what dimensions of child outcomes parents care about. Even less is known about parental preferences $V^P(\cdot)$ over these outcomes (see, e.g., Bergstrom, 1997). Parents may only value specific arguments of child preference functions rather than child utilities—the theme of many novels on parent-child conflict. Very little is known about how marriage and divorce affect $V^P(\cdot)$ (see, e.g., Weiss and Willis, 1985, Pollak, 1988, Becker, 1991, Behrman et al., 1995 and Bergstrom, 1997 for discussions of family preferences toward children).[61]

The mechanisms through which child preferences are formed are not well understood. Becker and Mulligan (1997) and the papers cited in Borghans, Duckworth, Heckman, and ter Weel (2008) discuss these issues. To the extent that θ_t can be linked to preferences as measured by psychological traits, the analyses of Cunha and Heckman (2007b, 2008) model preference formation, where preference is one of the capabilities formed through parental investment.

A fourth ingredient of any model of capability formation is *family resources and market constraints*. It is analytically useful to distinguish three types of market constraints: (i) the inability of parents to borrow against their own future income; (ii) the inability of parents to borrow against their child's future income, and (iii) the inability of the child to buy a good parent (or insure against a bad parent). Constraint (iii) is universally binding. The strength of the other constraints depends on the level of development of financial institutions in the society in which the family resides.

Cunha and Heckman (2007b) develop an intergenerational model with all four ingredients building on the model of Laitner (1992). We exposit their work in Web Appendix D.[62]

---

[59]See Masten and Coatsworth (1998), Masten (2004), and Masten, Burt, and Coatsworth (2006).

[60]Sampson and Laub (2003) dispute the Nagin and Tremblay (1999) specification, essentially introducing investment as a determinant of "desistence," i.e., recovery from adverse initial conditions.

[61]This issue is distinct from the effect of marriage and divorce on the level of resources spent on children.

[62]Cunha, Heckman, Lochner, and Masterov (2006) and Cunha and Heckman (2007b) survey the evidence on family credit constraints. See also Belley and Lochner (2007).

3.2 A Specific Technology of Capability Formation

The technology of capability formation is a central concept in the recent literature. Preferences, endowments, expectations and market structures together determine levels of inputs. The technology defines what is possible from inputs, irrespective of the investment levels chosen. It limits the possibilities for development and remediation. Cunha, Heckman, and Schennach (2008) present a flexible econometric framework that allows for l different developmental stages in the life of the child: $l \in \{1, \ldots, L\}$. Developmental stages may be defined over specific ranges of ages, $t \in \{1, \ldots, T\}$, so $L \leq T$. Assume that $\theta_t^C, \theta_t^N, \theta_t^H$, I_t and θ_t^P are scalars. Let I_t^j be investment in capability j at time t. The technology for producing capability j at stage l is

$$\theta_{t+1}^j = \left[\gamma_{C,l}^j (\theta_t^C)^{\varphi_l^j} + \gamma_{N,l}^j (\theta_t^N)^{\varphi_l^j} + \gamma_{H,l}^j (\theta_t^H)^{\varphi_l^j} + \gamma_{I,l}^j (I_t^j)^{\varphi_l^j} + \gamma_{P,l}^j (\theta_t^P)^{\varphi_l^j} \right]^{\frac{1}{\varphi_l^j}},$$
$$1 \geq \varphi_l^j, \gamma_{k,l}^j \geq 0, \quad \sum_k \gamma_{k,l}^j = 1 \text{ for all } j \in \{C, N, H\}, l \in \{1, \ldots, L\}, \text{ and } t \in \{1, \ldots, T\}. \quad (5)$$

This technology imposes the assumption of equal elasticity of substitution among all of the inputs for each capability at each stage, but allows for different substitutability of inputs for either different capabilities at the same stage or the same capability at different stages.[63] The ability to substitute may change over childhood, reflecting the basic biological determinants of development. Technology (5) imposes the assumption of direct complementarity among all inputs. Higher levels of parental environmental capital or stocks of capabilities raise the productivity of investment at stage l. *Ceteris paribus*, higher values of the parameters $\gamma_{I,l}^j$, $j \in \{C, N, H\}$ at earlier stages imply that early investment is more productive at those stages. Knowledge of the parameters of technology (5) is informative about the productivity of investment and remediation at different ages and stages of the life cycle. Children with high levels of parental environmental variables (θ_t^P) may be resilient to adversity even though they receive low levels of I_t^j. For a child born into a family with low levels of parenting skills, supplementary investment programs may only partially alleviate disadvantage.[64]

The substitution parameters φ_l^j, $j \in \{C, N, H\}$, $l \in \{1, \ldots, L\}$, are important for understanding the impact of early disadvantage and the effectiveness of later remediation. At any age t associated with stage l, and for fixed $\{\gamma_{k,l}^j\}$, $k \in \{C, N, H, I, P\}$, φ_l^j is informative on the substitutability of I_t^j for stocks of skills at age t, i.e. it informs us how easy it is to remedy early disadvantage as embodied in θ_t^P (parental environment) or θ_t^j, $j \in \{C, N, H\}$. Higher values of φ_l^j make it less easy to remediate. A main finding of Cunha, Heckman, and Schennach (2008) is that φ_l^C decreases with l. This is consistent with the evidence on the declining malleability of IQ with age, i.e., that cognitive deficits are easier to remedy at early ages than at later ages. They also find that φ_l^N increases with l. This implies that remediation in the adolescent years through noncognitive investments may be effective even if remediation through cognitive investments is not, a point we illustrate below.[65]

---

63 More precisely, $\varphi_l^C \neq \varphi_l^N, \varphi_l^C \neq \varphi_l^H, \varphi_l^H \neq \varphi_l^N$ and $\varphi_l^j \neq \varphi_{l'}^j$, $l' \neq l$, $j \in \{C, N, H\}$. Complementarity at stage l for capability j requires that $\varphi_l^j < 1$.

64 This is a manifestation of credit constraint (iii) discussed in Section 3.1.

65 It is also broadly consistent with the emergence of certain noncognitive traits at later ages, as discussed in Borghans, Duckworth, Heckman, and ter Weel (2008).

3.3 An Informative Special Case

To fix ideas, consider a special case of the technology where we ignore health and parental inputs:

$$\theta_{t+1}^{C}=\left[\gamma_{C,l}^{C}(\theta_t^C)^{\varphi_l^C}+\gamma_{N,l}^{C}(\theta_t^N)^{\varphi_l^C}+\gamma_{I,l}^{C}(I_t^C)^{\varphi_l^C}\right]^{\frac{1}{\varphi_l^C}}, \tag{6}$$

and

$$\theta_{t+1}^{N}=\left[\gamma_{C,l}^{N}(\theta_t^C)^{\varphi_l^N}+\gamma_{N,l}^{N}(\theta_t^N)^{\varphi_l^N}+\gamma_{I,l}^{N}(I_t^N)^{\varphi_l^N}\right]^{\frac{1}{\varphi_l^N}}, \quad t\in\{1,\ldots,T\}. \tag{7}$$

To complete this example, assume that the adult outcome is a scalar. It is a *CES* function of the two capabilities accumulated through period T, the end of childhood. The adult outcome for period $T + 1$ is

$$Y_{T+1}=\left[\alpha(\theta_{T+1}^C)^{\varphi^Y}+(1-\alpha)(\theta_{T+1}^N)^{\varphi^Y}\right]^{\frac{1}{\varphi^Y}}, \tag{8}$$

where $\alpha \in [0, 1]$ and $\varphi^Y \in (-\infty, 1]$.[66] In this parameterization, $1/(1-\varphi^Y)$ is the elasticity of substitution across different skills in the production of the adult outcome. α measures the share of the cognitive factor in explaining adult outcomes.

For the special case where $\varphi_l^C=\varphi_l^N=\varphi^Y=\varphi$ for all $l \in \{1, \ldots, L\}$, childhood lasts two periods ($T = 2$), there is one period of adult life and there are no period "0" investments, and there is a single investment $I_t^C=I_t^N$, one can write the adult outcome Y_3 in terms of investments, initial endowments, and parental characteristics as

$$Y_3=\left[\tau_1 I_1^{\varphi}+\tau_2 I_2^{\varphi}+\tau_3(\theta_1^C)^{\varphi}+\tau_4(\theta_1^N)^{\varphi}\right]^{\frac{1}{\varphi}}, \tag{9}$$

where the τ_i are defined in terms of the parameters of the technology and outcome equations.[67] Cunha and Heckman (2007b) analyze the optimal timing of investment using a special version of the technology embodied in (9). Adapting their analysis, the ratio of early to late investments varies as a function of φ, τ_1 and τ_2. τ_1 is a multiplier that reveals how much first-period investment affects adult outcomes through its direct effect on the stock of capabilities and its effect on raising second-period investment.

Assume that parents maximize Y_3. Parents decide how much to invest in each period and how much to transfer in risk-free assets, given total parental resources. For an interior solution, assuming that the price of investment is the same in both periods and the interest rate is r,

[66] We abstract from effort and the payment per unit effort in this formulation of the outcome equation.
[67] See Web Appendix B for a derivation and for the precise relationship between τ_i and the parameters of (6), (7), and (8).

$$\log\left(\frac{I_1}{I_2}\right) = \left(\frac{1}{1-\varphi}\right)\left[\log\left(\frac{\tau_1}{\tau_2}\right) - \log(1+r)\right]. \tag{10}$$

Figure 5 plots the ratio of early to late investment as a function of τ_1/τ_2 for different values of φ.

If $\tau_1/\tau_2 > (1 + r)$, the greater the *CES* complementarity, (i.e., the lower φ), the lower the ratio of I_1/I_2. In the limit, if investments complement each other strongly ($\varphi \to -\infty$) optimality implies that they should be equal in both periods. The higher is τ_1 relative to τ_2, the higher the first-period investments should be relative to second-period investments. The parameters τ_1 and τ_2 are affected by the productivity of investments in producing skills, which is governed by the parameters $\gamma_{k,l}^{j}$, for $l \in \{1,2\}$, $j \in \{C,N\}$ and $k \in \{C, N, I\}$, as well as the relative importance of cognitive skills, α, versus noncognitive skills, $1 - \alpha$, to produce the adult reward Y_3.

To see how these parameters affect the ratio of early to late investments, suppose that early investments only produce cognitive skills, so that $\gamma_{I,1}^{N}=0$, and late investments only produce noncognitive skills, so that $\gamma_{I,2}^{C}=0$. In this case, the ratio τ_1/τ_2 is

$$\frac{\tau_1}{\tau_2} = \frac{(\alpha\gamma_{C,1}^{C} + (1-\alpha)\gamma_{C,1}^{N})}{(1-\alpha)}\left(\frac{\gamma_{I,1}^{C}}{\gamma_{I,2}^{N}}\right).$$

For a given value of α, I_1/I_2 should be higher the greater is the ratio $\gamma_{I,1}^{C}/\gamma_{I,2}^{N}$. To investigate the role that α plays in determining the distribution of investment between early and late periods, assume that $\gamma_{C,1}^{C} \geq \gamma_{C,1}^{N}$, that is, that stocks of cognitive skills, θ_1^C, are at least as effective in producing next-period cognitive skills, θ_2^C, as in producing next-period noncognitive skills, θ_2^N. Under these assumptions, the higher α, that is, the more important are cognitive skills in producing Y_3, the higher the equilibrium ratio I_1/I_2. If, on the other hand, Y_3 is intensive in noncognitive skills, then relatively more investment should be directed to later periods.

3.4 Relationship of this Research to Previous Work on Child Skill Formation

In a seminal paper, Becker and Tomes (1986) analyze the intergenerational transmission of earnings, assets, and consumption. As part of their analysis, they consider parental investments in child skills. They analyze a one-period model of childhood and do not make the early-late distinction that is a crucial feature of child development. They assume that θ_t is one-dimensional, corresponding to general human capital, and do not distinguish among personality, cognition and health, which are essential and separate components of the human development process. They assume that child human capital endowments (the initial conditions of childhood) are not affected by parental investment, and are exogenous to their analysis. They assume a model of pure parental altruism under different assumptions about the ability of parents to borrow against future income. The empirically appropriate models for parental preferences and the credit markets that parents and children face are actively debated.

Leibowitz (1974) is a pioneering study of the role of family investment in generating child outcomes. She applies a variant of the Ben-Porath (1967) model of human capital accumulation to explain investments in children. Her empirical analysis uses maternal endowments (θ_t^P) as proxies for investments (I_t^j). As discussed in Web Appendix C to this paper, the Ben-Porath technology is a special case of technologies (3) and (5), which analyzes a scalar θ_t. It excludes stage-specific technologies, and the possibility that qualitatively different investments are used at different stages. Such features are required to rationalize the evidence on human and animal development.[68] Ben-Porath's model features the opportunity cost of time as an essential ingredient. For the analysis of parental investment in young children in advanced societies where child labor is atypical, the opportunity costs of a child's time are irrelevant. Ben-Porath assumes a Cobb-Douglas production function, which imposes a unitary elasticity of substitution among inputs that, as we show next, is inconsistent with the evidence from recent studies.

4 Estimating the Technology of Capability Formation

It would be nice to be able to report parameter estimates and policy implications of a full dynastic model of family investment, complete with convincing evidence on the structure of parental and child preferences and an investigation of the impact of alternative credit market arrangements on child outcomes. Unfortunately, all of the ingredients of the model of Section 3 are not yet empirically determined. Borghans, Duckworth, Heckman, and ter Weel (2008) summarize a body of empirical work on outcome equation (1) relating adult outcomes to personality and cognition. This paper reports on the progress that has been made in determining the technology of capability formation (3). The technology is the building block for a wide class of models irrespective of parental preferences and constraints. It defines what is technologically possible.

Cunha and Heckman (2008) estimate linear approximations to the technologies of skill formation (3).[69] Such approximations are easy to compute and analyze. However, linearity assumes perfect substitution among the inputs.[70] Models that impose specific substitution assumptions onto the data are not reliable guides for addressing the effectiveness of policies related to substitution, compensation and remediation. We discuss the implications from nonlinear models that identify substitution relationships after discussing the evidence from linear models.

Cunha and Heckman (2008) estimate the model

$$\theta_{t+1}=A_t\theta_t+B_tI_t+\eta_t, \tag{11}$$

where η_t is an unobserved shock.[71,72] The main problem that arises in estimating the technology is that vector (θ_t, I_t) is not directly observed. Cunha and Heckman (2008) treat (θ_t, I_t) as a vector of unobserved factors and use a variety of measurements of the latent constructs to proxy these factors. There is a substantial body of econometric work on linear factor models (see, e.g., Aigner et al., 1984). These models account for measurement errors in

[68]Cunha, Heckman, and Schennach (2008) show that the single-stage, one-skill, Ben Porath model is not consistent with their evidence on child development.

[69]One can interpret their estimates as log-linear approximations to the true technology if the components of θ_t, I_t and θ_t^P are expressed in logs.

[70]Since different scales (transformations) can be used for input measures, strict linearity in the original measurements is not required. Thus a Cobb-Douglas production function assumes perfect substitutability among the logs of inputs.

[71]Pfeiffer and Reuß (2008) report estimates of a related age-dependent technology of cognitive skill formation.

[72]Todd and Wolpin (2005, 2007) estimate linear models of ability (achievement test) formation but do not separate out cognitive from noncognitive components.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

the proxies which Cunha and Heckman (2008) find to be quantitatively large. If they are not accounted for, estimates of technology parameters are substantially biased.

In addition to the problem of measurement error, there is the problem of setting the scale of the factors and the further problem that elements of (θ_t, I_t) are likely correlated with the shock η_t. These problems are addressed by Cunha and Heckman (2008) using rich sources of panel data which provide multiple measurements on (θ_t, I_t). They use a dynamic state-space version of a "MIMIC" model.[73] In the linear setting, it is assumed that multiple measurements on inputs and outputs can be represented by a linear factor setup:

$$Y_{j,t}^{k}=\mu_{j,t}^{k}+\alpha_{j,t}^{k}\theta_{t}^{k}+\varepsilon_{j,t}^{k},\ \text{for } j\in\{1,\ldots,M_{t}^{k}\},k\in\{C,N,H,I\}, \quad (12)$$

where M_t^k is the number of measurements on latent factor k, and θ_t^I is latent investment at age t. They anchor the scales of the components of θ_t using outcome equations (1).

This approach generalizes to a nonlinear semiparametric framework. Equations (1) and (3) can be interpreted as general nonlinear factor models defined in terms of θ_t and I_t.[74] Cunha, Heckman, and Schennach (2008) generalize this framework to a nonlinear setup to identify technology (5). They present original results on identification of dynamic factor models in nonlinear frameworks.

4.1 Model Identification

As is standard in factor analysis, Cunha and Heckman (2008) use covariance restrictions to identify technology (11). Low dimensional (θ_t, I_t) (associated with preferences, abilities and investment) are proxied by numerous measurements for each component.

Treating each of a large number of measurements on inputs as separate inputs creates a problem for instrumental variables analyses of production functions. It is easy to run out of instruments for each input. Such an approach likely also creates collinearity problems among the inputs.

Cunha and Heckman avoid these problems by assuming that clusters of measurements proxy the same set of latent variables. Measurements of a common set of factors can be used as instruments for other measurements on the same common set of factors. Methods based on covariance restrictions and cross-equation restrictions provide identification and account for omitted inputs that are correlated with included inputs.[75] These methods provide an econometrically justified way to aggregate inputs into low-dimensional indices.

4.2 Empirical Estimates from the Linear Model

Cunha and Heckman (2008) estimate technology (11) using a sample of white males from the Children of the NLSY data (CNLSY).[76] These data provide multiple measurements on investments and cognitive and noncognitive skills at different stages of the life cycle of the

[73]See Jöreskog and Goldberger (1975). MIMIC stands for Multiple Indicators and Multiple Causes. Harvey (1989) and Durbin, Harvey, Koopman, and Shephard (2004) are standard references for dynamic state space models, which generalize MIMIC models to a dynamic setting.

[74]Nonlinear factor models are generated by economic choice models where risk aversion, time preference, and leisure preferences are low-dimensional factors that explain a variety of consumer choices.

[75]See Web Appendix E for an intuitive introduction to the identification strategy used in this work. See Abbring and Heckman (2007) for a comprehensive discussion of this approach.

[76]See Center for Human Resource Research (2006).

child. Table 1, extracted from their paper, reports estimates of technology (11). The scales of the factors in θ_t are anchored in log earnings.[77] They account for endogeneity of parental investment. Doing so substantially affects their estimates.

Their estimates show strong self-productivity effects (lagged coefficients of own variables) and strong cross-productivity of effects of noncognitive skills on cognitive skills (personality factors promote learning; those open to experience learn from it). The estimated cross-productivity effects of cognitive skills on noncognitive skills are weak. Contrary to models in criminology and psychology that assign no role to investment in explaining the life cycle evolution of capabilities, Cunha and Heckman (2008) find strong investment effects. Remediation and resilience are possible. Capabilities evolve and are affected by parental investment. Investment affects cognitive skills more at earlier ages than at later ages. Investment affects noncognitive skills more in middle childhood. This evidence is consistent with the literature in neuroscience on the slow maturation of the prefrontal cortex which governs personality development and expression, and the emergence of more nuanced manifestations of personality with age.

One way to interpret these estimates is to examine the impacts of investment at each age on high school graduation and adult earnings.[78] These outcomes depend differently on cognition and personality. Schooling attainment is more cognitively weighted than earnings.

The estimated effects of a ten percent increase in investment are reported in Table 2(a), for earnings, and Table 2(b), for high school graduation. Increasing investment in the first stage by 10% increases adult earnings by 0.25%. The increase operates equally through cognitive and noncognitive skills. Ten percent investment increments in the second stage have a larger effect (.3%) but mainly operate through improving noncognitive skills. Investment in the third stage has weaker effects and operates primarily through its effect on noncognitive skills.

For high school graduation (Table 2(b)), the effects are more substantial and operate relatively more strongly through cognitive skills rather than through noncognitive skills. The sensitive stage for the production of earnings is stage 2. The sensitive stage for producing secondary school graduation is stage 1. This rejects the differential dependence of the outcomes on the two capabilities and the greater productivity of investment in noncognitive skills in the second period compared to other periods. This evidence is consistent with other evidence that shows the greater malleability of noncognitive skills at later ages.[79]

4.3 Measurement Error

Accounting for measurement error substantially affects estimates of the technology of skill formation. This evidence sounds a note of caution for the burgeoning literature that regresses wages on psychological measurements. The share of error variance for proxies of cognition, personality and investment ranges from 30%–70%. Not accounting for measurement error produces downward-biased estimates of self-productivity effects and perverse estimates of investment effects.[80]

4.4 Estimates from Nonlinear Technologies

Linear technologies assume perfect substitutability among inputs in the scale in which investment is measured. Cunha, Heckman, and Schennach (2008) estimate nonlinear

---

[77]See Cunha and Heckman (2008) for a discussion of alternative anchors for θ_t and I_t.

[78]Results for high school graduation as an anchor are reported in Cunha and Heckman (2008).

[79]See Cunha, Heckman, Lochner, and Masterov (2006), Cunha and Heckman (2007b) and Heckman (2008) for a discussion of this evidence.

[80]See Cunha and Heckman (2008), Table 14.

technologies to identify key substitution parameters.[81] The ability to substitute critically affects the design of strategies for remediation and early intervention.

Cunha, Heckman, and Schennach (2008) estimate a version of technology (5) for general φ_l^j, $j \in \{C, N\}$, $l \in \{1, \ldots L\}$ using the same sample as used by Cunha and Heckman (2008).[82] They distinguish two types of maternal skills — cognitive and noncognitive (θ_C^P, θ_N^P)— and introduce both as arguments of the production function.[83] They estimate a two-stage model of childhood (L = 2). Stage 1 is birth through age 4. Stage 2 corresponds to age 5 through 14.

The major findings from their analysis are: (a) Self-productivity becomes stronger as children become older, for both cognitive and noncognitive capability formation. (b) Complementarity between cognitive skills and investment becomes *stronger* as children become older. The elasticity of substitution for cognitive inputs is *smaller* in second stage production.[84] It is more difficult to compensate for the effects of adverse environments on cognitive endowments at later ages than it is at earlier ages. This finding helps to explain the evidence on ineffective cognitive remediation strategies for disadvantaged adolescents. (c) Complementarity between noncognitive skills and investments becomes *weaker* as children become older. It is easier at *later* stages of childhood to remediate early disadvantage using investments in noncognitive skills.[85]

Cunha, Heckman, and Schennach (2008) report that 34% of the variation in educational attainment in their sample is explained by the measures of cognitive and noncognitive capabilities that they use.[86] Sixteen percent is due to adolescent cognitive capabilities. Twelve percent is due to adolescent noncognitive capabilities.[87] Measured parental investments account for 15% of the variation in educational attainment. These estimates suggest that the measures of cognitive and noncognitive capabilities that they use are powerful, but not exclusive, determinants of educational attainment and that other factors, besides the measures of family investment that they use, are at work in explaining variation in educational attainment.

To examine the implications of their estimates, we draw on their analysis and consider two social planning problems that can be solved from knowledge of the technology of capability formation and without knowledge of parental preferences and parental access to lending markets.[88] The first problem we consider determines the cost of investment required to produce high school attainment for children with different initial endowments of their own and parental capabilities. For the same distribution of endowments, the second problem determines optimal allocations of investments from a fixed budget to maximize aggregate schooling for a cohort of children. We also consider a version of this social planning problem that minimizes aggregate crime.

Suppose that there are H children indexed by $h \in \{1, \ldots, H\}$ Let ($\theta_{1,h}^C, \theta_{1,h}^N$) denote the initial cognitive and noncognitive skills of child h. She has parents with cognitive and noncognitive skills denoted by ($\theta_{C,h}^P, \theta_{N,h}^P$). Let π_h denote additional unobserved determinants of outcomes. Define $\theta_{1,h}=(\theta_{1,h}^C, \theta_{1,h}^N, \theta_{C,h}^P, \theta_{N,h}^P, \pi_h)$ and let $G(\theta_{1,h})$ be its distribution. We draw H people from

[81]They also account for measurement error and endogeneity of family inputs.
[82]They lack data on health.
[83]They establish semiparametric identification of their model, including measurement equations.
[84]It is 1.5 in the 3rst stage and .56 in the second stage. The estimates are precisely determined.
[85]The elasticity of substitution is .54 in the 3rst stage and .77 in the second stage. The estimates are precisely determined.
[86]These are the same measures as used in Cunha and Heckman (2008), which we previously discussed.
[87]The skills are correlated so the marginal contributions of each skill do not add up to 34%.
[88]As previously discussed, all of the parameters required to gauge parental responses to government policy are not yet reliably determined.

the initial distribution $G(\theta_{1,h})$ that is estimated by Cunha, Heckman, and Schennach (2008). The price of investment is assumed to be the same in each period, and is set at unity.

The criterion adopted for the first problem assumes that the goal of society is to get the schooling of every child to a twelfth grade level. The required investments measure the power of initial endowments in determining inequality and the compensation through investment required to eliminate their influence. Let $v(\theta_{1,h})$ be the minimum cost of attaining 12 years of schooling for a child with endowment $\theta_{1,h}$. Assuming a zero discount rate, $v(\theta_{1,h})$ is formally defined by

$$v(\theta_{1,h}) = \min[I_{1,h} + I_{2,h}]$$

subject to a schooling constraint $S(\theta^C_{3,h}, \theta^N_{3,h}, \pi_h) = 12$ where S maps end of childhood capabilities and other relevant factors (π_h) into schooling attainment, and also subject to the technology of capability formation constraint

$$\theta^k_{t+1,h} = f_{k,t}(\theta^C_{t,h}, \theta^N_{t,h}, \theta^P_{C,h}, \theta^P_{N,h}, I_{t,h}, \pi_h) \text{ for } k \in \{C, N\} \text{ and } t \in \{1, 2\},$$

and the initial endowments of the child and her parents. Cunha, Heckman, and Schennach (2008) estimate all of the ingredients needed to perform this calculation. We summarize some of their findings here.

Figure 6 plots the percentage increase in investment over that required for a child with mean parental and personal endowments to attain high school graduation. In analyzing the investment required for child endowments, we set parental endowments at mean values. 80% more investment is required for children with the most disadvantaged personal endowments. The negative percentages shown in Figure 6 for children with high initial endowments is a measure of their advantage.[89] The empirical analysis of Moon (2008) shows that investments *received* as a function of a child's endowments are typically in reverse order from what is required to attain the goal of universal high school graduation. Children born with advantageous endowments typically receive *more* parental investment than children from less advantaged environments.

A more standard social planner's problem maximizes aggregate human capital subject to a budget constraint B. We draw H children from the initial distribution $G(\theta_{1,h})$, and solve the problem of how to allocate finite resources B to maximize the average education of the cohort. Formally, the social planner maximizes aggregate schooling

$$\max \overline{S} = \frac{1}{H} \sum_{h=1}^{H} S(\theta^C_{3,h}, \theta^N_{3,h}, \pi_h)$$

subject to the aggregate budget constraint,

[89]The corresponding figure for children with the most disadvantaged parental endowments is 95%. See Cunha et al, 2008.

$$\sum_{h=1}^{H}(I_{1,h}+I_{2,h})=B,$$

the technology constraint,

$$\theta_{t+1,h}^{k}=f_{k,t}(\theta_{t,h}^{C}, \theta_{t,h}^{N}, \theta_{C,h}^{P}, \theta_{N,h}^{P}, \pi_h) \text{ for } k \in \{C, N\} \text{ and } t \in \{1, 2\},$$

and the initial conditions of the child. Solving this problem, we obtain optimal early and late investments, $I_{1,h}$ and $I_{2,h}$, respectively, for each child h. An analogous social planning problem is used to allocate investments to minimize crime.

Figure 7 shows the profile of early (left-hand side graph) and late (right-hand side graph) investment as a function of endowments. For the most disadvantaged, the optimal policy is to invest a lot in the early years. The decline in investment by level of initial advantage is substantial for early investment. Second-period investment profiles are much flatter and slightly favor more advantaged children. This is a manifestation of the dynamic complementarity that produces an equity-efficiency tradeoff for later stage investment but not for early investment. It is socially optimal to invest more in the second period of the lives of advantaged children than in disadvantaged children. A similar profile emerges for investments to reduce aggregate crime.[90]

The optimal ratio of early-to-late investment depends on the desired outcome, the endowments of children and budget B. Figure 8 plots the density of the ratio of early-to-late investment for education and crime derived by Cunha, Heckman, and Schennach (2008).[91] Crime is more intensive in noncognitive skill than educational attainment, which depends much more strongly on cognitive skills. Because compensation for adversity in noncognitive skills is less costly in the second period than in the first period, while the opposite is true for cognitive skills, it is optimal to weight first-period and second-period investments in the directions indicated in the figure.

These simulations suggest that the timing and level of optimal interventions for disadvantaged children depend on the conditions of disadvantage and the nature of desired outcomes.[92] Targeted strategies are likely to be effective, especially so if different targets weight cognitive and noncognitive traits differently.

4.5 Policy Analysis

Structural models based on latent capabilities facilitate comparisons across diverse intervention programs and diverse outputs of these programs.[93] They offer a scientifically valid alternative to crude metanalyses that force “treatment effects” from diverse programs and diverse populations into a common metric. Outcomes of various treatments can be placed on a common footing using versions of outcome equations (1). For example, Heckman, Malofeeva, Pinto, and Savelyev (2009) decompose outcomes and treatment effects for the Perry Preschool

[90]See Cunha, Heckman, and Schennach (2008). They report investment profiles similar to those displayed in Figure 7 when they plot optimal investment against parental endowments.

[91]The optimal policy is not identical for each h and depends on $\theta_{1,h}$, which varies in the population. The densities reflect this variation.

[92]See Cunha, Heckman, and Schennach (2008) for an extensive discussion of these and other simulations.

[93]This analysis is an application of Heckman and Vytlacil (2007, Appendix A).

Program in terms of their effects on the capabilities (θ_t) that determine outcomes. In this section we provide our vision for counterfactual policy analysis based on the technology of capability formation.

Different programs indexed by q, $q \in \{1, \ldots, Q\}$, provide different packages of investment at stage t, $I_{q,t}=(I^C_{q,t}, I^N_{q,t}, I^H_{q,t})$ at cost $C_{q,t}$. Discounted costs of program q are C_q. The programs affect output θ_{t+1} through production at stage t by technology (3). Using estimated structural models, analysts can compare different programs both in terms of their investment content and in terms of their output. Thus they can determine how different programs affect cognition, personality and health, and can extrapolate out of the sample of programs previously tried to predict the consequences of new programs never previously implemented.

Consider choice among a set of mutually exclusive programs that seek to boost outcomes at the first stage of adulthood, $T + 1$. The goal is to achieve target objective $\overline{Y}^k_{T+1}$, $k \in \{1, \ldots, K\}$, at $T + 1$ by a choice of program q. The problem can be formulated for objective k as

$$\min_{q \in \{1,\ldots,Q\}} C_q \tag{13a}$$

subject to technology constraints, initial endowments and the output constraint

$$Y^k_{T+1}(\theta_{T+1}, e^k_{T+1}) \geq \overline{Y}^k_{T+1}. \tag{13b}$$

A version of this problem is used to generate the cost-minimizing simulations for high school attainment reported in Section 4.4. Observe that some programs may fail to achieve the constraint in (13b). They may have high returns but lack the ability to scale adequately to achieve desired targets.

For programs in place, one may evaluate the costs and benefits of alternatives without determining technology (3) or outcomes (1), as in the traditional approach to program evaluation. However, if only some outcomes of a program are measured, but the investment content of other programs is known, we can construct the missing counterfactual outcomes using the estimated technology (3) and activity outcomes (1) determined on data from the other programs or from observational data like the CNLSY. We can also compare and evaluate a variety of programs never experienced. Characterizing outcomes by their capability content and diverse programs by their investment effect on capabilities, makes it possible to compare diverse outcomes and programs. This framework can be used to compare the effectiveness of historically experienced programs and proposed programs, never previously implemented. This approach can be extended to consider the choice of a portfolio of social programs.

As an application of this approach, consider the goal of reducing aggregate crime. It can be achieved by improving human capabilities or by changing incentives to commit crime. Carneiro and Heckman (2003) compare these strategies and find that for reducing crime, investing in capabilities is cheaper than reducing incentives of potential criminals to commit crime by hiring more police.[94] Our analysis suggests that programs that promote noncognitive skills and that concentrate relatively more investment in the later stages of childhood will be the most effective ones for fighting crime.

[94]Cunha and Heckman (2006) offer a crude prototype for a structural analysis of the Perry Preschool Program.

5 Summary and Conclusion

This paper reviews the evidence from recent research that addresses the origins of inequality and the evolution of the capabilities that partly determine inequality. Both cognitive and noncognitive capabilities are important in producing a variety of outcomes.[95] Noncognitive measurements capture aspects of what Marshall meant by “character.” An emerging literature relates psychological measurements of personality and cognition to economic preference parameters and extends conventional preference specifications in economics.

Comparative advantage is an empirically important feature of economic and social life. The same bundle of personal traits has different productivity in different tasks. Recent empirical work on the technology of capability formation provides an operational empirical framework. Capabilities are not invariant traits and are causally affected by parental investment. Genes and environments interact to determine outcomes. The technology of capability formation rationalizes a large body of evidence in economics, psychology, and neuroscience. Capabilities are self-productive and cross-productive. Dynamic complementarity explains why it is productive to invest in the cognitive skills of disadvantaged young children but why the payoffs are so low for cognitive investments in disadvantaged older children and are even lower for disadvantaged adults. There is no equity-efficiency trade-off for investment in the capabilities of young disadvantaged children. There is a substantial equity-efficiency trade-off for investment in the *cognitive* skills of disadvantaged adolescents and adults. The tradeoff is much less dramatic for investment in the *noncognitive* skills of adolescents. Parental environments and investments affect the outcomes of children. There are substantial costs to uninhibited libertarianism in one generation if the preferences and well-being of the next generation are ignored.[96]

Does recent research suggest an economic justification for the Victorian program that Marshall endorsed? The evidence supports a move in that direction. The preferences, motivations, and skill endowments of adults that are created in part in their childhoods play important roles in creating inequality. They can be influenced, in part, by policy. But, as Marshall argued, incentives matter too. Society can reduce crime and promote well-being by operating at both incentive and investment margins, corresponding, respectively, to the effort allocation function (2), which depends on R_t^k, and the endowment (θ_t) in outcome equation (1).

The right mix of intervention to reduce inequality and promote productivity remains to be determined. The optimal timing of investment depends on the outcome being targeted. The optimal intervention strategies depend on the stage of the life cycle and endowments at each stage. For severely disadvantaged adults with low levels of capabilities, subsidizing work and welfare may be a better response for alleviating poverty than investment in their skills.[97] The substantial heterogeneity in endowments and effects of interventions at different ages suggests that a universal policy to combat the adverse effects of early disadvantage is not appropriate. Optimal investment should be tailored to the specifics that create adversity and to the productivity of investment for different configurations of disadvantage. As research on the economics of capability formation matures, economists will have a greater understanding of how to foster successful people.

[95]Ongoing research suggests that health is an important determinant as well. Health is being integrated into these models. See Conti, Heckman, and Urzua (2009).

[96]See Moynihan (2006).

[97]See Heckman and Masterov (2007).

References

Abbring, JH.; Heckman, JJ. Econometric evaluation of social programs, part III: Distributional treatment effects, dynamic treatment effects, dynamic discrete choice, and general equilibrium policy evaluation. In: Heckman, J.; Leamer, E., editors. Handbook of Econometrics. Vol. 6B. Amsterdam: Elsevier; 2007. p. 5145-5303.

Aigner, DJ.; Hsiao, C.; Kapteyn, A.; Wansbeek, T. Latent variable models in econometrics. In: Griliches, Z.; Intriligator, MD., editors. Handbook of Econometrics. Vol. 2. Elsevier; 1984. p. 1321-1393.Chapter 23

Auld MC, Sidhu N. Schooling, cognitive ability and health. Health Economics 2005 October;14(10): 1019–1034. [PubMed: 16167318]

Barker, DJP. Mothers, Babies and Health in Later Life. 2. Edinburgh: Churchill Livingstone; 1998.

Becker, GS. A Treatise on the Family (Enlarged ed.). Cambridge, MA: Harvard University Press; 1991.

Becker GS, Mulligan CB. The endogenous determination of time preference. Quarterly Journal of Economics 1997 August;112(3):729–58.

Becker GS, Tomes N. Human capital and the rise and fall of families. Journal of Labor Economics 1986 July;4(3 Part 2):S1–S39.

Behrman, JR.; Pollak, RA.; Taubman, P. From Parent to Child: Intrahousehold Allocations and Intergenerational Relations in the United States. Chicago: University of Chicago Press; 1995.

Belley P, Lochner L. The changing role of family income and ability in determining educational achievement. Journal of Human Capital 2007 December;1(1):37–89.

Ben-Porath Y. The production of human capital and the life cycle of earnings. Journal of Political Economy 1967 August;75(4 Part 1):352–365.

Benabou R. Tax and education policy in a heterogeneous agent economy: What levels of redistribution maximize growth and efficiency? Econometrica 2002 March;70(2):481–517.

Benjamin, DJ.; Brown, SA.; Shapiro, JM. Who is 'behavioral'? cognitive ability and anomalous preferences. Cornell University; Ithaca, NY: 2006 May. Unpublished manuscript

Bergstrom, TC. A survey of the theories of the family. In: Rosenzweig, M.; Stark, O., editors. Handbook of Population and Family Economics. Vol. 1A. Amsterdam: North Holland; 1997. p. 21-80.

Borghans L, Duckworth AL, Heckman JJ, ter Weel B. The economics and psychology of personality traits. Journal of Human Resources 2008 Fall;43(4):972–1059.

Borghans, L.; Golsteyn, BHH.; Heckman, JJ. IQ, achievement, and personality. University of Maastricht and University; Chicago: 2008. Unpublished manuscript

Borghans L, Meijers H, ter Weel B. The role of noncognitive skills in explaining cognitive test scores. Economic Inquiry 2008 January;46(1):2–12.

Bowles, S.; Gintis, H. Schooling in Capitalist America: Educational Reform and the Contradictions of Economic Life. New York: Basic Books; 1976.

Bowles S, Gintis H, Osborne M. The determinants of earnings: A behavioral approach. Journal of Economic Literature 2001 December;39(4):1137–1176.

BrooksGunn, J.; Cunha, F.; Duncan, G.; Heckman, JJ.; Sojourner, A. Infant Health and Development Program. Northwestern University; 2006. A re-analysis of the IHDP program. Unpublished manuscript

Camerer, C.; Loewenstein, G.; Rabin, M. Advances in Behavioral Economics. New York: Russell Sage Foundation; 2004.

Cameron SV, Heckman JJ. The dynamics of educational attainment for black, hispanic, and white males. Journal of Political Economy 2001 June;109(3):455–99.

Carneiro, P.; Heckman, JJ. Human capital policy. In: Heckman, JJ.; Krueger, AB.; Friedman, BM., editors. Inequality in America: What Role for Human Capital Policies?. Cambridge, MA: MIT Press; 2003. p. 77-239.

Carneiro P, Heckman JJ, Masterov DV. Labor market discrimination and racial differences in pre-market factors. Journal of Law and Economics 2005 April;48(1):1–39.

Caspi A, McClay J, Mofftt TE, Mill J, Martin J, Craig IW, Taylor A, Poulton R. Role of genotype in the cycle of violence in maltreated children. Science 2002 August;297(5582):851–854. [PubMed: 12161658]

Center for Human Resource Research. NLSY79 Child and Young Adult Data Users Guide: A Guide to the 1986–2004 Child Data and 1994–2004 Youth Data. Columbus, OH: Center for Human Resource Research; 2006 Dec.

Champagne, FA. Epigenetics and the long-term effects of early experience. Presented at the NIA Workshop on Genetic Mechanisms and Life Course Development; Bethesda, MD. February 11–12, 2008; 2008.

Charney DS. Psychobiological mechanisms of resilience and vulnerability: Implications for successful adaptation to extreme stress. American Journal of Psychiatry 2004 February;161(2):195–216. [PubMed: 14754765]

Coleman, JS. Equality of Educational Opportunity. Washington, DC: U.S. Dept. of Health, Education, and Welfare, Office of Education; 1966.

Collins WA, Maccoby EE, Steinberg L, Hetherington EM, Bornstein MH. Contemporary research on parenting: The case for nature and nurture. American Psychologist 2000 February;55(2):218–232. [PubMed: 10717969]

Colvin CR, Funder DC. Predicting personality and behavior: A boundary on the acquaintanceship effect. Journal of Personality and Social Psychology 1991 December;60(6):884–894. [PubMed: 1865326]

Conti, G.; Heckman, JJ.; Urzua, S. The effects of early endowments on labor market outcomes, health, and social behavior. University of Chicago, Department of Economics; 2009. Unpublished manuscript

Costello EJ, Compton SN, Keeler G, Angold A. Relationships between poverty and psychopathology: A natural experiment. Journal of the American Medical Association 2003 October;290(15):2023–2029. [PubMed: 14559956]

Cunha, F. PhD thesis. University of Chicago; 2007. An Essay on Skill Formation.

Cunha, F.; Heckman, JJ. Investing in our young people. University of Chicago, Department of Economics; 2006. Unpublished manuscript

Cunha, F.; Heckman, JJ. The evolution of uncertainty in labor earnings in the U.S. economy. Unpublished manuscript; University of Chicago; 2007a. Under revision

Cunha F, Heckman JJ. The technology of skill formation. American Economic Review 2007b May;97 (2):31–47.

Cunha F, Heckman JJ. Formulating, identifying and estimating the technology of cognitive and noncognitive skill formation. Journal of Human Resources 2008 Fall;43(4):738–782.

Cunha, F.; Heckman, JJ.; Lochner, LJ.; Masterov, DV. Interpreting the evidence on life cycle skill formation. In: Hanushek, EA.; Welch, F., editors. Handbook of the Economics of Education. Vol. Chapter 12. Amsterdam: North-Holland; 2006. p. 697-812.

Cunha, F.; Heckman, JJ.; Schennach, SM. Estimating the technology of cognitive and noncognitive skill formation. Econometrica; Presented at the Yale Conference on Macro and Labor Economics; May 5–7, 2006; University of Chicago, Department of Economics; 2008. Unpublished manuscriptUnder revision

Currie, J. Working Paper 13987. National Bureau of Economic Research; 2008 May. Healthy, wealthy, and wise: Socioeconomic status, poor health in childhood, and human capital development.

Damasio, AR. Descartes' Error: Emotion, Reason, and the Human Brain. New York: Putnam; 1994.

Danese A, Moffitt TE, Pariante CM, Ambler A, Poulton R, Caspi A. Elevated inflammation levels in depressed adults with a history of childhood maltreatment. Archives of General Psychiatry 2008 April;65(4):409–415. [PubMed: 18391129]

Deci EL, Koestner R, Ryan RM. Extrinsic rewards and intrinsic motivation in education: Reconsidered once again. Review of Educational Research 2001 Spring;71(1):1–27.

Deci, EL.; Ryan, RM. Intrinsic Motivation and Self-Determination in Human Behavior. New York: Plenum Press; 1985.

DeLong J, Magin K. The U.S. equity return premium: Past, present and future. Journal of Economic Perspectives 2009 Winter;23(1):193208.

Dohmen, T.; Falk, A.; Huffman, D.; Sunde, U. Are risk aversion and impatience related to cognitive ability?. Discussion Paper 2735; IZA, Bonn, Germany. 2007 Apr.

Durbin, J.; Harvey, AC.; Koopman, SJ.; Shephard, N. State Space and Unobserved Component Models: Theory and Applications: Proceedings of a Conference in Honour of James Durbin. New York NY: Cambridge University Press; 2004.

Edwards RC. Individual traits and organizational incentives: What makes a ‘good’ worker? Journal of Human Resources 1976 Winter;11(1):51–68.

Ellwood, D.; Jencks, C. The uneven spread of single-parent families: What do we know? where do we look for answers?. In: Neckerman, KM., editor. Social Inequality. Vol. Chapter 1. New York: Russell Sage Foundation; 2004. p. 3-78.

Engle PL, Black MM, Behrman JR, Cabral de Mello M, Gertler PJ, Kapiriri L, Martorell R, Eming Young M. The International Child Development Steering Group. Strategies to avoid the loss of developmental potential in more than 200 million children in the developing world. The Lancet 2007 January;369:229–242.

Fraga MF, Ballestar E, Paz MF, Ropero S, Setien F, Ballestar ML, Heine-Suer D, Cigudosa JC, Urioste M, Benitez J, Boix-Chornet M, Sanchez-Aguilera A, Ling C, Carlsson E, Poulsen P, Vaag A, Stephan Z, Spector TD, Wu YZ, Plass C, Esteller M. Epigenetic differences arise during the lifetime of monozygotic twins. Proceedings of the National Academy of Sciences of the United States of America 2005 July;102(30):10604–10609. [PubMed: 16009939]

Frederick S. Cognitive reflection and decision making. Journal of Economic Perspectives 2005 Fall;19 (4):25–42.

Funder DC, Colvin CR. Explorations in behavioral consistency: Properties of persons, situations, and behaviors. Journal of Personality and Social Psychology 1991 May;60(5):773–794. [PubMed: 2072255]

Funder DC, Ozer DJ. Behavior as a function of the situation. Journal of Personality and Social Psychology 1983 January;44(1):107–112.

Georgieff MK. Nutrition and the developing brain: Nutrient priorities and measurement. American Journal of Clinical Nutrition 2007 February;85(2):614S–620S. [PubMed: 17284765]

Ginther DK, Pollak RA. Family structure and children’s educational outcomes: Blended families, stylized facts, and descriptive regressions. Demography 2004 November;41(4):671–696. [PubMed: 15622949]

Gluckman, PD.; Hanson, M. The Fetal Matrix: Evolution, Development, and Disease. Cambridge, UK: Cambridge University Press; 2005.

Gneezy, U. The ‘W’ effect of incentives. University of Chicago, Graduate School of Business; 2004. Unpublished manuscript

Goldberg LR. An alternative ‘description of personality’: The Big-Five factor structure. Journal of Personality and Social Psychology 1990 December;59(6):1216–1229. [PubMed: 2283588]

Grantham-McGregor S, Cheung YB, Cueto S, Glewwe P, Richter L, Strupp B. The International Child Development Steering Group. Developmental potential in the first 5 years for children in developing countries. The Lancet 2007 January;369:60–70. Series, Child development in developing countries.

Hampson, SE.; Friedman, HS. Personality and health: A lifespan perspective. In: John, OP.; Robins, R.; Pervin, L., editors. The Handbook of Personality: Theory and Research. 3. New York: Guilford; 2008. p. 770-794.

Hampson SE, Goldberg LR, Vogt TM, Dubanoski JP. Mechanisms by which childhood personality traits influence adult health status: Educational attainment and healthy behaviors. Health Psychology 2007 January;26(1):121–125. [PubMed: 17209705]

Hansen KT, Heckman JJ, Mullen KJ. The effect of schooling and ability on achievement test scores. Journal of Econometrics 2004 July–August;121(1–2):39–98.

Harris, JR. The Nurture Assumption: Why Children Turn Out the Way They Do. New York: Free Press; 1998.

Harris, JR. No Two Alike: Human Nature and Human Individuality. New York: W.W. Norton and Company; 2006.

Harvey, AC. Forecasting, Structural Time Series Models and the Kalman Filter. New York: Cambridge University Press; 1989.

Heckman JJ. The economics, technology and neuroscience of human capability formation. Proceedings of the National Academy of Sciences 2007 August;104(3):13250–13255.

Heckman JJ. Schools, skills and synapses. Economic Inquiry 2008 July;46(3):289–324. [PubMed: 20119503]

Heckman, JJ.; Lochner, LJ.; Cossa, R. Learning-by-doing versus on-the-job training: Using variation induced by the EITC to distinguish between models of skill formation. In: Phelps, ES., editor. Designing Social Inclusion: Tools to Raise Low-End Pay and Employment in Private Enterprise. Cambridge: Cambridge University Press; 2003.

Heckman, JJ.; Malofeeva, L.; Pinto, R.; Savelyev, PA. The effect of the Perry Preschool Program on the cognitive and non-cognitive skills of its participants. University of Chicago, Department of Economics; 2009. Unpublished manuscript

Heckman JJ, Masterov DV. The productivity argument for investing in young children. Review of Agricultural Economics 2007;29(3):446–493.

Heckman, JJ.; Moon, SH.; Pinto, R.; Savelyev, PA.; Yavitz, AQ. The rate of return to the Perry Preschool program. University of Chicago, Department of Economics; 2009a. Unpublished manuscript

Heckman, JJ.; Moon, SH.; Pinto, R.; Savelyev, PA.; Yavitz, AQ. A reanalysis of the High/Scope Perry Preschool Program. University of Chicago, Department of Economics; 2009b. Unpublished manuscriptFirst draft, September, 2006

Heckman, JJ.; Pinto, R.; Savelyev, PA. Why early education works: Exploring the role of noncognitive skills in determining adult outcomes in the Perry experiment. University of Chicago, Department of Economics; 2009. Unpublished manuscript

Heckman JJ, Rubinstein Y. The importance of noncognitive skills: Lessons from the GED testing program. American Economic Review 2001 May;91(2):145–149.

Heckman JJ, Stixrud J, Urzua S. The effects of cognitive and noncognitive abilities on labor market outcomes and social behavior. Journal of Labor Economics 2006 July;24(3):411–482.

Heckman, JJ.; Vytlacil, EJ. Econometric evaluation of social programs, part I: Causal models, structural models and econometric policy evaluation. In: Heckman, J.; Leamer, E., editors. Handbook of Econometrics. Vol. 6B. Amsterdam: Elsevier; 2007. p. 4779-4874.

Heijmans BT, Tobi EW, Stein AD, Putter H, Blauw GJ, Susser ES, Slagboom PE, Lumey LH. Persistent epigenetic differences associated with prenatal exposure to famine in humans. Proceedings of the National Academy of Sciences 2008 November;105(44):17046–17049.

Herrnstein, RJ.; Murray, CA. The Bell Curve: Intelligence and Class Structure in American Life. New York: Free Press; 1994.

Himmelfarb, G. The De-moralization Of Society: From Victorian Virtues to Modern Values. New York: Alfred A. Knopf; 1995.

Jöreskog KG, Goldberger AS. Estimation of a model with multiple indicators and multiple causes of a single latent variable. Journal of the American Statistical Association 1975 September;70(351):631–639.

Kaestner, R. Adolescent cognitive and non-cognitive correlates of adult health. Institute of Government and Public Affairs, University of Illinois at Chicago, Department of Economics; 2008 Sep. Unpublished manuscript

Knudsen EI. Sensitive periods in the development of the brain and behavior. Journal of Cognitive Neuroscience 2004 October;16(1):1412–1425. [PubMed: 15509387]

Knudsen EI, Heckman JJ, Cameron J, Shonkoff JP. Economic, neurobiological, and behavioral perspectives on building America’s future workforce. Proceedings of the National Academy of Sciences 2006 July;103(27):10155–10162.

Kohn, A. Punished by Rewards: The Trouble with Gold Stars, Incentive Plans, A’s, Praise, and Other Bribes. Boston, MA: Houghton Mifflin Company; 1993.

Laitner J. Random earnings differences, lifetime liquidity constraints, and altruistic intergenerational transfers. Journal of Economic Theory 1992 December;58(2):135–170.

LeDoux, JE. The Emotional Brain: The Mysterious Underpinnings of Emotional Life. New York: Simon and Schuster; 1996.

Leibowitz A. Home investments in children. Journal of Political Economy 1974 March/April;82 (2):S111–S131.

Loewenstein, G. Exotic Preferences: Behavioural Economics and Human Motivation. Oxford, UK: Oxford University Press; 2007.

Marshall, A. Principles of Economics. New York: Macmillan and Company; 1890.

Marshall, A. Preliminary statement and evidence before the Royal Commission on the Aged Poor. In: Keynes, JM., editor. Official Papers. London: Macmillan and Co., Ltd; 1926. Report originally given in 1893

Masten AS. Regulatory processes, risk and resilience in adolescent development. Annals of the New York Academy of Sciences 2004;1021:310–319. [PubMed: 15251901]

Masten, AS.; Burt, KB.; Coatsworth, JD. Competence and psychopathology in development. In: Cicchetti, D.; Cohen, DJ., editors. Developmental Psychopathology: Risk, Disorder, and Adaptation. 2. Vol. 3. Hoboken: John Wiley and Sons, Inc; 2006. p. 696-738.

Masten AS, Coatsworth JD. The development of competence in favorable and unfavorable environments: Lessons from research on successful children. American Psychologist 1998 February;53(2):205–220. [PubMed: 9491748]

Mayer, SE. What Money Can't Buy: Family Income and Children's Life Chances. Cambridge, MA: Harvard University Press; 1997.

McArdle JJ, Ferrer-Caja E, Hamagami F, Woodcock RW. Comparative longitudinal structural analyses of the growth and decline of multiple intellectual abilities over the life span. Developmental Psychology 2002 January;38(1):115–142. [PubMed: 11806695]

McEwen BS. Physiology and neurobiology of stress and adaptation: Central role of the brain. Physiological Review 2007 July;87(3):873–904.

Meaney MJ, Szyf M. Maternal care as a model for experience-dependent chromatin plasticity? Trends in Neurosciences 2005 September;28(9):456–463. [PubMed: 16054244]

Meghir, C.; Palme, M. The effect of a social experiment in education. Technical Report W01/11. Institute for Fiscal Studies; 2001.

Mischel, W. Personality and Assessment. New York: Wiley; 1968.

Mischel W, Shoda Y. A cognitive-affective system theory of personality: Reconceptualizing situations, dispositions, dynamics, and invariance in personality structure. Psychological Review 1995 April; 102(2):246–268. [PubMed: 7740090]

Moffitt, TE. Gene-environment interaction in problematic and successful aging. Presented at the Workshop on Genetic Methods and Life Course Development, National Institute on Aging; Bethesda MD. February 11–12, 2008; 2008.

Moon, SH. PhD thesis. University of Chicago, Department of Economics; 2008. Skill Formation Technology and Multi-Dimensional Parental Investment.

Mosteller, F.; Moynihan, DP., editors. On Equality of Educational Opportunity: Papers Deriving from the Harvard University Faculty Seminar on the Coleman Report. New York: Random House; 1972.

Moynihan, DP. The Future of the Family. New York: Russell Sage Foundation Publications; 2006.

Mueser, PR. The effects of noncognitive traits. In: Jencks, C.; Bartlett, S.; Corcoran, M.; Crouse, J.; Eaglesfield, D.; Jackson, G.; McClelland, K.; Mueser, P.; Olneck, M.; Schwartz, J.; Ward, S.; Williams, J., editors. Who Gets Ahead? The Determinants of Economic Success in America. New York, NY: Basic Books; 1979. p. 122-158.

Murnane RJ, Willett JB, Levy F. The growing importance of cognitive skills in wage determination. Review of Economics and Statistics 1995 May;77(2):251–266.

Nagin, DS. Group-Based Modeling of Development. Boston: Harvard University Press; 2005.

Nagin DS, Tremblay RE. Trajectories of boys' physical aggression, opposition, and hyperactivity on the path to physically violent and nonviolent juvenile delinquency. Child Development 1999 September/October;70(5):1181–1196. [PubMed: 10546339]

Neal DA, Johnson WR. The role of premarket factors in black-white wage differences. Journal of Political Economy 1996 October;104(5):869–895.

Nilsson, JP. Working Paper Series 2008. Vol. 4. Institute for Labour Market Policy Evaluation; 2008 Mar. Does a pint a day affect your child's pay? the effect of prenatal alcohol exposure on adult outcomes.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

O'Connell M, Sheikh H. Achievement-related attitudes and the fate of 'at-risk' groups in society. Journal of Economic Psychology 2008 August;29(4):508–521.

Olds DL. Prenatal and infancy home visiting by nurses: From randomized trials to community replication. Prevention Science 2002 September;3(2):153–172. [PubMed: 12387552]

Pfeiffer F, Reuß K. Age-dependent skill formation and returns to education. Labour Economics 2008;15 (4):631–646.

Phelps EA. Emotion and cognition: Insights from studies of the human amygdala. Annual Review of Psychology 2006 January;57:27–53.

Phelps, EA. The study of emotion in neuroeconomics. In: Glimcher, PW.; Camerer, CF.; Fehr, E.; Poldrack, RA., editors. Neuroeconomics: Decision Making and the Brain. London, UK: Academic Press; 2009. p. 233-250.

Pollak RA. Tied transfers and paternalistic preferences. American Economic Review 1988 May;78(2): 240–44.

Reynolds, AJ.; Temple, JA. Economic returns of investments in preschool education. In: Zigler, E.; Gilliam, W.; Jones, S., editors. A Vision For Universal Preschool Education. New York: Cambridge University Press; 2009. p. 37-68.

Roberts BW. Contextualizing personality psychology. Journal of Personality 2007;75(6):1071–82. [PubMed: 17995457]

Roberts BW, DelVecchio WF. The rank-order consistency of personality traits from childhood to old age: A quantitative review of longitudinal studies. Psychological Bulletin 2000 January;126(1):3–25. [PubMed: 10668348]

Rowe, DC. The Limits of Family Influence: Genes, Experience, and Behavior. New York NY: Guilford Press; 1994.

Rutter, M. Genes and Behavior: Nature–Nurture Interplay Explained. Oxford, UK: Blackwell Publishers; 2006.

Ryan RM, Koestner R, Deci EL. A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation. Psychological Bulletin 1999 November;125(6):627–668. [PubMed: 10589297]

Sampson RJ, Laub JH. Life-course desisters? Trajectories of crime among delinquent boys followed to age 70. Criminology 2003 August;41(3):319–339.

Schuerger JM, Witt AC. The temporal stability of individually tested intelligence. Journal of Clinical Psychology 1989 March;45(2):294–302.

Segal, C. Motivation, test scores, and economic success. Economics working papers, Department of Economics and Business. Universitat Pompeu Fabra; Barcelona, Spain: 2008 Oct.

Shoda Y, Mischel W, Peake PK. Predicting adolescent cognitive and self-regulatory competencies from preschool delay of gratification: Identifying diagnostic conditions. Developmental Psychology 1990 November;26(6):978–986.

Sowell, T. Race and Culture: A World View. New York: Basic Books; 1994.

Suomi, SJ. A biobehavioral perspective on developmental psychopathology: Excessive aggression and serotonergic dysfunction in monkeys. In: Sameroff, AJ.; Lewis, M.; Miller, SM., editors. Handbook of Developmental Psychopathology. Vol. Chapter 13. New York: Kluwer Academic/Plenum; 2000. p. 237-256.

Szyf M. The dynamic epigenome and its implications in toxicology. Toxicological Sciences 2007 November;100(1):7–23. [PubMed: 17675334]

Todd, PE.; Wolpin, KI. Working paper. Penn Institute for Economic Research, Department of Economics, University of Pennsylvania; 2005. The production of cognitive achievement in children: Home, school and racial test score gaps.

Todd PE, Wolpin KI. The production of cognitive achievement in children: Home, school, and racial test score gaps. Journal of Human Capital 2007 Winter;1(1):91–136.

Tucker-Drob EM. Differentiation of cognitive abilities across the lifespan. Developmental Psychology. 2009 Forthcoming.

Turkheimer E, Haley A, Waldron M, D'Onofrio B, Gottesman II. Socioeconomic status modifies heritability of IQ in young children. Psychological Science 2003 November;14(6):623–628. [PubMed: 14629696]

van den Berg, GJ.; Doblhammer-Reiter, G.; Christensen, K. Evidence based on individuals born at different stages of the business cycle. Technical Report 3635. Institute for the Study of Labor; Bonn, Germany: 2008 Aug. Being born under adverse economic conditions leads to a higher cardiovascular mortality rate later in life.

Walker SP, Wachs TD, Gardner JM, Lozoff B, Wasserman GA, Pollitt E, Carter JA. The International Child Development Steering Group. Child development: Risk factors for adverse outcomes in developing countries. The Lancet 2007 January;369:145–157.

Weaver ICG, Cervoni N, Champagne FA, DAlessio AC, Sharma S, Seckl JR, Dymov S, Szyf M, Meaney MJ. Epigenetic programming by maternal behavior. Nature Neuroscience 2004 August;7(8):847–854.

Weiss Y, Willis RJ. Children as collective goods and divorce settlements. Journal of Labor Economics 1985 July;3(3):268–292.

Werner, EE.; Bierman, JM.; French, FE. The Children of Kauai: A Longitudinal Study from the Prenatal Period to Age Ten. Honolulu, HI: University of Hawaii Press; 1971.

Whitaker JK. Some neglected aspects of Alfred Marshall's economic and social thought. History of Political Economy 1977;9(2):161–197.

Whitelaw NC, Whitelaw E. How lifetimes shape epigenotype within and across generations. Human Molecular Genetics 2006 January;15(2):131–137.

Wood D. Using the PRISM to compare the explanatory value of general and role-contextualized trait ratings. Journal of Personality 2007 December;75(6):1103–1126. [PubMed: 17995459]

Wood D, Roberts BW. Cross-sectional and longitudinal tests of the personality and role identity structural model (PRISM). Journal of Personality 2006 June;74(3):779–809. [PubMed: 16684253]

Wößmann L. Efficiency and equity of European education and training policies. International Tax and Public Finance 2008 April;15(2):199–230.

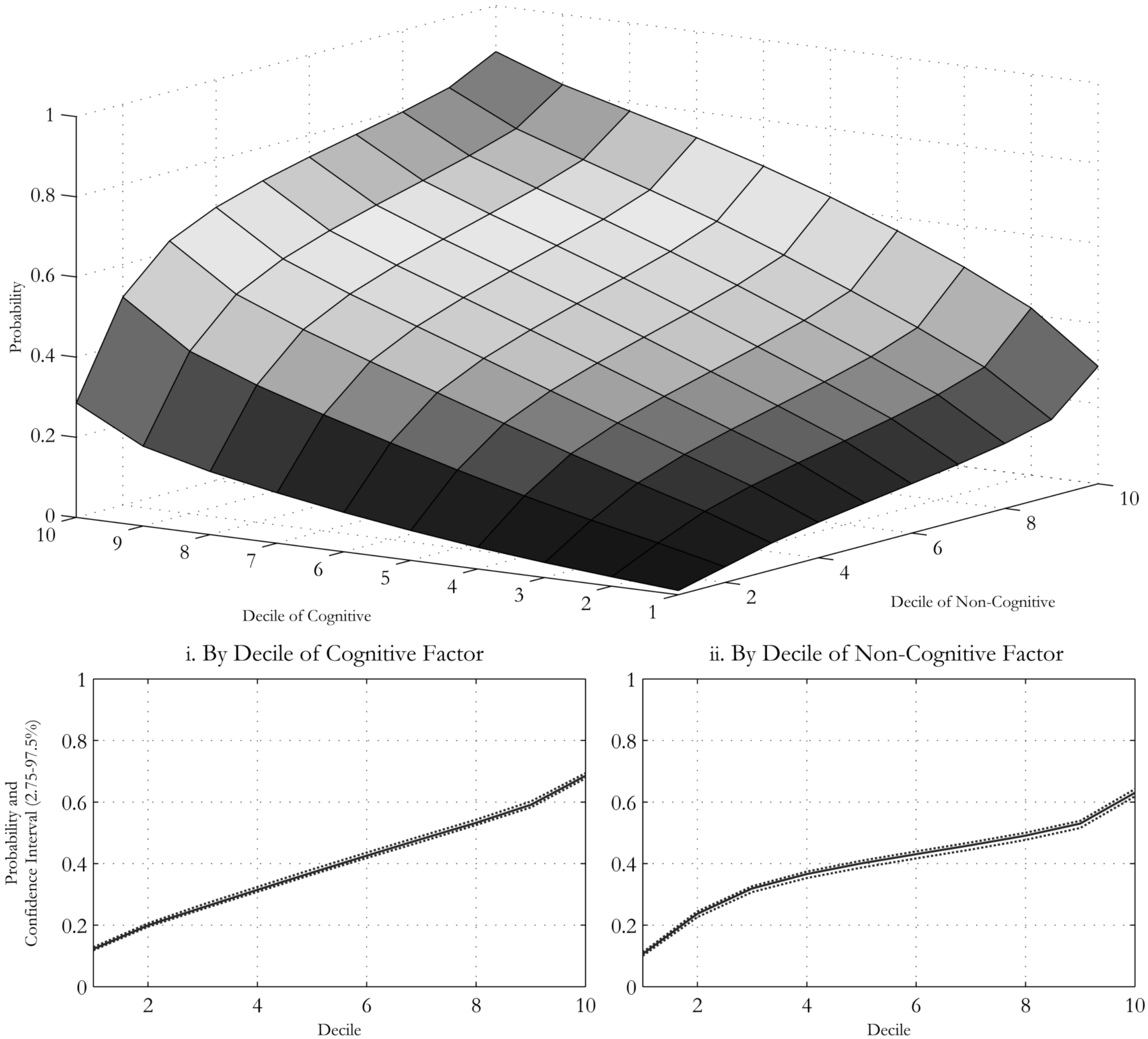


Figure 1.
Probability of being a white collar worker by age 30 (males). Higher deciles are associated with higher values of the indicated variable. Figure (i) and Figure (ii) are marginals derived from the joint distribution by setting the other variable at its mean. Source: Heckman et al. (2006).

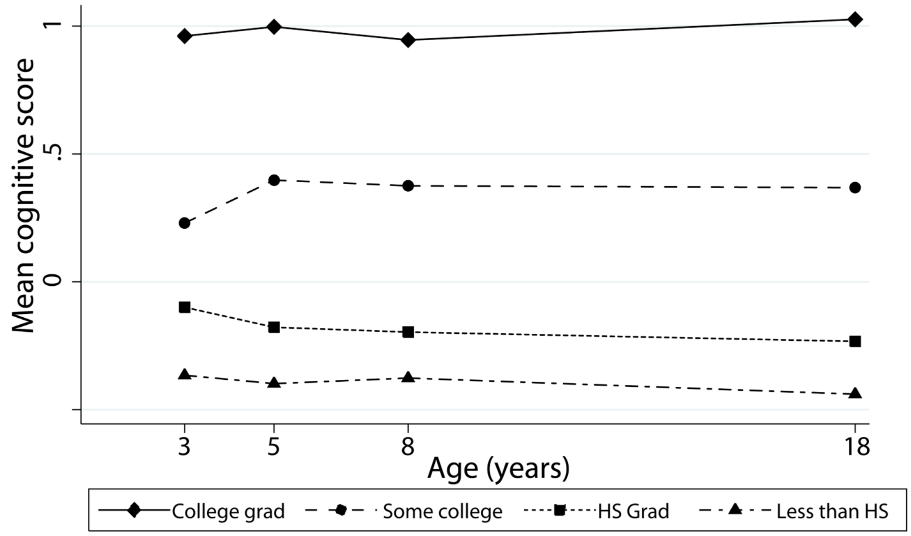
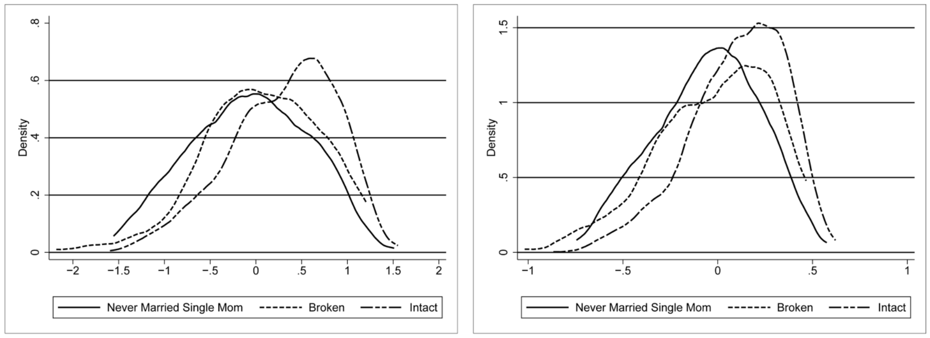


Figure 2.
Trend in mean cognitive score by maternal education. Each score standardized within observed sample. Using all observations and assuming data missing at random. Source: Brooks-Gunn et al. (2006).



(a) Cognitive Stimulation (b) Emotional Support

Figure 3.

Age 0–2, female white children, by family type. Source: Moon (2008) analysis of CNLSY data. Cognitive stimulation is measured by how often parents read to children, and the learning environment in the home. Emotional support is measured by how often child receives encouragement (e.g., meals with parents).

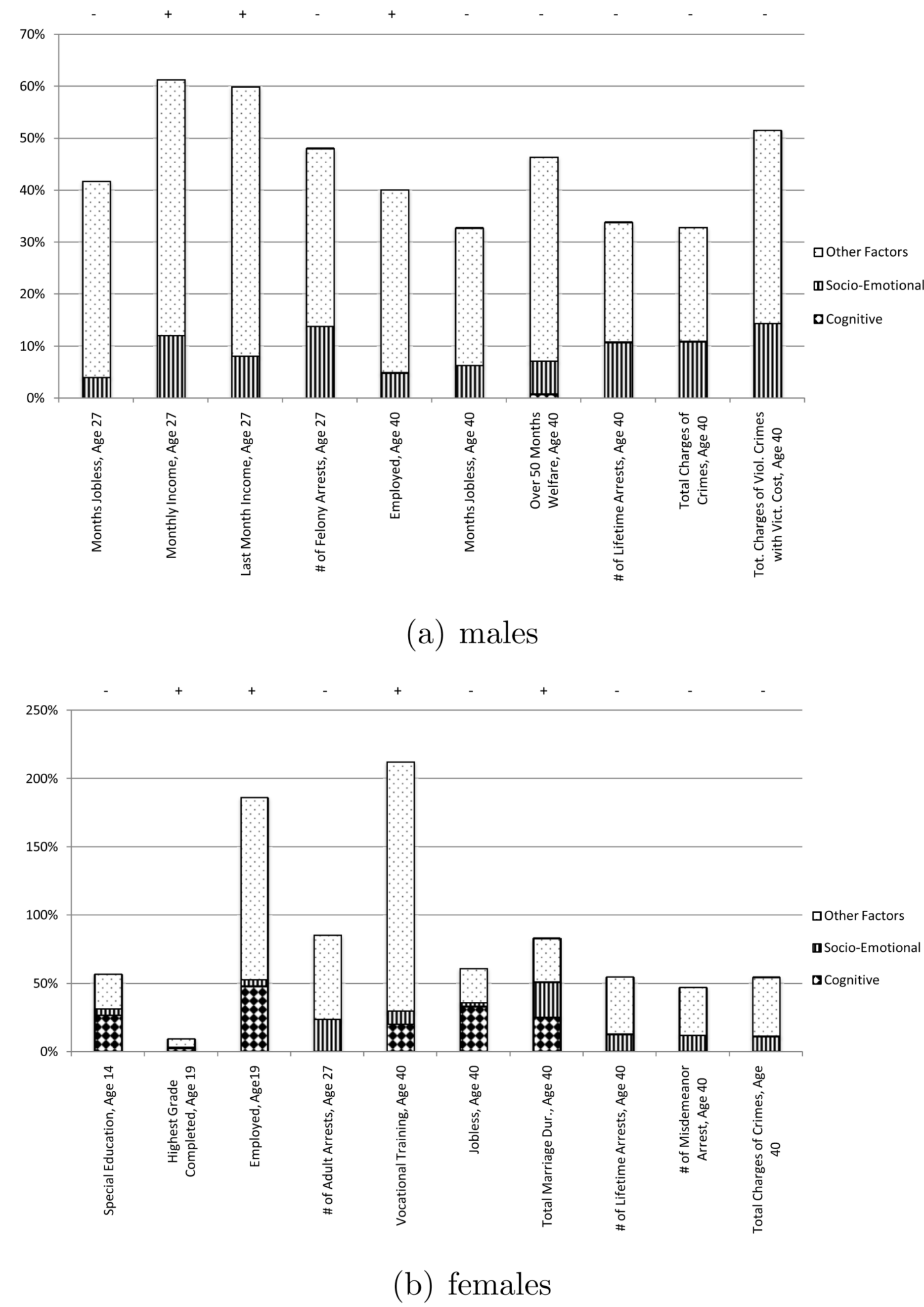


Figure 4.

Decomposition of treatment effects expressed as a percentage gain over control outcomes for selected outcomes by cognitive, socioemotional and other determinants, Perry Preschool Program. Scales differ by gender. Stanford Binet scores at ages 8, 9 and 10 are used as cognitive measures. Scores representing misbehavior at ages 6–9 are used as socioemotional measures. (+) and (−) denote the sign of the total treatment effect. Results are reported for statistically significant treatment effects. The set of statistically significant outcomes differs across gender groups. Source: Heckman, Malofeeva, Pinto, and Savelyev (2009).

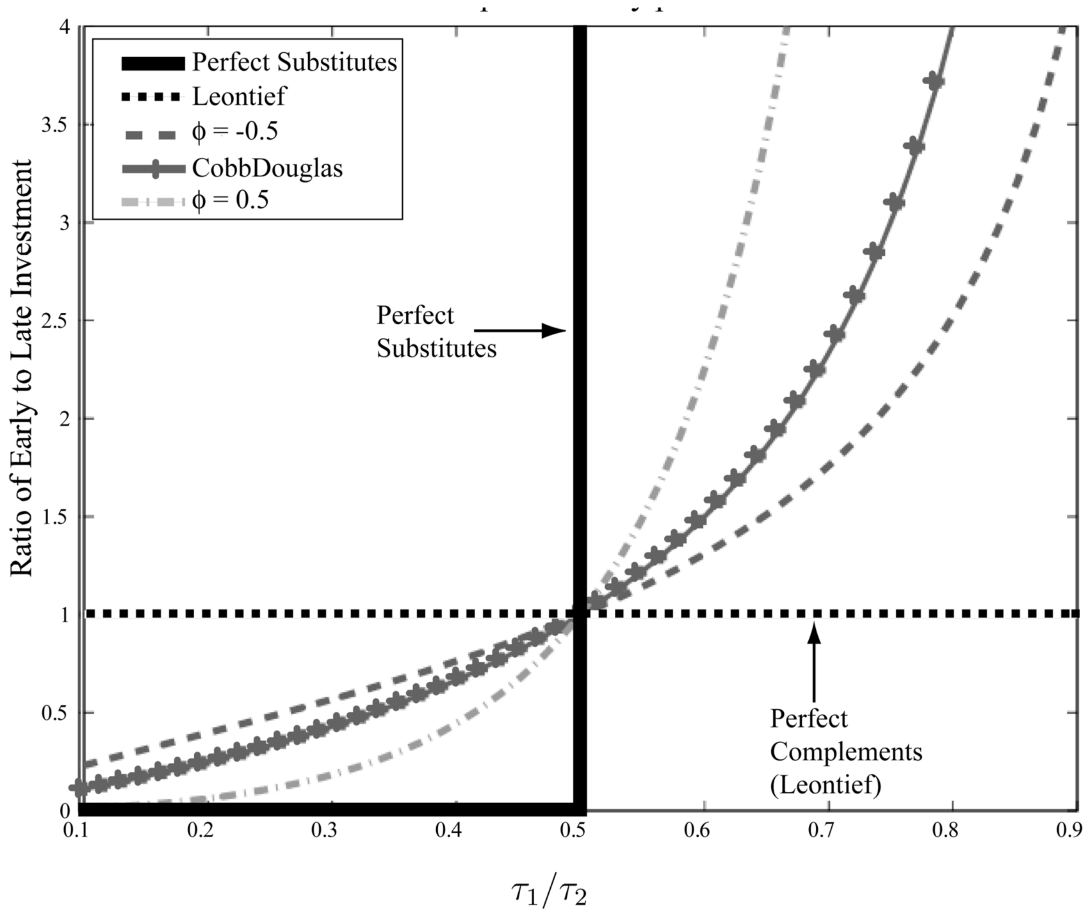


Figure 5.
Ratio of early to late investment in human capital (I_1/I_2) as a function of τ_1/τ_2 for different values of complementarity (φ). Assumes $r = 0$. Source: Cunha and Heckman (2007b).

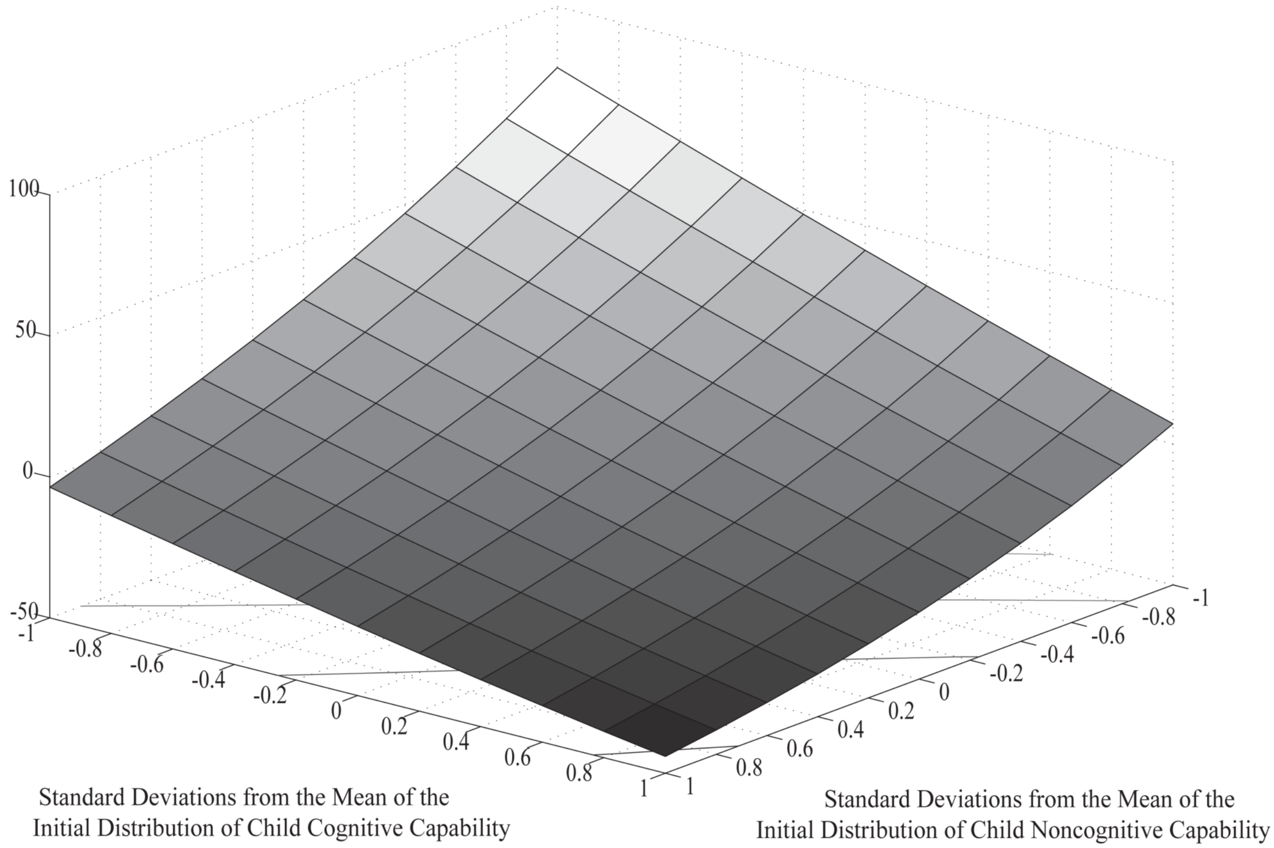


Figure 6.
Percentage increase in total investments as a function of child initial conditions of cognitive and noncognitive capabilities. Lighter shading corresponds to larger values.

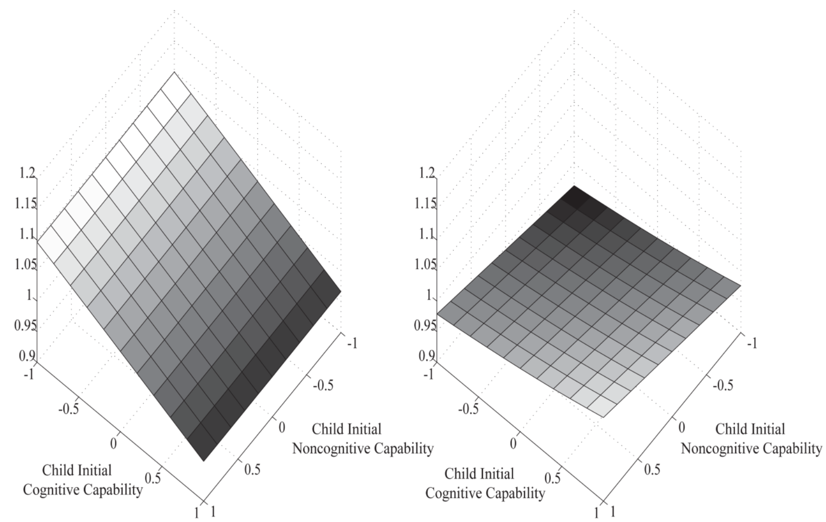


Figure 7.
Optimal early (left) and late (right) investments by child initial conditions of cognitive and noncognitive capabilities maximizing aggregate education. Lighter shading corresponds to larger values.

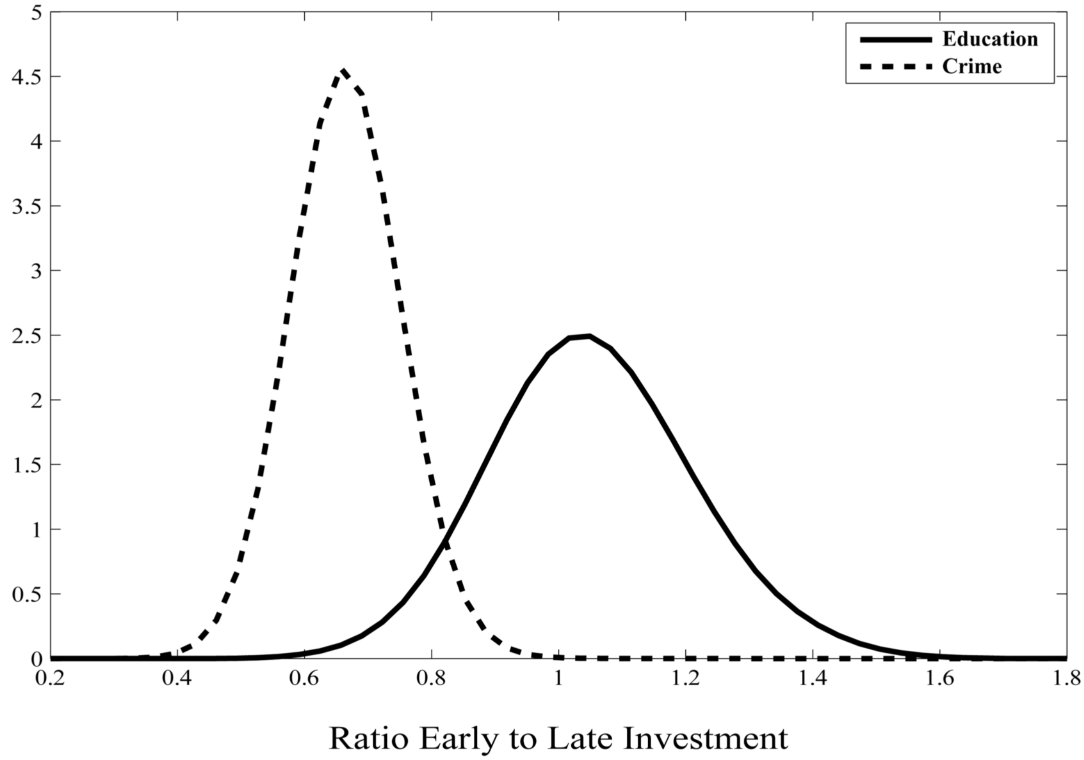


Figure 8.
Densities of ratio of early to late investments maximizing aggregate education versus minimizing aggregate crime

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 1

Anchor: Log Earnings of the Child Between Ages 23–28, Correcting for Classical Measurement Error, White Males, CNLSY/79*.

Independent Variable	Noncognitive Skill (θ_{t+1}^{N})			Cognitive Skill (θ_{t+1}^{C})		
	Stage 1	**Stage 2**	**Stage 3**	**Stage 1**	**Stage 2**	**Stage 3**
Lagged Noncognitive Skill (θ_t^N)	0.9849 (0.014)	0.9383 (0.015)	0.7570 (0.010)	0.0216 (0.004)	0.0076 (0.003)	0.0005 (0.003)
Lagged Cognitive Skill (θ_t^C)	0.1442 (0.120)	−0.1259 (0.115)	0.1171 (0.115)	0.9197 (0.023)	0.8845 (0.021)	0.9099 (0.019)
Parental Investment, (θ_t^I)	0.0075 (0.002)	0.0149 (0.003)	0.0064 (0.003)	0.0056 (0.002)	0.0018 (0.001)	0.0019 (0.001)
Maternal Education (*S*)	0.0005 (0.001)	−0.0004 (0.001)	0.0019 (0.001)	−0.0003 (0.001)	0.0007 (0.001)	0.0001 (0.001)
Maternal Cognitive Skill (*A*)	0.0001 (0.000)	−0.0011 (0.000)	−0.0019 (0.000)	0.0025 (0.001)	0.0002 (0.000)	0.0010 (0.000)

*Standard errors in parentheses. Cognitive skills are proxied by math PIAT and reading PIAT. Noncognitive skills are proxied by the components of the behavioral problem index. Investments are proxied by components of the home score. Stage 1 is age 6–7 to 8–9; Stage 2 is 8–9 to 10–11; Stage 3 is 10–11 to 12–13.

Source: Cunha and Heckman (2008, Table 11).

Table 2

Percentage Impact of an Exogenous Increase by Ten Percent in Investments of Different Periods for Two Different Anchors, White Males, CNLSY/79.*

(a) On Log Earnings at Age 23			(b) On the Probability of Graduating from Secondary School		
Total Impact on Log Earnings	**Impact on Log Earnings Exclusively through Cognitive Skills**	**Impact on Log Earnings Exclusively through Noncognitive Skills**	**Total Impact**	**Impact through Cognitive Skills**	**Impact Exclusively through Noncognitive Skills**
Period 1			Period 1		
0.25 (0.03)	0.12 (0.015)	0.12 (0.015)	0.64 (0.08)	0.55 (0.07)	0.096 (0.012)
Period 2			Period 2		
0.31 (0.03)	0.04 (0.005)	0.26 (0.03)	0.40 (0.047)	0.20 (0.02)	0.20 (0.024)
Period 3			Period 3		
0.21 (0.023)	0.054 (0.006)	0.16 (0.017)	0.36 (0.04)	0.24 (0.03)	0.12 (0.013)

* Standard errors in parentheses. Source: Cunha and Heckman (2008), Table 11.