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Abstract

This paper distills and extends recent research on the economics of human development and social mobility. It summarizes the evidence from diverse literatures on the importance of early life conditions in shaping multiple life skills and the evidence on critical and sensitive investment periods for shaping different skills. It presents economic models that rationalize the evidence and unify the treatment effect and family influence literatures. The evidence on the empirical and policy importance of credit constraints in forming skills is examined. There is little support for the claim that untargeted income transfer policies to poor families significantly boost child outcomes. Mentoring, parenting, and attachment are essential features of successful families and interventions to shape skills at all stages of childhood. The next wave of family studies will better capture the active role of the emerging autonomous child in learning and responding to the actions of parents, mentors and teachers.

Keywords: capacities, dynamic complementarity, parenting, scaffolding, attachment, credit constraints

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1 Introduction[1]

A growing literature in economics, epidemiology, and psychology establishes the importance of attributes shaped in childhood in determining adult outcomes. At least 50% of the variability of lifetime earnings across persons is due to attributes of persons determined by age 18.[2] Childhood is the province of the family. Any investigation of how conditions in childhood affect life outcomes is a study of family influence.

This essay summarizes the recent economic literature on human development through adolescence and early adulthood, focusing on simple models that convey the essential ideas in the literature on family influence. A large literature surveyed in Heckman et al. (2006) and Rubinstein and Weiss (2006) models schooling choices and post-school on-the-job investment. The output of the models we discuss are the initial conditions of those models.

We draw from multiple sources of information: observational studies of family influence including structural models and the literature on social experiments. The early literature on family influence and the determinants of social mobility pioneered by Becker and Tomes (1979, 1986) presents multiple generation models with one period of childhood, one period of adulthood, one-child families (with no fertility choices), and a single parent. These models are precursors to the models reviewed in this paper. They do not analyze marital sorting and family formation decisions. Parental engagement with the child is in the form of investments in educational goods analogous to firm investments in capital equipment. In the early literature on child development, the role of the child is passive and the information available to the parents is assumed to be perfect. Parental time investments in children are ignored. Investments at any stage of childhood are assumed to be equally effective in producing adult skills. The output of child quality from family investment is a scalar measure

[1]This paper draws on, updates, and substantially extends two previous papers by Cunha et al. (2006) and Cunha and Heckman (2007).

[2]See, for example, Cunha et al. (2005), Huggett et al. (2011), and Keane and Wolpin (1997).

of cognition (IQ or an achievement test) or "human capital." These notions are often used synonymously.

Recent research in the economics of human development and social mobility retains its focus on skills and the technology of skill formation. It establishes the importance of accounting for: (1) multiple periods in the life cycle of childhood and adulthood and the existence of critical and sensitive periods of childhood in the formation of skills, (2) multiple skills for both parents and children which extend traditional notions about the skills required for success in life, and (3) multiple forms of investment. Some of the most exciting recent research models parent-child, mentor-child, and parent-teacher-child relationships as interactive systems, involving attachment and scaffolding[3] as major determinants of child learning. The recent literature also takes a more nuanced view of child investment and accounts for parental time and lack of parental knowledge about the capacities of children and effective parenting practices. It creates and implements an econometric framework that unifies the study of family influence and the consequences of external interventions in child outcomes.

There is a well established empirical relationship between family income and child achievement. Many interpret this relationship as evidence of market restrictions including credit constraints. While it is conceptually attractive to do so, and amenable to analysis using standard methods, the empirical evidence that credit constraints substantially impede child skill formation is not strong. Family income proxies many aspects of the family environment—parental education, ability, altruism, personality, and peers. The empirical literature suggests that unrestricted income transfers are a weak reed for promoting child skills.

This paper proceeds in the following way. Section 2 reviews recent empirical evidence on the expression and formation of capacities over the life cycle. Section 3 lays out basic concepts developed in the recent literature. Section 4 presents bare bones

[3]Scaffolding is an adaptive interactive strategy that recognizes the current capacities of the child (trainee) and guides him/her to further learning without frustrating the child. Activities are tailored to the individual child's ability to do the activities so they are neither too hard or too easy in order to keep in the "zone of proximal development" which is the level of difficulty at which the child can learn the most.

models of human development that capture the central features of the literature as well as some recent extensions. It also discusses evidence on the importance of family income and credit constraints in shaping child development. Section 5 amplifies the discussion of Sections 3 and 4 to demonstrate the fundamental role of dynamic complementarity in shaping life cycle skills. It justifies policies that redistribute resources toward disadvantaged children in the early years on the grounds of *efficiency* without any appeal to fairness or social justice, although those too might be invoked to strengthen the argument for early intervention. Section 6 presents a dynamic state-space framework that operationalizes the theory and unifies the interpretation of the intervention literature and the literature on family influence. Section 7 presents evidence on the effectiveness of interventions over the life cycle and interprets its findings using the framework developed in this paper. Section 8 summarizes recent models of the development and expression of capacities as the outcomes of parent-child, mentor-child interactions that have common features across the life cycle. A web appendix (`heckman.uchicago.edu/hum-dev`) presents more formal arguments and extensive empirical evidence on each topic covered in this paper.

2 Some Facts about Skills Over the Life Cycle

Skills are multiple in nature and encompass cognition, personality, preference parameters, as well as health. Skills are capacities to act. They include some of the capabilities defined by Sen (1985) and Nussbaum (2011) but focus on individual attributes and not aspects of society such as political freedoms. They shape expectations, constraints, and information. More capacities enlarge agent choice sets.[4] The recent empirical literature has established eight important facts about the process of human development and skill formation. Each fact is extensively documented in our Web Appendix.

1. Multiple Skills Multiple skills vitally affect performance in life across a variety of dimensions. A large body of evidence shows that cognitive and noncognitive skills affect labor market outcomes, the likelihood of marrying and divorcing, receiving welfare, voting, and health.[5] Comprehensive surveys are presented in Borghans et al. (2008) and Almlund et al. (2011).

2. Gaps in Skills Gaps in skills between individuals and across socioeconomic groups open up at early ages for both cognitive and noncognitive skills. Carneiro and Heckman (2003), Cunha et al. (2006), and Cunha and Heckman (2007) present evidence of early divergence in cognitive and noncognitive skills before schooling begins. Many measures show near-parallelism during the school years across children of parents from different socioeconomic backgrounds even though schooling quality is very unequal.[6]

[4]Capacities may also shape preferences but in this case the interpretation placed on the benefit of enlarged choice sets is quite different.

[5]See Section E in the Web Appendix.

[6]Cunha et al. (2006) and Cunha and Heckman (2007) present evidence on gaps from numerous data sources. The pattern of these gaps is evident using both raw and age-adjusted scores. See Section A of our Web Appendix for an extensive analysis of gaps in cognitive and noncognitive skills.

3. Genes The early emergence of skill gaps might be interpreted as the manifestation of genetics: smart parents earn more, achieve more, and have smarter children.[7] There is, however, a strong body of experimental evidence on the powerful role of parenting and parenting supplements including mentors and teachers in shaping skills, which we document in this essay.

Genes are important, but skills are not solely genetically determined. The role of heritability is exaggerated in many studies and in popular discussions. Nisbett et al. (2012), Tucker-Drob et al. (2009), and Turkheimer et al. (2003) show that estimated heritabilities are higher in families of higher socioeconomic status. Genes need sufficiently rich environments to fully express themselves. There is mounting evidence that gene expression is itself mediated by environments.[8] Epigenetics[9] informs us that environmental influences are partly heritable[10].

4. Critical and Sensitive Periods in the Technology of Skill Formation There is compelling evidence for critical and sensitive periods in the development of a child. Different capacities are malleable at different stages of the life cycle (see Thompson and Nelson, 2001, Knudsen et al., 2006, and the body of evidence summarized in Cunha et al., 2006). For example, IQ is rank stable after age 10, while personality skills are malleable through adolescence and into early adulthood. A substantial body of evidence from numerous disciplines shows the persistence of early life disadvantage in shaping later life outcomes. Early life environments are important for explaining a variety of diverse outcomes such as crime, health, education, occupation, social engagement, trust, and voting. See Cunha et al. (2006) and Almond and Currie (2011)

[7]See Section M of the Web Appendix. Estimates using the standard ACE model widely used to estimate heritability (see Kohler et al. (2011), for its limitations) show that, on average, 50% of child attributes are heritable. See, for example, Krueger and Johnson (2008) who show that parenting style affects heritability of personality.

[8]See the evidence in Web Appendix M.

[9]The study of heritability not related with DNA sequencing.

[10]See Cole et al. (2012); Gluckman and Hanson (2005, 2006); Jablonka and Raz (2009); Kuzawa and Quinn (2009); Rutter (2006).

for reviews of numerous studies on the importance of prenatal and early childhood environments on adolescent and adult health[11] and socioeconomic outcomes.

5. Family Investments Gaps in skills by age across different socioeconomic groups have counterparts in gaps in family investments and environments. Hart and Risley (1995), Fernald et al. (2013), and many other scholars show how children from disadvantaged environments are exposed to a substantially less rich vocabulary than children from more advantaged families. At age three, children from professional families speak 50% more words than children from working-class families and more than twice as many compared to children from welfare families.[12] There is a substantial literature summarized in Cunha et al. (2006), Lareau (2011), Kalil (2013), and Moon (2014) showing that disadvantaged children have compromised early environments as measured on a variety of dimensions.[13] Recent evidence from Cunha et al. (2013) documents the lack of parenting knowledge among disadvantaged parents. Parenting styles are much less supportive of learning and encouraging child exploration (see Hart and Risley, 1995; Kalil, 2013; Lareau, 2011).[14]

6. Resilience and Targeted Investment While early life conditions are important, there is considerable evidence of resilience and subsequent partial recovery. To our knowledge there is no evidence of full recovery from initial disadvantage. The most effective adolescent interventions target formation of personality, socioemotional, and character skills through mentoring and guidance, including providing information. This evidence is consistent with the greater malleability of personality and character skills into adolescence and young adulthood. The body of evidence to date shows that, as currently implemented, many later life remediation efforts are not effective in improving capacities and life outcomes of children from disadvan-

[11]For example, Barker (1990) and Hales and Barker (1992) propose a "thrifty phenotype" hypothesis, now widely accepted, that reduced fetal growth is associated with a number of chronic conditions later in life (Gluckman and Hanson, 2005, 2006).

[12]See Table A.1 in the Web Appendix.

[13]A large body of evidence on this question is summarized in Section B of the Web Appendix.

[14]See the evidence in Web Appendix B.

taged environments.[15,16] As a general rule, the economic returns to these programs are smaller compared to those policies aimed at closing gaps earlier (see Cunha et al., 2006; Heckman and Kautz, 2014; Heckman et al., 1999). However, workplace-based adolescent intervention programs and apprenticeship programs with mentoring, surrogate parenting, and guidance show promising results. They appear to foster character skills such as increasing self-confidence, teamwork ability, autonomy, and discipline which are often lacking in disadvantaged youth. In recent programs with only short-term follow-ups, mentoring programs in school that provide students with information that improves their use of capacities has been shown to be effective. (See, e.g., Bettinger et al., 2012; Carrell and Sacerdote, 2013; Cook et al., 2014).

7. Parent-child/Mentor-child Interactions Play Key Roles in Promoting Child Learning A recurrent finding from the family influence and intervention literatures is the crucial role of child-parent/child-mentor relationships that "scaffold" the child, i.e. track the child closely, encourage the child to take feasible next steps forward in his or her "proximal zone of development," and do not bore or discourage the child. Successful interventions across the life cycle share this feature.

8. High Returns to Early Investment Despite the generally low returns to interventions targeted toward the cognitive skills of disadvantaged adolescents, the empirical literature shows high economic returns for investments in young disadvantaged children.[17] There is compelling evidence that high-quality interventions targeted at the early years are effective in promoting skills (Heckman and Kautz, 2014).[18] The

[15]See Table I.1 in the Web Appendix.

[16]Rutter et al. (2010) show that Romanian orphans reared in severely disadvantaged environments but adopted out to more advantaged environments partially recover, with recovery being the greatest among those adopted out the earliest.

[17]Recent interventions with short term follow ups appear to show remarkable effects on cognitive achievement as measured by achievement tests (See Cook et al., 2014). These findings may appear to contradict the claim in the text. However, as noted by Borghans et al. (2008), Almlund et al. (2011), Heckman and Kautz (2012, 2014) and Borghans et al. (2011b) the scores on achievement tests are heavily weighted by personality skills. Achievement tests are designed to measure "general knowledge"—acquired skills. This evidence is consistent with the evidence from the Perry Preschool Program that showed boosts in achievement test scores without raising IQ. Perry boosted noncognitive skills.

[18]See Section I.1 of the Web Appendix.

evidence is explained by dynamic complementarity which is discussed in the next section.

3 Skills, the Technology of Skill Formation, and the Essential Ingredients of a Life Cycle Model of Human Development

Skills, the technology of producing skills, and parental preferences and constraints play key roles in explaining the dynamics of family influence.

3.1 Skills

We represent the *vector* of skills at age t by $\boldsymbol{\theta_t}$ over lifetime T. Decompose $\boldsymbol{\theta_t}$ into three subvectors:

$$\boldsymbol{\theta_t} = (\boldsymbol{\theta_{C,t}}, \boldsymbol{\theta_{N,t}}, \boldsymbol{\theta_{H,t}}), \quad t = 1, \ldots, T, \tag{1}$$

where $\boldsymbol{\theta_{C,t}}$ is a vector of cognitive skills (e.g. IQ) at age t, $\boldsymbol{\theta_{N,t}}$ is a vector of noncognitive skills (e.g. patience, self control, temperament, risk aversion, discipline, and neuroticism) at age t and $\boldsymbol{\theta_{H,t}}$ is a vector of health stocks for mental and physical health at age t.

Skills can evolve with age and experience t. The dimensionality of $\boldsymbol{\theta_t}$ may also change with t. As people mature, they acquire new skills previously missing in their personas and sometimes shed old attributes. Skills determine in part (a) resource constraints, (b) agent information sets, and (c) expectations.[19]

A key idea in the recent literature is that a core *low-dimensional* set of skills joined with incentives and constraints, generates a variety of diverse outcomes, although both the skills and their relationship with outcomes may change with the stage of the life cycle.

Age-specific outcome $Y_{j,t}$ for action (task) j at age t is:

$$Y_{j,t} = \psi_{j,t}(\boldsymbol{\theta_t}, e_{j,t}, \boldsymbol{X_{j,t}}), \quad j \in \{1, \ldots, J_t\} \quad \text{and} \quad t \in \{1, \ldots, T\}, \tag{2}$$

[19] They may also shape preferences.

$\boldsymbol{X_{j,t}}$ is a vector of purchased inputs that affect outcomes. Effort $e_{j,t}$ is characterized by the supply function:

$$e_{j,t} = \delta_j(\boldsymbol{\theta_t}, \boldsymbol{A_t}, \boldsymbol{X_{j,t}}, \boldsymbol{R^a_{j,t}}(\mathcal{I}_{t-1}) \,|\, \boldsymbol{u}), \tag{3}$$

where $\mathcal{I}_{t-1}$ is the information set, on the basis of which the agent evaluates outcomes, $\boldsymbol{R^a_{j,t}}(\mathcal{I}_{t-1})$ is the anticipated reward per unit effort in activity j in period t, $\boldsymbol{A_t}$ represents other determinants of effort and $\boldsymbol{u}$ represents a *vector* of parameters characterizing the preference function.[20]

An active body of research investigates the role of skills in producing outcomes (see Almlund et al., 2011; Borghans et al., 2008; Bowles et al., 2001; Dohmen et al., 2010). In general, each outcome is differentially affected by components of the (possibly age-dependent) capacity vector $\boldsymbol{\theta_t}$. Schooling, for example, depends more strongly on cognitive abilities, while earnings are equally affected by cognitive capacities and noncognitive capacities such as conscientiousness.[21] Scores on achievement tests depend on both cognitive and noncognitive capacities.[22] Evidence that achievement tests predict outcomes better than measures of personality or IQ alone miss the point that achievement tests capture both.[23] As the mapping of capacities to outputs differs among tasks, people with different levels of capacities will also have comparative advantages in performing different tasks.[24]

Equation (2) emphasizes that there are many ways to achieve a level of performance in any given activity. One can compensate for a shortfall in one dimension through greater strength in the other. For example, for some tasks deficiencies in cognitive ability can be compensated by greater motivation, determination, and effort. Grades in school depend more on personality traits than pure cognition.[25]

[20]In models of parent-child interactions, the utility functions of the parent and the child govern effort.

[21]See Appendix E, Table E.1 for the definition of the Big Five attributes used in personality psychology. They have been called the "latitude and longitude of personality."

[22]See Borghans et al. (2008) and Heckman and Kautz (2012, 2014). This point is confused in a literature that equates cognition with achievement tests.

[23]For a recent example of this confusion, see Duckworth et al. (2012).

[24]One version of this is the Roy Model of occupational choice. See e.g. Heckman and Sedlacek (1985).

[25]See Borghans et al. (2011a).

Equation (2) informs a recurrent debate about the relative importance of the "person" vs. "the situation" that is alive and well in modern behavioral economics: are outcomes due to attributes of the individual ($\boldsymbol{\theta_t}$), the situation ($\boldsymbol{A_t}$) or the effort evoked by the interaction between $\boldsymbol{\theta_t}$, $\boldsymbol{A_t}$, and the incentives to attain a given result ($\boldsymbol{R^a_{j,t}}$)? Thaler (2008) and many behavioral economists (e.g., Mullainathan and Shafir, 2013) treat actions of agents as largely the outcomes of situations and incentives in situations. Extreme views claim that there is no stable construct associated with personality or preferences.

Almlund et al. (2011) review a large body of empirical evidence that refutes this claim. Stable personality and other capacities play empirically important roles in shaping performance in a variety of tasks apart from the effects of incentives in situations.

Equation (2) has important implications for the use of psychological constructs in the economics of human development and social mobility. Economists routinely use test scores developed by psychologists to capture IQ, achievement, and personality.

Psychologists offer their measures as independent indicators of attributes that can be used to predict behaviors. As discussed in Almlund et al. (2011), and Heckman and Kautz (2012, 2014), all tests are just measures of performance on some tasks, i.e. some other behaviors. The tasks usually differ across tests. A large body of evidence shows that effort on test-taking tasks can be incentivized and the response to incentives varies depending on other capabilities.[26] Scores on IQ tests can be substantially boosted by directly rewarding successful answers. The elasticity of response to rewards depends on levels of conscientiousness. The less conscientious are more sensitive to rewards (see Borghans, Duckworth, Heckman, and ter Weel, 2008, Borghans, Meijers, and ter Weel, 2008). Incentivized boosts in achievement have not been shown to persist when the incentives are removed.[27]

[26]See Borghans et al. (2008).

[27]A literature in psychology by (Deci and Ryan, 1985; Ryan and Deci, 2000) suggests the performance is actually lower in the baseline after incentives are removed.

Taking a test is just one of many tasks in life. Behaviors are also as informative about skills as tests. This insight is the basis for the empirical strategy employed in the recent literature using early behaviors as measures of child attributes (see Heckman et al., 2011; Jackson, 2013; Piatek and Pinger, 2010). Any distinction between tests (or "assessments") and behaviors is intrinsically arbitrary even though it is enshrined in the literature in psychology and often uncritically adopted by economists.

Equation (2) reveals an important identification problem. In order to use any set of measurements of outcomes to identify capacities, one needs to control for incentives and the situations that generate performance on a task (see Almlund et al., 2011; Heckman and Kautz, 2012, 2014). The system of equations (2) does not isolate $\boldsymbol{\theta_t}$ unless outcomes are standardized for incentives and environments. Even then, equations in the system (2), which are in the form of nonlinear factor models, are not identified even in the linear case unless certain normalizations are imposed that associate a factor with a specific set of measurements.[28] At best we can identify factors normalized relative to each other (see Almlund et al., 2011; Borghans et al., 2008; Cunha et al., 2010; Heckman and Kautz, 2012, 2014).

A proper understanding of the relevant skills and how they can be modified allows for a unification of the findings from the treatment effect literature for interventions and the more economically motivated family economics literature. Using the empirically specified system of equations in (2), and the technology of skill formation (4) exposited below, one can characterize how different interventions or different family influence variables affect $\boldsymbol{\theta_t}$ and hence outcomes ($\boldsymbol{Y_t}$) and make comparisons across those literatures (see Cunha and Heckman, 2007).

Outcomes studied include earnings, crime, health, education, trust, and health behaviors. By accounting for multiple skills, their mutual interactions and evolution over time, the recent literature goes well beyond saying that schooling is the principal determinant of individual productivity, that measures of cognition are the principal predictors of child outcomes, or that only early health affects adult health.

[28]See Anderson and Rubin (1956) and Williams (2012).

Using these notions, analysts of human development can draw on frontier production theory (Fried et al., 2008) and define the set of possible actions for people—their *action spaces*. This is closely related to the space of "functionings" in Sen's capability theory. A fundamental notion in that literature is that of maximum possible flexibility. As noted by Foster (2011), this conceptualization is, in turn, closely related to Kreps's (1979) notion of flexibility in choice sets that give agents options to act whatever their preferences may turn out to be. One goal of many parents is to allow children to be able to be the best that they want to be.[29]

3.2 Technology

An important ingredient in the recent literature is the *technology of skill formation* (Cunha, 2007; Cunha and Heckman, 2007), where the vector $\boldsymbol{\theta_t}$ evolves according to a law of motion affected by investments broadly defined as actions specifically taken to promote learning, and parental skills (environmental variables):

$$\boldsymbol{\theta_{t+1}} = \boldsymbol{f^{(t)}}(\underbrace{\boldsymbol{\theta_t}}_{\substack{\text{self productivity}\\ \text{and cross effects}}}, \underbrace{\boldsymbol{I_t}}_{\text{investments}}, \underbrace{\boldsymbol{\theta_{P,t}}}_{\substack{\text{parental}\\ \text{skills}}}). \tag{4}$$

$\boldsymbol{f^{(t)}}$ is assumed to be twice continuously differentiable, increasing in all arguments and concave in $\boldsymbol{I_t}$. As previously noted, the dimension of $\boldsymbol{\theta_t}$ and $\boldsymbol{f^{(t)}}$ likely increases with stage of the life cycle t, as does the dimension of $\boldsymbol{I_t}$. New skills emerge along with new investment strategies. The technology is stage-specific, allowing for critical and sensitive periods in the formation of capabilities and the effectiveness of investment.[30] This technology accommodates family formation of child preferences as in Becker

[29]However, as noted in Doepke and Zilibotti (2012) and the large literature they cite, parenting styles differ, and some parents are paternalistic, seeking to shape child preferences and choices (see, e.g., Chan and Koo, 2011).

[30]The technology is a counterpart to the models of adult investment associated with Ben-Porath (1967) and its extensions (see, e.g., Browning et al., 1999 and Rubinstein and Weiss, 2006). It is more general than the Ben-Porath model and its extensions, because it allows for multiple skill outputs ($\boldsymbol{\theta_t}$) and multiple inputs ($\boldsymbol{I_t}$), where inputs at one stage of the life cycle can be qualitatively different from investments at other stages of the life cycle. Cunha et al. (2006) compare technology (4) with the Ben-Porath model.

and Mulligan (1997), Becker et al. (2012), Bisin and Verdier (2001), and Doepke and Zilibotti (2012).

The first term in (4) captures two distinct ideas: (a) that investments in skills do not fully depreciate within a period and (b) that stocks of skills can act synergistically (cross partials may be positive). For example, higher levels of noncognitive skills promote higher levels of cognitive skills, as shown in the econometric studies of Cunha and Heckman (2008) and Cunha et al. (2010).

A crucial concept emphasized in the recent literature is *complementarity between skills and investments at later stages* ($t > t^*$) of childhood:

$$\frac{\partial^2 \boldsymbol{\theta_{t+1}}}{\partial \boldsymbol{\theta_t} \partial \boldsymbol{I_t'}} > 0, \quad t > t^*.^{31}$$

The empirical literature reviewed below is consistent with the notion that investments and endowments are direct substitutes (or at least weak complements) at early ages:

$$\frac{\partial^2 \boldsymbol{\theta_{t+1}}}{\partial \boldsymbol{\theta_t} \partial \boldsymbol{I_t'}} \leq 0, \quad t < t^*, \left(\text{or } \epsilon > \frac{\partial^2 \boldsymbol{\theta_{t+1}}}{\partial \boldsymbol{\theta_t} \partial \boldsymbol{I_t'}} > 0, \text{ for } \epsilon \text{ “small”} \right)$$

but that complementarity increases with age:

$$\frac{\partial^2 \boldsymbol{\theta_{t+1}}}{\partial \boldsymbol{\theta_t} \partial \boldsymbol{I_t'}} \uparrow t \uparrow .^{32}$$

Growing complementarity with stage of the life cycle captures two key ideas. The first is that investments in adolescents and adults with higher levels of capacity $\boldsymbol{\theta_t}$ tend to be more productive. This is a force for social disequalization of investment. It is consistent with evidence reported in Cameron and Heckman (2001), Cunha et al. (2006), Carneiro et al. (2013) and Eisenhauer et al. (2013) that returns to college are higher for more able and motivated students.[33] The second idea is that complemen-

[31]There are other notions of complementarity. For a discussion with reference to the technology of skill formation, see Cunha et al. (2006).

[32]See Cunha (2007), Cunha and Heckman (2008), and Cunha et al. (2010).

[33]See, e.g., Table G.1 Web Appendix.

tarity tends to increase over the life cycle. This implies that compensatory investments tend to be less effective the later the stage in the life cycle. This feature is consistent with a large body of evidence reviewed below that later life remediation is generally less effective than early life prevention and investment (Cunha et al., 2006; Heckman and Kautz, 2014; Knudsen et al., 2006; Sroufe et al., 2005).[34] The dual face of later life complementarity is that early investment is most productive if it is followed up with later life investment.

Complementarity coupled with self-productivity leads to the important concept of *dynamic complementarity* introduced in Cunha and Heckman (2007, 2009). Because investment produces greater stocks of skills, $\boldsymbol{I_t} \uparrow \Rightarrow \boldsymbol{\theta_{t+1}} \uparrow$, and because of self-productivity, $\boldsymbol{\theta_{t+1}} \uparrow \Rightarrow \boldsymbol{\theta_{t+s}} \uparrow$, $s \geq 1$, it follows that:

$$\frac{\partial^2 \boldsymbol{\theta_{t+s+1}}}{\partial \boldsymbol{I_t} \partial \boldsymbol{I'_{t+s}}} > 0, \quad s \geq 1.$$

Investments in period $t+s$ and investments in any previous period t are *always* complements as long as $\boldsymbol{\theta}_{t+s}$ and $\boldsymbol{I}_{t+s}$ are complements, irrespective of whether $\boldsymbol{I}_t$ and $\boldsymbol{\theta}_t$ are complements or substitutes in some earlier period t.[35] Early investment

[34]It is not inconsistent with the notion that later life investments may have substantial effects and may be cost effective. It is also consistent with the notion that later life information and guidance can enhance the effectiveness of a given stock of skills.

[35]Dynamic complementarity is a consequence of static complementarity in later life periods. Because future capacities are increasing in current investments and future investments are complements with future capacities, current and future investments tend to be complements the stronger the static complementarity in future periods. Consider the following specification for the technology with scalar θ_t and I_t:

$$\theta_{t+1} = f^{(t)}(\theta_t, I_t).$$

Denoting by f_1^t and f_2^t the derivatives with respect to the first and second arguments, respectively,

$$sign\left\{\frac{\partial^2 f^{(t+s)}(\theta_{t+s}, I_{t+s})}{\partial I_{t+s} \partial I_t}\right\} = sign\{f_{21}^{(t+s)}\}$$

independently of the sign of f_{21}^t, for $s \geq 1$. To prove the claim, note that

$$\frac{\partial^2 f^{(t+s)}(\theta_{t+s}, I_{t+s})}{\partial I_{t+s} \partial I_t} = f_{21}^{(t+s)} \underbrace{\left(\prod_{j=1}^{s-1} f_1^{(t+j)}\right)}_{>0} \underbrace{f_2^{(t)}}_{>0}.$$

enhances later life investment even if early investment substitutes for early stage capabilities.

These properties of the technology of skill formation show why investment in disadvantaged young children can be both socially fair and economically efficient, whereas later stage investments in disadvantaged (low $\boldsymbol{\theta_t}$) persons, while fair, may not be economically efficient. Building the skill base of disadvantaged young children makes them more productive at later ages. Dynamic complementarity also shows why investments in disadvantaged adolescents and young adults who lack a suitable skill base are often less effective.

These properties of the technology explain, in part, why more advantaged children were the first to respond in terms of college attendance to the rising returns to education (see Cunha et al., 2006). They had the necessary skill base to benefit from more advanced levels of schooling as the returns increased. They also explain the failure of tuition subsidy policies in promoting educational participation of disadvantaged adolescents (see Heckman, 2008). Dynamic complementarity also suggests that limited access to parenting resources at early ages can have lasting lifetime consequences that are difficult to remediate at later ages.

Parental skills also play a disequalizing role as they enhance the productivity of investments ($\frac{\partial^2 \boldsymbol{\theta_{t+1}}}{\partial \boldsymbol{\theta_{P,t}} \partial \boldsymbol{I_t'}} > 0$). There is evidence (Lareau, 2011) that more educated parents, by engaging their children more, increase the formative value of investments such as sports or cultural activities.

Public investment are usually thought to promote equality. Whether they do so depends on the patterns of substitutability with private investments and parental skills. If more skilled parents are able to increase the productivity of public investments as they are estimated to do with private ones, or if public investments crowd out private

The extension to the vector case is straightforward. See Section L of the Web Appendix. (We keep the arguments of the right-hand side expressions implicit to simplify the notation.)

Empirical evidence (Cunha, 2007; Cunha and Heckman, 2008; Cunha et al., 2010) shows that in multi-period models, $\cdots > f_{12}^{(3)} > f_{12}^{(2)} > f_{12}^{(1)}$. Moreover, the elasticity of substitution in the first stage between capabilities and investments is greater than 1 making these gross substitutes, while they are gross complements in later stages as the elasticity of substitution becomes lower than 1. For further discussion see Cunha et al. (2006).

investments relatively more among disadvantaged families, then public investments will also play a role towards disequalization.[36]

3.3 Other Ingredients

In addition to the functions linking outcomes to skills and the technology of capability formation, a fully specified model of family influence considers *family preferences for child outcomes*. Parents have different beliefs about "proper" child rearing, and can act altruistically or paternalistically (see, e.g., Baumrind, 1968, Bisin and Verdier, 2001, and Doepke and Zilibotti, 2012).[37] A fully specified model also includes family resources broadly defined, including parental and child interactions with financial markets and external institutions. This includes restrictions (if any) on transfers across generations, restrictions on transfers within generations (parental lifetime liquidity constraints), and public provision of investment in children.

Such constraints are traditional. Less traditional, but central to the recent literature are other constraints on parents: (a) information on parenting practices and parental guidance, (b) genes, and (c) the structure of households, including assortative matching patterns.

3.4 The Empirical Challenge

There is a substantial empirical challenge facing the analyst of family influence. Influences at different stages of the life cycle build on each other. Evidence of early family influence on adult outcomes is consistent with strong initial effects that are attenuated at subsequent stages of the life cycle or weak initial effects that are amplified at later stages of the life cycle. The empirical challenge is to sort out the relative

[36]This is an argument against universal provision of policies to promote equality of outcomes. The evidence supporting the complementarity hypothesis is mixed. See Pop-Eleches and Urquiola (2013) and Gelber and Isen (2013). See Web Appendix J.

[37]Altruistic parents care about the utility of their child and therefore evaluate their child's actions using the child's utility function. Paternalistic parents, on the other hand, potentially disapprove of their child's actions, as these are evaluated through the lenses of the parents' utility function. As discussed below, the literature divides in terms of its specification of parental preferences and the evidence on the precise form of parental preferences for child outcomes is scant.

importance of the different causal influences on adult outcomes and stages of the life cycle where they are most influential. This paper reviews the evidence on these links.

4 A Bare-Bones Model of Parenting as Investment

To focus ideas we present a simple model of family investment and skill development based on Cunha (2007) and Cunha and Heckman (2007). Section D of the Web Appendix provides much greater detail on these and more general models. This model extends the traditional literature on human capital accumulation and parental investments (Aiyagari et al., 2002; Becker and Tomes, 1986; Loury, 1981). It has multiple periods of productive investments, dynamic complementarity in the process of skill accumulation, and incorporates family transactions with financial markets. We show how intergenerational links between parental and child skills emerge even in the absence of life cycle credit constraints.

The deliberately simplified model with a scalar skill and scalar investment presented in this section misses key implications of richer models with multiple skills and multiple investments which we discuss after presenting the basic model. They also fail to capture the change in the dimensionality of $\boldsymbol{\theta_t}$ with t and the associated change in the dimensions of $\boldsymbol{f^{(t)}}(\cdot)$ and $\boldsymbol{I_t}$.

4.1 The Problem of the Parent

Life is assumed to last four periods: two periods as a passive child who makes no economic decisions (and whose consumption is ignored), but who receives investment in the form of goods and two periods as a parent. When the parent dies she is replaced by the generation of her grandchild. Denote by θ_1 the initial capability level of a child drawn from the distribution $J(\theta_1)$[38]. The evolution of child skills depends on parental investments in the first and second period I_1 and I_2. (For notational simplicity, we set $\theta_{P,t} = \theta_P$.) The productivity of parental investment depends on parental human capital θ_P. We follow conventions in the literature and equate scalar human capital with skill for both parents and children. Denoting by θ_3 the human capital of the child when he/she reaches adulthood, recursive substitution of the technology of

[38]This may depend on parental skills $\theta_{P,t}$ and parental care in utero. See, e.g., Gluckman and Hanson (2005, 2004).

skill formation gives the following representation:

$$\theta_3 = \delta_2 \left[\theta_1, \theta_P, \left(\gamma \left(I_1 \right)^{\phi} + (1-\gamma) \left(I_2 \right)^{\phi} \right)^{\frac{\rho}{\phi}} \right], \tag{5}$$

for $0 < \rho \leq 1$, $\phi \leq 1$ and $0 \leq \gamma \leq 1$, γ is a skill multiplier.

To develop intuition about representation (5), consider the following parameterization of the stage-specific production functions:

$$\theta_{t+1} = \delta_t \left\{ \gamma_{1,t} \theta_t^{\phi_t} + \gamma_{2,t} I_t^{\phi_t} + \gamma_{3,t} \theta_P^{\phi_t} \right\}^{\frac{\rho_t}{\phi_t}}$$

with $0 < \gamma_{1,t}, \gamma_{2,t}, \gamma_{3,t}, \rho_t \leq 1$, $\phi_t \leq 1$, $\sum_k \gamma_{k,n_t} = 1$. Substitute recursively. If $T = 2$, $\rho_1 = \rho_2 = 1$, $\delta_1 = 1$, and $\phi_1 = \phi_2 = \phi \leq 1$, skills at adulthood, $\theta_3 = \theta_{T+1}$ can be expressed as

$$\theta_3 = \delta_2 \left[\gamma_{1,2}\gamma_{1,1}\theta_1^{\phi} + \underbrace{\gamma_{1,2}\gamma_{2,1}}_{\textbf{“Multiplier”}} I_1^{\phi} + \gamma_{2,2} I_2^{\phi} + \left(\gamma_{3,2} + \gamma_{1,2}\gamma_{3,1} \right) \theta_P^{\phi} \right]^{\frac{1}{\phi}}.$$

The multiplier is $\gamma = \gamma_{1,2}\gamma_{2,1}$. It arises from the conjunction of self-productivity ($\gamma_{2,1} \neq 0$) and productivity of investment ($\gamma_{1,2} \neq 0$). Self-productivity joined with productivity of investment generates dynamic complementarity. $\gamma_{2,1}$ characterizes how much of the investment in period $t = 1$ propagates into skills at adulthood, θ_3. The parameter ϕ captures the substitutability/complementarity of investments. If $\phi = 1$, investments at different periods are (almost) perfect substitutes. They are perfect substitutes if $\gamma_{12}\gamma_{21} = \gamma_{22}$, in which case the timing of investment in skills does not matter for the developmental process. This is the only circumstance in which collapsing childhood into one period as in Becker–Tomes is without loss of generality. The polar opposite case is $\theta_3 = \delta_2 \left(\theta_1, \theta_P, \min \left(I_1, I_2 \right) \right)$ which is closer to the empirical truth than perfect substitution. In that case, complementarity has a dual face. Early investment is essential but ineffective unless later investments are also made. In this extreme case there is no possibility of remediation. If parents are poor and unable to

borrow against the future earnings of their children, and, as a result, I_1 is low, there is no amount of investment at later age, I_2, that can compensate for early neglect.

The parameters of the technology determine whether early and later investments are complements or substitutes.[39] Given ρ, the smaller ϕ, the harder it is to remediate low levels of early investment I_1 by increasing later investments. At the same time, the stronger the complementarity (the lower ϕ), the more important it is to follow high volumes of early investments with high volumes of late investments to achieve high levels of production of adult human capital.

The parent decides how to allocate resources across household consumption in both periods of the child's life, c_1 and c_2, early and late investments, I_1 and I_2, and bequests b'. Assets at the end of the first period, period a may be constrained to be non-negative. Bequests are received when entering adulthood and may be positive or negative. The state variables for the parent are her initial wealth b, her human capital level θ_P, and the initial skill level of the child θ_1. Human capital is rewarded in the labor market according to the wage rate w. The economy is characterized by one risk-free asset with return r.

Denoting parental financial assets by a and allowing parental labor market productivity to grow at exogenous rate g, the stage-of-childhood-specific budget constraints can be represented by:

$$c_1 + I_1 + \frac{a}{(1+r)} = w\theta_P + b \tag{6}$$

and

$$c_2 + I_2 + \frac{b'}{(1+r)} = w\,(1+g)\,\theta_P + a \tag{7}$$

We allow for the possibility of borrowing constraints $a \geq \underline{a}$ (intragenerational) and $b' \geq 0$ (intergenerational). When g is high (high income in the second stage of the

[39] "Direct" complementarity for (5) holds if $\rho > \phi$, while substitutability holds otherwise. Another definition of complementarity in the literature distinguishes (in the case $\rho = 1$) whether $\phi > 0$ (*gross* substitutes, the elasticity of substitution is greater than 1) or $\phi < 0$ (*gross* complements, the elasticity of substitution is less than 1) so that Cobb-Douglas ($\phi = 0$) is the boundary case.

child's life), parents might hit the constraint $a \geq \underline{a}$. In the absence of these constraints, one simple lifetime budget constraint governs the parental choices of investment in children.

Let $u(\cdot)$ denote the parental utility function, β the discount factor, and v the parental altruism given by the weight assigned to the utility of future generations. Letting θ_1' be the uncertain initial endowment of the child's child, the goal of the parent is to optimize:

$$V(\theta_P, b, \theta_1) = \max_{c_1, c_2, I_1, I_2} \left\{ u(c_1) + \beta u(c_2) + \beta^2 v \mathbb{E}\left[V\left(\theta_3, b', \theta_1'\right) \right] \right\} \tag{8}$$

subject to (5), (6) and (7).[40] In models of paternalism, parental preferences are defined over specific outcomes and not necessarily the adult utility of children.[41]

4.2 Implications of the Model

A model with multiple periods of childhood is essential for understanding investment dynamics and rationalizing the empirical evidence on the effectiveness of programs targeted toward promoting human capital at different ages. The earlier literature (Becker and Tomes, 1986), as well as some recent work (Lee and Seshadri, 2014), limits itself to a one-period model of childhood. Inputs at any age are implicitly assumed to be perfect substitutes, contrary to the evidence discussed below. Application of the one-period model supports the widely held, but empirically unfounded, intuition that diminishing returns make investment in less advantaged adolescents *more* productive. The assumed magnitudes of the substitution (ϕ), multiplier (γ), and scale (ρ) parameters play key roles in shaping policy.

If no intra- and intergenerational credit constraints are assumed, a key property of the Becker and Tomes (1986) model persists in this framework. There is no role for initial financial wealth b, parental income, parental utility, or the magnitude of

[40] One can interpret this specification of preferences as excluding any utility from child consumption or else as assuming that c_1 and c_2 are pure public goods, and parent and child utilities are identical.

[41] See, for example, Del Boca et al. (2012).

parental altruism v (above zero) in determining the optimal level of investment, because parents can borrow freely in the market to finance the wealth maximizing level of investment.[42] However, even in this setup, returns to parental investments depend on parental skills θ_P, as they affect the productivity of investments. The returns to investments are higher for children of parents with higher θ_P. These children will receive higher levels of investment. This is a type of market failure due to the "accident of birth" that induces a correlation of human capital and earnings across generations even in the absence of financial market imperfections. The initial condition θ_1 also affects investments. It creates a second channel of intergenerational dependence due to the "accident of birth" if it is genetically related to parental endowments, as considerable evidence suggests.[43]

Imperfect credit markets create another channel of intergenerational dependence. One possible constraint is the impossibility of borrowing against the child's future earnings (Becker and Tomes, 1986). This constraint likely emerges because children cannot credibly commit to repay the loans parents would take out on their behalf. Because $b' \geq 0$, parental wealth matters in this model when this constraint binds. Children coming from constrained families will have lower early and late investments. Carneiro and Heckman (2003) show that permanent income has a strong effect on child outcomes. However, even with $b' \geq 0$, the *ratio* of early to late investment is not affected.[44]

A second type of constraint arises when parents are prevented from borrowing against their own future labor income ($\underline{a} \geq q > -\infty$). In this case, when parents cannot borrow against their own future income, investments are not perfect substitutes ($-\infty < \phi < 1$), $\rho = 1$ and parental utility is given by $u(c) = \left(c^{\lambda} - 1\right)/\lambda$,[45] the ratio

[42]Even if the altruism parameter is zero ($v = 0$), if the parents can make binding commitments selfish parents ($v = 0$) will still invest in the child as long as the economic return in doing so is positive.

[43]Becker and Tomes (1986) discuss the importance of children's initial endowments. A third channel is parental paternalism. If parents value the child's θ_3 for itself, they may subsidize child education even if the investment is economically inefficient.

[44]The constraint binds uniformly across periods within generations.

[45]$\lambda = 1$ corresponds to perfect intertemporal substitutability.

of early to late investment is

$$\frac{I_1}{I_2} = \underbrace{\left(\frac{\gamma}{(1-\gamma)(1+r)}\right)^{\frac{1}{1-\phi}}}_{\substack{\text{unconstrained ratio} \\ \frac{I_1}{I_2}\uparrow \text{ as } \gamma\uparrow,\ \phi\uparrow, \text{ and } r\downarrow}} \quad \underbrace{[\beta(1+r)]^{\frac{1}{1-\phi}} \left(\frac{c_1}{c_2}\right)^{\frac{1-\lambda}{1-\phi}}}_{\substack{=1 \text{ if unconstrained,} \\ <1 \text{ if constrained}(a \geq \underline{a} \text{ binds})}}. \tag{9}$$

In the constrained case, $\frac{I_1}{I_2}$ is less than it is in the unconstrained case and I_1 is less than optimal.[46] The *ratio* of early to late investments depends on parental preferences and endowments. If early parental income is low compared to later life income or if λ is low, the level and timing of family resources will influence the parental investment.[47] This constraint could be very harmful to a child if it binds in a critical period of development and complementarity parameter ϕ is low so that later life remediation is ineffective.

The presence of such credit constraints affects investment levels. They induce a suboptimal level of investment (and consumption) in each period in which the constraint is binding. If the constraint is binding during the early periods, because of the dynamic links induced by the technology of skill formation, late investments will be lower even if the parent is not constrained in later periods.[48]

However, the presence of constraints is not necessarily synonymous with a low level of investment. For a given family, a binding constraint implies that the investments are lower than the unconstrained optimum. Whether a family is constrained or not, however, is uninformative on how that family compares with others in terms of the effective level of investments provided. Families might be constrained, for example, when they have an extremely high productivity of investments in children or give

[46] In the extreme case of a Leontief technology, this ratio goes to 1. In the case of a linear technology, the solution is a corner solution: invest only in the early years if $\gamma > (1-\gamma)(1+r)$.

[47] Estimates from Cunha et al. (2010) suggest that $1/(1-\phi) = .\bar{3}$ which, combined with an estimate of $\lambda \in [-3, -1.5]$ (Attanasio and Browning, 1995), imply $(1-\lambda)/(1-\phi) \in [0.8\bar{3}, 1.\bar{3}]$. Notice that even if $\lambda = 1$, parents may hit constraints on the level of investment if future resources are of insufficient magnitude.

[48] The case of low initial income and high growth rate corresponds to the earnings profiles of educated parents. The relevance of the model just discussed critically relies on exogeneity of fertility. If more educated families postpone fertility (as in Almlund 2013), the relevance of this constraint is lessened. The greater the altruism of the parent, and the lower λ in equation 9, the more likely it is that families will postpone fertility to match their life cycle income growth profiles.

birth to a gifted child. This induces a high optimal level of investment which might not be affordable to the family at its current resource level. Thus, while constrained, the family might still be investing more than others.

More educated parents might face such situations. The steeper the expected income growth, the higher the probability of being constrained. Relaxing this constraint likely impedes intergenerational mobility as measured by the intergenerational elasticity (IGE).[49] Low skill parents, on the other hand, have a low θ_P which makes investments less productive. In this case, it is the "accident of birth" that harms a gifted child rather than the intertemporal credit constraints of the parents. We assess the quantitative importance of credit constraints in section 4.4.

If early investments matter a lot and parents are credit market-constrained in the early years of their children, investments are suboptimal (see equation (9)). Caucutt and Lochner (2012) use a variant of the model of Cunha (2007) to investigate the role of income transfers and credit constraints in the early years. They find that a large proportion of young parents are credit constrained (up to 68% among college graduates) but that reducing borrowing constraints is effective in promoting skills only for the children in the generation where they are relaxed.[50] As previously noted, the families constrained by their criteria may be quite affluent. Indeed, they report evidence showing that families that benefit from a reduction in the credit constraints are the ones with college educated parents. These families are usually well off. Even if some of these families receive "bad shocks", it is hard to think that 68% of college graduates can be considered "poor."

Introducing income uncertainty. Cunha (2007) presents an overlapping generations model with stochastic innovations to parental income. If g is stochastic on the interval $[-1, \infty)$, so parents face uncertain income growth, constraints play a dual role. First, as before, if they bind they reduce investments in the constrained periods. Second, because future income is uncertain so is the likelihood of binding future con-

[49] See Black and Devereux (2011) for a definition and discussion of the IGE.

[50] After credit constraints are relaxed, future generations move back to a constrained position.

straints. Absent full insurance markets, consumption and investments in children are less than optimal even if the parent is not currently constrained, but expects to be constrained in the future with probability greater than zero.[51] Under this scenario, young parents who just entered the labor force accumulate more assets than they would in the absence of possible future constraints to ensure against bad future shocks. This implies a reduction in household consumption and investments in child human capital.

4.3 Recent Extensions of the Basic Model

By and large, the recent literature has moved beyond the simple models just discussed.[52] Table K.1 in the Web Appendix summarizes a recent literature in rapid flux.

Most of the models in the literature are multiple generation frameworks. Most assume parental altruism, but a few are explicitly paternalistic. They all feature investment in goods. Only recently has parental time been analyzed as an explicit input to child quality. Most models analyze how child investment depends on parental skills.

Surprisingly, some of the recent models omit parental skills as arguments in the technology of capability formation despite the evidence in a large literature that parental skills (apart from explicit parental investments) are important factors in producing child skills.[53] Until recently, most studies consider self-productivity of skills. Some recent papers ignore this feature despite the empirical evidence that supports it.

Most analyses assume that parents know the technology of skill formation as well as the skills of their children in making investment decisions. Cunha et al. (2013) is an exception. The recent literature also ignores intergenerational transfers. Some of the papers consider extreme credit constraints that do not permit any borrowing (or lending) even within a lifetime of a generation, much less inter-generational transfers. Virtually the entire literature focuses on single child models, exogenous fertility, and

[51] See Subsection D.6 of the Web Appendix for a mathematical proof of this statement.
[52] Tables K.1-K.3 in Subsection K.1 of the Web Appendix discuss each model in detail.
[53] See, e.g., Cunha and Heckman (2008) and Cunha et al. (2010).

exogenous mating decisions. Most models are for single parent families, where the match characteristics of the parents are irrelevant.

These models do not capture the richness of the framework sketched in Section 3. First, with the exception of Cunha and Heckman (2008) and Cunha et al. (2010), human capital is treated as a scalar. This is inconsistent with fact one. It is a practice inherited from the early literature of Becker and Tomes (1979, 1986), and Solon (2004). Skills are multidimensional. Borghans et al. (2008), Almlund et al. (2011), and Heckman and Kautz (2012, 2014) present evidence showing that a single skill such as cognitive ability or IQ is insufficient to summarize the determinants of life achievements[54].

In some of the recent models, investments are also treated as scalars. In truth, parents and schools have access to and use multiple methods of investment, and the nature of the investments changes over the life cycle of the child. The most relevant omissions in the first stage models are time investments. Quality parenting is a time-intensive process. The recent literature shows that parental time is a prime factor influencing child skill formation (Bernal, 2008; Bernal and Keane, 2010, 2011; Del Boca et al., 2014; Gayle et al., 2013; Lee and Seshadri, 2014). Families differ in their productivity and availability of time, and face different opportunity costs. Time investments may complement or substitute for goods investments. In addition, spending time with children allows parents to more accurately assess the capacities of their children and to make more precisely targeted investment decisions. As discussed in Section 8, parent-child/child-mentor interactions operate in real time and parents/mentors actively engage the child to stimulate learning.

Third, families usually have more than one child. Parents make decisions on how to allocate investments across different siblings, compensating for or reinforcing initial differences among them (Behrman et al., 1982). Parental preferences might conflict with what is socially optimal. Del Boca et al. (2014) and Gayle et al. (2013) present models with multiple children. Firstborn children receive relatively more early invest-

[54]See the analysis in Web Appendix E.

ment and appear to do better as adults (Hotz and Pantano, 2013). This is consistent with dynamic complementarity.

Fourth, the models in the literature ignore the interaction of parents and children in the process of development. They treat the child as a passive being whose skills are known to the parent. They often assume that the parent fully internalizes the child's utility as her own and the child's utility function is that of the parents. We discuss models that account for parent-child interaction in Section 8.

Fifth, fertility is taken as exogenous. Forward-looking parents might attempt to time their fertility to balance the benefit from the presence of a child with the need and desire to provide a certain amount of monetary and time investments. The motive to avoid credit constraints, for example, may induce a greater delay in fertility for the parents with a high preference for child quality. The greater the desired level of investment, the costlier it is to hit an early constraint. To avoid this risk, parents may delay fertility until a sufficient level of precautionary assets has been accumulated. This observation seems to be consistent with the fertility decisions of more educated parents (Almlund, 2013).[55] This consideration suggests caution in taking too literally the models of credit constraints interacting with dynamic complementarity that take fertility as exogenously determined. The parents who hit the constraints may be less farsighted, have less information, and a variety of other traits that might be confounded with any effect of the levels of income or the constraint itself. In the empirical work on the importance of credit constraints, these factors are rarely accounted for.

Finally, the child's development is influenced by the environment outside his family: day care, kindergarten, school, and neighborhood. In addition, the effectiveness of policies is determined in part by parental responses to them. Policies that complement rather than substitute for family investments will have greater impacts and lower costs. We discuss the evidence on parental responses to interventions in Section 8.

[55]Gayle et al. (2013) is the only paper of which we are aware that analyzes the impact of endogenous fertility choices on child outcomes.

4.4 Empirical Estimates of Credit Constraints and the Effects of Family Income

Economists have a comparative advantage in analyzing the effects of constraints on behavior. There is an active literature analyzing the effects of various constraints on child outcomes. One strand summarized in Table 1a focuses on testing the effects of parental income on child outcomes, while another (summarized in Table 1b) tests for the presence of credit constraints directly. The two are not synonymous although they are often confused in the literature.

4.4.1 The Effects of Family Income

The literature is unanimous in establishing that families with higher levels of long-run (or permanent) income on average invest more in their children and have children with greater skills. The literature is much less clear in distinguishing the effect of income by source or in distinguishing pure income effects from substitution effects induced by changing wages and prices (including child care subsidies). If some part of a family income change is due to changes in labor supply, this will have implications for child development (see, e.g., Bernal, 2008; Bernal and Keane, 2010, 2011; Del Boca et al., 2012; Gayle et al., 2013). Higher levels of parental permanent income are associated with higher levels of parental education, better schools, more capable parents, better peers, more engaged parenting, etc. All of these factors likely affect child development.

Carneiro and Heckman (2003) and Cunha et al. (2006) present evidence that child cognitive and noncognitive skills diverge at early ages across families with different levels of permanent income during childhood.[56] Levels of permanent income are highly correlated with family background factors like parental education and maternal ability, which, when statistically controlled for, largely eliminate the gaps across income classes.[57] The literature sometimes interprets this conditioning as reflecting

[56]This evidence is reviewed in Section A of the Web Appendix.
[57]See Figure A.2 and A.3 in the Web Appendix.

parenting and parental investments, but it could arise from any or all of the panoply of correlates of permanent income associated with parental preferences and skills. This poses a major empirical challenge.

Table 1a: Studies of the Role of Income on Child Outcomes

	Dataset	Outcome Studied: Test Scores (T), Schooling (S)	Timing of Income (Developmental Stage of the Child at Which Income Effects are Studied)	Separate the Effect of Income from Changes in Labor Supply or Family Environment	Distinguishes the Effects of Contempora-neous vs Permanent Income	Sources of Income Whose Effects are Studied	Instrument Used	Effect of Income on Human Capital Investments
Carneiro and Heckman (2002)	NLSY79*	S	E and L College Enrollment	X	✓	Total family income	None	(1) Conditioning on ability and family background factors, the role of income in determining schooling decisions is minimal. The strongest evidence is in the low ability group. The test is not robust to accounting for parental preferences and paternalism. Observed differences in attendance might be due to a consumption value of child's schooling for parents. Percentage of people constrained = weighted gap in educational outcome to highest income group: 5.1% are constrained in college enrollment (1.2% among low income, low ability, 0.2% low income high ability), 9% in completion of 2-year college (5.3% among low income, low ability, 0.3% low income high ability). (2) There is no evidence of a independent effect on college enrollment of early or late income once permanent income is accounted for. (3) The claim that higher IV than OLS estimates of the Mincer coefficient implies credit constraints are incorrect: instruments used are invalid, the quality margin is ignored and self selection and comparative advantage can produce the result also in absence of financial constraints.
Belley and Lochner (2007)	NLSY79*, NLSY97*	S	L High school completion and College Enrollment	X	X	Total family income	None	High school completion: +8.4% for highest income quartile compared to lowest in 79, +6.7 in 97 cannot reject equal effect of income; college enrollment: +9.3% for highest income quartile compared to lowest in 79, +16 in 97, cannot reject equal effect of income.
Dahl and Lochner (2012)	NLSY79*, C-NLSY79*	T	E Preadolescence (ages 8 to 14)	X[a]	X[b]	Total family income	Policy variation in EITC eligibility	$1,000 extra per year for 2 years: +6% of a standard deviation in math and reading combined PIAT score.
Duncan et al. (1998)	PSID*	S[d]	E and L Childhood and Preadolescence (ages 0 to 15)	X	✓	Total family income	None	$10,000 increase in average (age 0-15) family income: +1.3 years of schooling in low income (<$20,000) families, +0.13 in high income ones. Relevance of income is stronger in the early years (age 0-5): $10,000 increase in average (age 0-5) family income leads to extra 0.8 years of schooling in low income families, 0.1 in high income ones. Income at age 6-10 and 11-15: no significant effect. Similar results in a sibling differences model.
Duncan et al. (2011)	Randomized Interventions on Welfare Support	T	E Early Childhood (ages 2 to 5)	X	X	Total family income	Random assignment to programs offering welfare transfers conditional on employment or education related activities, or full time work	$1,000 extra per year for 2 to 5 years: +6% of a standard deviation in child's achievement score.
Loken (2010)	Norwegian Administrative Data	S	E Childhood (ages 1 to 11)	✓[c]	X	Total family income	Oil discovery (inducing regional increase in wages)	OLS: positive relationship of average (age 1-13) family income on children's education, IV: no causal effect. Results are robust to different specification and splitting the sample by parental education.
Loken et al. (2012)	Norwegian Administrative Data	S	E Childhood (ages 1 to 11)	X	X	Total family income	Oil discovery (inducing regional increase in wages)	Non-linear IV (quadratic model): increase of $17,414, +0.74 years of education for children in poor families, +0.05 for children in rich families.[†]
Milligan and Stabile (2011)	CCTB**, NCBS***	T	E Childhood (ages 0 to 10)	X	X	Child related tax benefits and income transfers	Variation in benefits eligibility	Low education mothers: positive effects of child benefits on cognitive outcomes for boys, on emotional outcomes for girls, weak on health. Results are non robust to the exclusion of Quebec.
Carneiro et al. (2013)	Norwegian Registry	S[e]	E and L Childhood to Adolescence (ages 0 to 17)	X	✓	Total family income	None	All outcomes: monotone and concave relationship with permanent income. £100,000 increase in permanent father's earnings: +0.5 years of schooling. Timing of income: a balanced profile between early (age 0-5) and late childhood (age 6-11) is associated with the best outcomes; shifting income to adolescence is associated with better outcomes in dropping out of school, college attendance, earnings, IQ and teen pregnancy. Early and late childhood income are complements in determining schooling attainment, early and adolescent income are substitutes.

E refers to "early" years (childhood), L refers to "late" years (adolescence).

[a]Control for labor supply, but endogeneity is not considered, [b]Only analysis of past versus contemporaneous income, [c]Labor supply is not modeled, but the effects of the instrument on it are studied and found insignificant, [d]Hazard of non marital birth is also studied, [e]Other outcomes (health, teenage pregnancy, IQ) are studied as well.

*NLSY79: National Longitudinal Survey of Youth 1979, NLSY97: National Longitudinal Survey of Youth 1997, C-NLSY79: Children on the National Longitudinal Survey of Youth 1979, PSID: Panel Study of Income Dynamics; **Canada Child Tax Benefit; ***National Child Benefit Supplement. [†]Unfortunately, this study is flawed by using an IV procedure for ordered choice models of schooling that counts outcomes for certain subsets of the population multiple times and is difficult to interpret economically (see Heckman et al. (2006)) for a critical discussion of the method used.

Table 1b: Studies of Credit Constraints

	Dataset	Outcome Studied: Test Scores (T), Schooling (S)	Timing of Income (Developmental Stage of the Child at Which Constraints are Studied)	Explicit Dynamic Model	Who is Affected by Constraints: Parent of the Agent (P), Agent / Child (C)	Method to Test for Credit Constraints	Find Presence of Credit Constraints	Effect of Income or Constraints on Human Capital Investments
Keane and Wolpin (2001)	NLSY79*	S	L College Enrollment	✓	C	Structural estimation of the lower bound on asset level	YES But irrelevant for schooling decisions	Increase borrowing limit to $3,000 (3× max estimated): no change in mean highest grade completed; +0.2% in college enrollment; -0.2$ on mean hourly wage rate; increase in consumption and reduction in market hours; moderate reduction in parental transfers especially for the least educated parents.
Cameron and Taber (2004)	NLSY79*	S	L Adolescence and College Enrollment	X	C	IV estimation of "returns" to schooling using costs of schooling or foregone earnings as instruments	NO	Theoretical prediction: if borrowing constraints, IV estimates using direct costs of schooling higher than using opportunity costs. Data: IV estimates using the presence of a local college are smaller than the ones using foregone earnings. Regressions which interact college costs and characteristics potentially related to credit availability: no evidence of excess sensitivity to costs for potentially constrained sample. Structural model: almost 0%of the population is found to borrow at a rate higher than the market one.
Caucutt and Lochner (2012)	NLSY79*, C-NLSY79*	T[a]	E and L Childhood and Adolescence	✓	P	Structural estimation of the lower bound on asset level	YES Stronger effect on high skilled parents	50% of young parents are constrained: high school dropouts (50%), high school graduates (38%), college dropouts (60%), college graduates (68%); and 12% of old parents are constrained. Families with college graduate parents benefit the most from a reduction in credit constraints.

E refers to "early" years (childhood), L refers to "late" years (adolescence).
[a] The consequences on child's schooling outcomes are studied as well.
* NLSY79: National Longitudinal Survey of Youth 1979, NLSY97: National Longitudinal Survey of Youth 1997, C-NLSY79: Children on the National Longitudinal Survey of Youth 1979.

4.4.2 Effects of Borrowing Constraints

The literature also analyzes the effect of borrowing constraints on child outcomes. It considers whether there are Pareto-optimal interventions in borrowing markets that can improve the welfare of children and parents, given initial distributions of income (see, e.g., the survey by Lochner and Monge-Naranjo, 2012). If markets are perfect, altruistic parents or selfish parents who can write binding contracts with their children will ensure that marginal returns to investments in skills will equal the market opportunity costs of funds. However, the presence of the parent environmental input θ_P in the technology of skill formation affects the level of investment in children and the initial condition θ_1 (which may be genetically determined) and hence a child's skills and the welfare of the child even with perfect lending and borrowing markets. Allocations are Pareto-optimal *given* initial parental conditions. From other perspectives, however, these market-efficient outcomes may be suboptimal because they depend on the "accident of birth". If, for example, parenting is deficient for whatever reason, choice outcomes might be improved by supplementing family resources (apart from income). A whole host of endowments of the child at the college-going age might be enhanced if the parental environment does not provide the information, the mentoring, and the encouragement (summarized in θ_P and I) children cannot insure against these aspects of the environment.[58]

The recent literature that considers multiperiod childhoods builds on the analysis surrounding equation (9) and investigates the role of *the timing of the receipt* of income as it interacts with restrictions on credit markets and dynamic complementarity. We consider evidence from these strands of the literature.

4.4.3 Restrictions in Lending Markets for College Education

Using a variety of empirical approaches, Carneiro and Heckman (2002), Keane and Wolpin (2001), and Cameron and Taber (2004) find little evidence of an important role

[58] Aiyagari et al. (2002) present an analysis of full insurances against the accident of birth.

for credit constraints in access to college education.[59] Carneiro and Heckman (2002) show that while income is a determinant of enrollment in college, its effect disappears once ability in the adolescent years is controlled for.[60] Cameron and Taber (2004) develop and test the novel theoretical prediction that in the presence of borrowing constraints, instrumental variable (IV) estimates of the Mincer coefficient using direct costs of schooling should be higher than IV estimates using opportunity costs. They reject the hypothesis that there are binding credit constraints.

Belley and Lochner (2007), Bailey and Dynarski (2011), and Lochner and Monge-Naranjo (2012) claim that in later cohorts (in the NLSY97) there is stronger evidence of credit constraints as captured by the estimated effects of quantiles of family income (from whatever source) on college participation.

The Belley and Lochner test of credit constraints is different from the one used in Keane and Wolpin (2001) or Cameron and Taber (2004). They update the NLSY79 analysis of Carneiro and Heckman (2002) using NLSY97 data and claim that credit constraints seem to bind predominantly among less able poor children. However, the Belley and Lochner analysis shows that, across all ability groups, college enrollment increased in 1997 compared to 1979. The increases are more substantial for the more affluent low-ability children.[61]

They estimate the changing effects of affluence by comparing enrollments of children at the same quantiles of family income over time. Their analysis ignores the evolution of the shape of the income distribution over this period. Inequality increases arise mostly from outward shifts of the right tail of the income distribution. Their documented increase in college enrollment of more affluent children might simply be a consequence of paternalism. If the education of children is a normal or supernormal good for families, and higher quantile families receive a disproportionate share of the increase in family income, their results are readily explained.

[59] Keane and Wolpin (2001) provide evidence for constraints affecting other dimensions of behavior such as labor supply.

[60] They also show flaws in the argument proposed by Card (1999, 2001) that evidence of higher IV estimates than OLS estimates of the 'returns' to schooling is evidence of credit constraints.

[61] See Figures H.1 through H.3 of the Web Appendix.

Individuals with low ability, but affluent parents are more likely to enroll in college. The estimates of Keane and Wolpin (2001) suggest that the source of the intergenerational correlation of school attainment is due to more educated parents making larger *tied* financial transfers to their children, conditional on their college attendance. The higher the educational level of the parents, the greater are the tied transfers to their children. Under this scenario, the education of their children is valued by parents as a consumption good (paternalism) even in the absence of a greater return from it.[62] The fact that low income parents with low ability children cannot provide the same tied transfers is a constraint due to the "accident of birth". According to the Keane-Wolpin estimates, if credit constraints are relieved, educational attainment does not increase, while consumption increases and work in school declines. Their evidence suggests that distortions may operate differently at different margins of choice. Interventions may be (conditionally) Pareto-optimal for financing life cycle consumption, but not for schooling. Empirical evidence by Carneiro et al. (2011) and Eisenhauer et al. (2013) using NSLY79 data suggests that for low ability individuals the returns to college enrollment are close to 0 if not negative. If schooling investments are inefficient, there is no clear cost-benefit case for investing in the children of poorer families given parental endowments θ_P.

Despite disagreements on the importance of credit constraints, this strand of the literature agrees that ability is a first order determinant not only of schooling attainment, but also of the returns to schooling. Ability is the outcome of a process that starts early in life.

4.4.4 The Timing of Income, Dynamic Complementarity, and Credit Constraints

[62] Alternatively, parents may prefer in-kind transfers to cash transfers to avoid the "Samaritan's dilemma" (Buchanan, 1975).

The interaction of dynamic complementarity and lifetime liquidity constraints motivates a recent literature. Dahl and Lochner (2012) investigate how credit constraints affect test scores of children in early adolescence. They exploit the policy variation in the Earned Income Tax Credit (EITC) as an exogenous instrument for the effect of income on child outcomes. The EITC does not have a uniform effect across income or education classes.[63] The magnitude of their reported estimated effect of a $1,000 increase in pure transfer is 6% of a standard deviation in test scores. If families take their decisions under the assumption that the policy will persist forever, the cost of the improvements would be large (given by $1,000 times the expected amount of years the average family expect to benefit from the EITC), diminishing further their estimated effect.

The "income effect" that they estimate is not a pure income effect. EITC induces greater employment but may reduce hours of work for workers, depending on where the family is located on the EITC budget set (see Heckman et al., 2003). The evidence from Gayle et al. (2013), Bernal (2008), and Bernal and Keane (2010) suggests that maternal working time has substantial effects on child test scores. Dahl and Lochner (2012) attempt to control for the time allocation effects of EITC (which may reduce parental time with children) but do not control for the endogeneity of the labor supply decisions of the families, or for parental investments.

Duncan et al. (2011) analyze a series of randomized interventions on welfare support. Their estimate of the role of income on test scores is surprisingly similar to the estimate obtained by Dahl and Lochner (2012) for income received and children's test scores at later ages. They do not control for the source of income, any effects on labor supply, or for any subsidy elements for child education. Many of the programs they study subsidize child education. Although they pool evidence from many different programs, their estimates are driven by the results of one particular program in

[63]Some parents might have advance information on expected policy changes. This makes policy changes in the EITC an invalid instrument. Parents who have more information will adjust their investments in advance of receipt of payment. This likely biases downward their estimate.

Canada.[64] An average effect obtained across diverse programs is not an informative guide for policy. It would be more interesting to investigate why apparently similar programs produce such different results and what features make some programs more effective.

Milligan and Stabile (2011) find positive effects of child benefit programs in Canada, but their results are driven by strong positive effects in Quebec, a province where assistance programs consist of more than just income transfers, such as subsidized child care (Almond and Currie, 2011). Evidence of a role of income from whatever source on child outcomes in a reduced form regression that does not separate effects from subsidy and relative price effects is not convincing evidence that credit constraints matter.

Carneiro and Heckman (2002) respond to an analysis by Duncan et al. (1998) that early receipt of family income has more substantial effects on educational attainment than later receipt of income. Expressing income in terms of present value units, and conditioning on an early measure of child ability, they find no effect of the timing of income on child educational attainment. Their analysis has been faulted by Caucutt and Lochner (2012), who argue that the early measure of child ability may be a consequence of receipt of family income in the early years of childhood, and hence understates the importance of early receipt of income.

4.4.5 Lessons from the Literature on Family Income and Credit Constraints

The literature on credit constraints and family income shows that higher levels of parental resources, broadly defined, promote child outcomes. However, a clear separation of parental resources into pure income flows, parental environmental variables, and parental investment has not yet been done. It is premature to advocate income transfer policies as effective policies for promoting child development.

[64]The Canadian Self-Sufficiency Project which does not have a child care component.

The literature establishes the first order importance of child ability for college going, irrespective of family income levels. More advantaged families with less able children send their children to college at greater rates than less advantaged families, but the literature does not establish the existence of market imperfections or any basis for intervention in credit markets. The observed empirical regularity may be due to the exercise of parental preferences. Recent work shows that the returns to college for less able children are low, if not negative.

The literature that presents formal econometric analyses of the importance of credit market restrictions on educational attainment shows little evidence for them. The analysis of Caucutt and Lochner (2012) is an exception. They calibrate that a substantial fraction of the population is constrained due to the interaction of dynamic complementarity, the receipt of income, and the imperfection of lending markets. Much further research is required before definitive policy conclusions can be drawn on the empirical importance of the timing of receipt of income over the life cycle for child outcomes.

4.5 Structural Estimates of Behavioral Responses to Public Policies

Most of the studies of the role of income transfer programs discussed in Section 4.4 do not investigate the interactions of public policy interventions and family investments. In order to do so, some authors have employed fully specified structural models and use them to study the effect of various types of policy experiments. Table K.4 in the Web Appendix reports the outcomes of these policy experiments.

Few clean conclusions emerge and many that do are obvious. The authors estimate different models under different assumptions about their financing. Four main facts emerge from the literature. First, subsidies to parental investments are more cost effective in improving adult outcomes of children such as schooling attainment or earnings, when provided in the early stages of life (Caucutt and Lochner, 2012;

Cunha, 2007; Cunha and Heckman, 2007). Second, financial investment subsidies have stronger effects for families who are already engaging in complementary investments. Targeted public investments and targeted transfers restricted to child related goods that guarantee minimum investment amounts to every child increase the level of investments received by the children of the least active parents (Caucutt and Lochner, 2012; Del Boca et al., 2014). Lee and Seshadri (2014) provide evidence on the importance of targeted education subsidies for increasing the educational expenditures of poor families. Third, time allocation decisions are affected by transfers. Del Boca et al. (2014) show that unrestricted transfers increase the time parents spend with their children through a wealth effect. The increase in child quality is minimal. Lee and Seshadri (2014) show how this effect is especially strong for parents without college education, while, in their model, public transfers negatively affect time spent with children for college educated parents. Fourth, targeted conditional transfers (on child's ability improvements) are more cost effective than pure transfers to achieve any objective.

5 The Implications of Dynamic Complementarity for Investments across Children with Different Initial Endowments

Few models in the literature consider the allocation of investments across multiple children.[65] The average family usually has more than one child, and society allocates public investments across multiple children.

The problem of intra-child allocations is sometimes formulated as a problem in fairness. A CES representation of parental utility V is often used:

$$V = \left(\sum_{k=1}^{N} \omega_k V_k^{\sigma} \right)^{\frac{1}{\sigma}}. \tag{10}$$

[65]See, however Becker and Barro (1988), Gayle et al. (2013), and Del Boca et al. (2014).

V_k represents the adult outcome for child k which is valued by parents.[66] The ω_k are weights assigned to each child and σ is a measure of inequality aversion. A Benthamite model sets $\sigma = 1$ so child utilities are perfect substitutes. A Rawlsian version of maximal inequality aversion is obtained when $\sigma \to -\infty$, so utilities are perfect complements, and parents are concerned only with the maximization of the minimum outcome across children.

In a two child version of the one-period-of-childhood model analyzed by Becker and Tomes (1979, 1986), under complementarity between initial endowment and investment, the optimal policy when $\sigma = 1$ is to invest less in the initially disadvantaged child. Under substitutability it is optimal to invest more in that child.

The story is richer when we consider a multiperiod model with dynamic complementarity. *Investing relatively more in initially disadvantaged young children can be efficient even when the ω_k are equal and $\sigma = 1$* even if there is complementarity in each period of the life cycle. Dynamic complementarity is a force promoting compensating early stage investments even in the absence of family inequality aversion. Thus, in a multiperiod model, where at stage t

$$\theta_{t+1} = f^{(t)}(\theta_t, I_t), \tag{11}$$

even if there is complementarity at all stages so $f_{12}^{(t)}(\cdot) > 0$ (where $(\cdot)$ denotes the argument of the function), output maximizing investments can be compensating.

In the two period–two child model developed in Web Appendix D.7, if $f_{12}^{(1)}(\cdot) < 0$, but $f_{12}^{(2)}(\cdot) > 0$, it is *always* efficient to invest relatively more in the initially disadvantaged child in the first period.[67] But it can also be productively efficient to invest in the disadvantaged child if $f_{12}^{(1)}(\cdot) > 0$, when initial endowments and investments are complements.

The intuition for this result comes from increasing complementarity over the life cycle. In this case, the stock of skills in the second period has a greater effect on the

[66] Behrman et al. (1982) introduced this formulation into the literature.
[67] For a proof, see Section D.7 of the Web Appendix.

productivity of investments than it does in the first period $\left(f_{12}^{(2)}(\cdot) > f_{12}^{(1)}(\cdot)\right)$. First period investments bolster the stock of second period skills and prepare disadvantaged children to make productive use of them in the second period. This effect is stronger when $f_{12}^{(2)}(\cdot)$ is larger. Another force promoting greater initial investment in the disadvantaged child is diminishing self productivity of skills in the first period $\left(f_{11}^{(1)}(\cdot) < 0\right)$. The greater are the diminishing returns to investment for the better endowed child the lower the benefits of early advantage. Diminishing productivity of the stock of second period skills $\left(f_{11}^{(2)}(\cdot) < 0\right)$ operates in the same fashion to limit the effects of initial advantage. The smaller the effect of the initial stock of skills on the productivity of investment in the first period $\left(f_{12}^{(1)}(\cdot)\right)$, the weaker is the disequalizing force of complementarity toward promoting investment in the initially advantaged child.

Roughly speaking, the more concave are the technologies in terms of stocks of skills (the more they exhibit decreasing returns in the stocks of skills), the more favorable is the case for investing in more disadvantaged children. The stronger second period complementarity $\left(f_{12}^{(2)}(\cdot)\right)$, the stronger the case for investing more in the initially advantaged child to build skill stocks to take advantage of this opportunity. The weaker the first period complementarity $\left(f_{12}^{(1)}(\cdot)\right)$, the less offsetting is the disequalizing effect of complementarity coupled with initial advantage.

In general, even when investment is greater in the first period for the disadvantaged child, second period investment is greater for the initially advantaged child. It is generally not efficient to make the disadvantaged child whole as it enters the second period. Greater second period complementarity then kicks in to promote disequalizing second period investments.

Web Appendix D.8 illustrates these general features for CES technologies with different patterns of concavity and complementarity. We review the literature on multi-child investment in Web Appendix D.9.

6 Operationalizing the Theory

A dynamic state space model with constraints and family investment decisions is the natural econometric framework for operationalizing the model of equation (2) and the evolution of capacities, as presented in equation (4). Many studies in the literature focus attention on estimating the technology of skill formation without formulating or estimating models with explicit representation of parental preferences or budget constraints. They account for the endogeneity of input choice through a variety of strategies. This approach is more robust in that it focuses only on one ingredient of a model of family influence. It is, however, clearly limited in the information obtained about the process of human development.

6.1 Skills as Determinants of Outcomes

Cunha et al. (2010) present conditions under which the outcome equations (2) and technology equations (4) are non-parametrically identified. They develop methods for accounting for measurement error of inputs, anchoring estimated skills on adult outcomes (so that scales are defined in meaningful units), and accounting for endogeneity of investments.[68] Heckman et al. (2013) develop and apply simple and easily implemented least-squares estimators of linear factor models to estimate equations for outcomes.

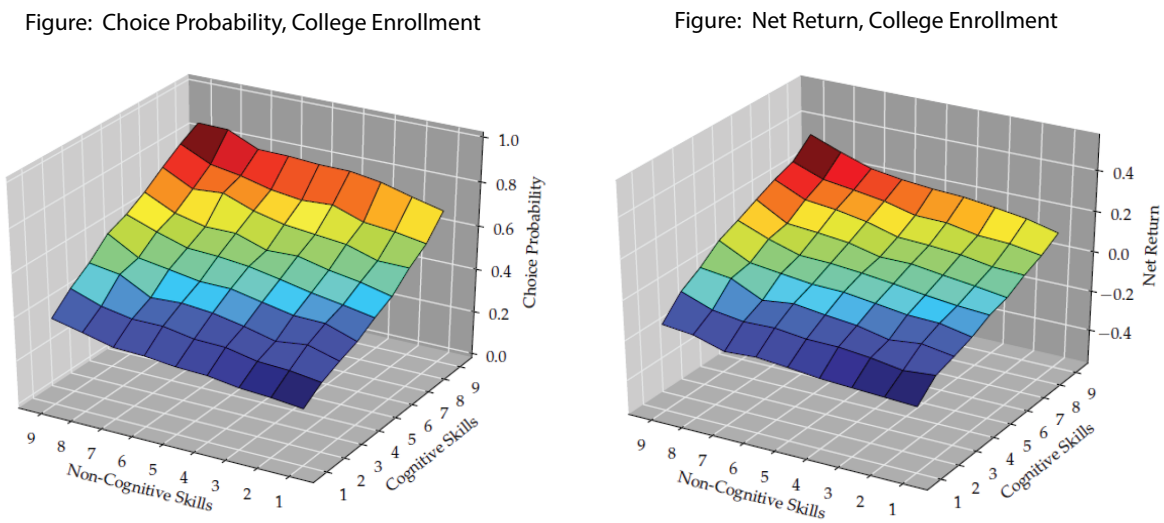
6.2 Multiple Skills Shape Human Achievement Across a Variety of Dimensions

The relationship between the skills estimated in the recent literature that links economics and personality psychology and traditional preference parameters (time

[68]They show that accounting for measurement error substantially affects estimates of the technology of skill formation. Caution should be adopted in interpreting the burgeoning literature regressing wages or other outcomes on psychological measurements. The share of error variance for proxies of cognition, personality, and investments ranges from 30% to 70%. Not accounting for measurement error produces downward-biased estimates of self-productivity effects and perverse estimates of investment effects (Cunha and Heckman, 2008; Cunha et al., 2010).

preference, leisure, risk aversion, etc.) is weak (see Dohmen et al., 2011). This evidence suggests that richer descriptions of preferences and constraints than the ones traditionally used characterize choice behavior. The two literatures complement each other. Figure 1 from (Eisenhauer et al., 2013) plot the probability and the return[69] of enrolling in college immediately after having graduated high school as a function of the deciles of scalar summaries of cognitive and noncognitive skills.[70]

Figure 1: The Probability and Returns of College Enrollment by Endowments Levels



Source: Eisenhauer et al. (2013)
Note: College enrollment refers to the individuals who enroll in college immediately after having finished high school. Returns are expressed in units of millions of dollars. Higher deciles correspond to higher levels. See Eisenhauer et al. (2013) for greater details.

6.3 Estimates of the Technology of Skill Formation in the Literature

The main features of the empirical models of the technology of skill formation are summarized in Table F.1. Most of the literature estimates models only for cognitive

[69]The return is calculated over a 65 years-long working life. Lifecycle earning profiles are simulated using the estimated parameters. See Eisenhauer et al. (2013) for a precise description of model, data and computations.

[70]Section E of the Web Appendix gives a variety of other plots based on the same low-dimensional measures of capability.

skills.[71] Cunha and Heckman (2008) and Cunha et al. (2010) estimate models for both cognitive and noncognitive skills. They report evidence of cross-productivity (that noncognitive skills foster cognitive skills) and that failure to account for noncognitive skills substantially distorts estimates of the cognitive technology. The literature has not yet estimated dynamic models of health.[72]

We briefly summarize the findings of the most general specification estimated to date, that of Cunha et al. (2010). They estimate a model with two stages of childhood (birth through age 4) and later childhood (age 5 through age 14) and two skills (cognitive and noncognitive skill) with skill measures anchored in outcomes.[73]

Their model explains 34% of the variance of educational attainment by the measures of cognitive and noncognitive skills.[74] They find that self-productivity becomes stronger as children become older, for both cognitive and noncognitive skills (i.e., $\frac{\partial \boldsymbol{\theta}_{t+1}}{\partial \boldsymbol{\theta}_t} \uparrow t$).[75] They report asymmetric cross effects. Noncognitive skills foster cognitive investment but not vice versa. There is static complementarity at each stage of the life cycle. Estimated complementarity between cognitive skills and investment becomes *stronger* at later stages of the life cycle. The elasticity of substitution for cognitive skill production is *smaller* in second stage production. This evidence is consistent with emerging dynamic complementarity.[76] However, estimated complementarity between noncognitive skills and investments is roughly constant over the life cycle of childhood. It is slightly easier at *later* stages of childhood to remediate early disadvantage using investments in noncognitive skills. This econometric evidence is consistent with a broad array of evidence from intervention studies across the life cycle which we discuss in Section 7. It is also consistent with a large literature showing the emer-

[71]Section F of the Web Appendix presents a detailed summary of the specifications and estimates of the technology of skill formation listed in Table F.1. There we compare the estimates of self- and cross-productivity and the productivity of investment (of each type).

[72]Shakotko et al. (1981) is an early example of a dynamic model of health. There is no investment, per se, but he models the effect of parental environmental variables on child health.

[73]Since any monotonic function of a test score is still a valid test score, anchoring scores in outcomes is essential for producing interpretable estimates of the technology (see Cunha and Heckman, 2008; Cunha et al., 2010).

[74]They find substantial evidence of measurement error and show the importance of accounting for it.

[75]This is consistent with earlier findings by Cunha (2007) and Cunha and Heckman (2008).

[76]This is also found in Cunha (2007) and Cunha and Heckman (2008).

gence of self-control and other regulatory functions associated with the developing prefrontal cortex (see, e.g., Steinberg, 2007, 2008).

Simulations from their estimated model show that in spite of complementarity between investment and skills at each stage of the life cycle, and emerging dynamic complementarity, a socially efficient policy designed to maximize aggregate education or to minimize crime targets relatively more investment in the early years of children with poor initial endowments, in agreement with the analysis of section 5.[77]

[77] For a more extensive discussion of these results see Cunha and Heckman (2009) and Web Appendix F.

7 Interpreting the Intervention Literature

The models developed in the recent literature in the economics of the family can be used to interpret the intervention literature. Heckman and Kautz (2014) summarize the empirical evidence from a variety of interventions targeting disadvantaged children that range in their target populations from infants to adults. They analyze programs that have been well studied (usually by randomized trials), have long-term follow-ups, and have been widely advocated. Comparisons among programs are problematic as the various programs often differ in the baseline characteristics for the targeted population, in the measurements available to evaluate their effects, and in the packages of interventions offered.

Table I.1 in the Web Appendix summarizes the estimated effects for the most important interventions. Three striking patterns emerge. First, many early childhood interventions have longer follow-ups (10 or 20 years) then adolescent interventions. Second, evaluations of early childhood programs tend to measure cognitive and noncognitive skills in addition to a variety of later-life outcomes. Many evaluations of programs for adolescents focus solely on labor market outcomes. Examination of the curriculum of these programs is necessary to understand their primary program focus (e.g. cognitive or noncognitive stimulation). Third, selection of children into early interventions is often dependent on parental choices, while adolescents participants decide themselves whether to opt in.

Three main findings emerge. First, only very early interventions (before age 3) improve IQ in a lasting ways consistent with the evidence that early childhood is a critical period for cognitive development. Second, programs targeting disadvantaged adolescents are less effective than early intervention programs. This evidence is broadly consistent with dynamic complementarity. The few successful programs are a consequence of the direct effect of incentives put in place in these programs (versions of incapacitation effects), but they fail to have lasting effects. Third, the most promising adolescent interventions feature mentoring and scaffolding. They often integrate

work with traditional education and attenuate the rigid separation between school and work that characterizes the American high school. Mentoring involves teaching valuable character (noncognitive) skills (showing up for work, cooperating with others, and persevering on tasks). The effectiveness of mentoring programs is consistent with the evidence on the importance of attachment parenting and interaction discussed below. Some form of mentoring and parenting is present in all successful intervention programs at all stages of childhood.

7.1 The Mechanisms Producing the Treatment Effects

The literature on program evaluation usually focuses on estimating treatment effects and not the mechanisms producing the treatment effects. The model of skill formation presented in this paper facilitates understanding of the mechanisms producing treatment effects by distinguishing the effect of interventions on the vector of skills $\boldsymbol{\theta_t}$ (equation (4)) from the effects the skills themselves have on outcomes (equation (2)). It facilitates unification of the family influence literature with the literature on treatment effects.

Heckman et al. (2013) use the dynamic factor approach discussed in Section 6 to study a major intervention with a long-term (age 40) follow-up of the Perry preschool program.[78,79] They decompose the experimentally determined treatment effects for adult outcomes into components due to treatment-induced changes in cognitive and noncognitive capacities. They show how the effects of the program primarily operate through enhancement of noncognitive skills.[80] The program boosted adult health, education, wages, and reduced crime and social isolation for males and females.

[78]The program provided disadvantaged 3 and 4 year old children the social and emotional stimulation available to most children from more advantaged families (see Griffin et al., 2013). The program is discussed in detail in Subsection I.1.2 of the Web Appendix.

[79]It has a rate of return of 7–10% per annum for boys and girls, analyzed separately (Heckman et al., 2010a,b).

[80]The program and the decomposition are presented in Section I.1.2 of the Web Appendix. See Table I.2 and Figures I.1–I.5.

The core ingredients of the Perry program are similar to those of the ABC program (see Griffin et al., 2013). Both promote cognitive and noncognitive skills through scaffolding the child. A long-term evaluation of the ABC program shows striking effects on adult health and other child outcomes (see Campbell et al., 2013). The program boosted the cognitive and noncognitive skills of participants which led to healthier lifestyle choices. This emerging body of research demonstrates the value of the skill formation approach for interpreting and guiding the analysis of interventions.

8 Attachment, Engagement, and Interaction: Toward a Deeper Understanding of Parenting, Mentoring, and Learning

A major lesson from the intervention literature is that successful early childhood interventions scaffold children and supplement parenting. They generate positive and sustained parent-child interactions that last after the interventions end. When programs strengthen home environments in lasting ways, the effects of any intervention are more durable. The early investment administered by an effective program stimulates parental investment contemporaneously, which, through complementarity between parental skills and investment, enhances the impact of any intervention.

This section reports evidence of the impacts of interventions on parent-child interactions. Successful interventions are more than just subsidies to disadvantaged families. They scaffold children by interacting closely with them, encouraging and mentoring them, mimicking what successful parents do.[81] Recent evidence shows that they are also effective in increasing the parental capacities to provide mentoring and scaffolding after the interventions are over.[82]

8.1 Parental Responses to Intervention

Altering the course of parental investment and engagement with the child during and after the preschool years extends the reach of any intervention as parents nurture their children through childhood. In the presence of dynamic complementarities in the production function for capacities, the most effective remediation strategy for disadvantaged children is to couple increased early investments with increased later ones. Improving parenting is a complementary investment. Section J of the Web Appendix presents evidence for some major early childhood programs on parental re-

[81] This is consistent with the wisdom of John Dewey summarized in Appendix N.
[82] See the evidence in Web Appendix J.

sponses to interventions in terms of interactions with the child and in terms of boosting the quality of home environments. On a variety of dimensions, these programs increase the parental investments of treated group members during the course of their intervention. Parents held more positive views about parenting and their role in shaping the character and abilities of their children. Parental attitudes and the home environment also improved. Follow-up measurements provide evidence of the capacity to permanently alter the parents' investment strategy. If after a few years of formal intervention it is possible to boost parental investment for all child-rearing years, the potential for improvement grows substantially. The mechanisms through which these programs are effective are enhanced information (as in the Nurse Family Partnership program)[83], changing the preferences of the response of a parents to the enhanced curiosity and engagement of the child induced by participation of the program.[84]

8.2 What Parents Know and How They Parent

There are two main explanations for the changes in parental behavior induced by successful interventions. First, intervention increases the child's skills and this in turn induces a change in parental behavior. This is consistent with the complementarity central to the models presented in Section 4. Second, the interventions may convey information to the parents about their child's skills, on successful investment strategies and on their returns, and thereby increase parental knowledge. The evidence on the effectiveness of the Nurse Family Partnership Program shows that giving beneficial information to parents improves child outcomes and changes parenting behavior.[85]

The research of Cunha et al. (2013) directly investigates beliefs and information mothers have about parenting. They find considerable heterogeneity among less edu-

[83]See Web Appendix I.1.

[84]Cole et al. (2012) and Conti et al. (2012) experimentally examine the role of parenting and attachment on the health and genetic expression of rhesus monkeys. They establish that when infant monkeys are deprived of early stimulation and interaction with their mothers, their gene expression is altered in ways that make them more susceptible to disease in adulthood. See Suomi (1999) for discussion of a systematic body of evidence on withdrawal of attachment and stimulation on monkey development.

[85]Heckman and Kautz (2014) discuss the evidence on the effectiveness of the NFP program and provide detailed references to numerous evaluation studies.

cated mothers. Compared with a benchmark estimated technology, socio-economically disadvantaged mothers underestimate the responsiveness of child development with respect to investments.

National samples also provide evidence that maternal knowledge is a main factor in explaining differences in the amount of activities children are involved in. Through in-depth interviews of dozens of middle class, working class, and poor families, Lareau (2011) shows that professional parents often engage children after an activity to determine what they have learned, while in working-class homes those activities are mostly viewed as finalized at children's amusement doing them. Middle class families have a better understanding of the educational institutions their children are involved with and hope to attend. They also intervene far more frequently on their child's behalf, whereas working class and poor families generally allow the school to guide their child's educational decisions. Additionally, for middle-class families, social ties tend to be woven through children's lives, especially through the organized activities they participate in, as well as through informal contacts with educators and other professionals. In contrast, the social networks of working-class and poor families tend to be rooted in and around kinship groups. Ties to other parents and to professionals are considerably less common (Lareau and Cox, 2011).

8.3 Towards a More General Model of Parent-Child Interactions

The productivity of any investment or parental stimulus is influenced by the child's response to it. Parents and children can have different goals. For example, the child can be more shortsighted than the parent (Akabayashi, 2006) or have different values for leisure and future human capital (Cosconati, 2013). The parent may act as a principal whose goal is to maximize the effort from an agent—their child. The child's ability and effort are not observed by the parent and this creates a moral hazard problem. As the interaction is repeated over time, parents can learn about the child's ability by us-

ing responses to stimuli as signals of it. The greater the knowledge about the child's ability, the easier it is for the parent to induce the desired effort via better-targeted stimuli.

The models discussed thus far do not consider the role of a child's own actions on his human capital accumulation, nor do they consider parental learning about child ability and about the most effective parenting strategies. In most of the literature, parental investments are assumed to be made under perfect knowledge of the child's current skills as well as the technology that determines their law of motion. In truth, parent-child interactions are an emergent system shaped by mutual interactions and learning (Gottlieb, 1999; Sroufe et al., 2005). Parents learn about a child's characteristics and about the effectiveness of their investments by observing their child's behavior and directly interacting with the child. A child's accumulation of skills is a process of learning guided by the mentoring role of parents and educators. Parental guidance often involves conflicts with the child's own desires. Paternalistic parents evaluate the child's future outcomes differently than the child does, and the capacities, knowledge, and autonomy of the child evolve with experience. A richer model of child learning investigates the formation of agency of the child—his ability to shape his own environment including his learning environment. As children mature they generally make wiser choices.[86]

Akabayashi (2006) is one of few examples of a model of parent-child interactions and parental learning in the literature.[87] He considers a framework in which a myopic child does not take into account the value of future human capital. As the child's effort is productive, but unobservable to the parent, an altruistic parent forms beliefs on the child's human capital and effort from observations of his performances and incentivize effort by choosing the quality of interactions (praise or punishment) to engage the child. This process of interaction determines the evolution of a child's skills and parental beliefs. Substantial uncertainty about a child's human capital might pro-

[86]Even ardent libertarians like Mill (1859) grant a role for informal paternalism on the part of the parents.
[87]We summarize this literature in Table K.5 in the Web Appendix.

duce divergence between parental expectations about it and its actual level leading to pathological interactions such as maltreatment.

Cosconati (2013) relaxes Akabayashi's myopic child assumptions and develops a related model of parent-child interactions where parents are also more patient than their child and cannot directly observe his effort. To incentivize effort and human capital accumulation, parents limit the child's leisure. The stricter the limits set by the parents, the higher is their monitoring cost. Cosconati shows how an authoritative parenting style (Baumrind, 1968) emerges in equilibrium as the optimal strategy for parents. He presents preliminary estimates of his model.

The preceding models are built around "arms-length" parent-child interactions where parents respond to child behavior and children reciprocate. The model of Lizzeri and Lizzeri and Siniscalchi (2008) involves a deeper type of interaction where parents can help the child in performing a task (e.g., getting good grades in school). Failure to properly perform the task has negative consequences for the child's utility. For this reason, the parents may help the child in order to make them happier. If the child fails, however, he learns about his ability and this has long-term benefits. If the child is helped to avoid failure due to deficiencies in his own ability, learning is diminished. This creates a tradeoff in parental preferences. They prove that partial sheltering from failure (limited parental intervention) is optimal. The model generates correlations patterns between parents' and children's performance that are consistent with what is found in the literature on behavioral genetics. Contrary to the interpretation in a literature that claims a limited role for parental influence (Harris, 2009), the observed correlations are the result of successful active parenting.[88]

These studies go behind the technology of skill formation to understand the interactions that transform time and goods investments to shape children's capacities. They are the first step toward formalizing notions such as attachment, mentoring, and scaffolding that have long been associated with the successful process in human development (see Sroufe et al., 2005; Vygotskii, 1978). They help to explain the observed

[88]The model of multiple children presented in Section 5 can rationalize the evidence on limited impacts of *common* family influences. Child investment is individuated for reasons of both equity and efficiency.

heterogeneity in parental behavior and help interpret why interventions promoting parental engagement with the child show stronger beneficial long term results. A greater knowledge of the mechanisms behind learning are crucial for the design of more effective policies and interventions. Successful interventions alter parental behavior. Understanding why this happens, how parenting can be incentivized and through which channels parenting influences child development are crucial tasks for the next generation of studies of child development.

9 Summary

This paper reviews a vibrant recent literature that investigates the determinants and consequences of parental actions and environments on child outcomes. It documents differences in investments received by children of different socioeconomic status.

The recent literature is based on multiple generation models with multiple periods of childhood and adulthood. It emphasizes the dynamics of skill formation. Central to the literature are the concepts of *complementarity*, *dynamic complementarity*, *multiplicity of skills* and *critical* and *sensitive periods* for different skills. These concepts account for a variety of empirical regularities that describe the process of human development.

Family environments during the early years and parenting are critical determinants of human development because they shape the lifetime skill base. Through dynamic complementarity they enhance the productivity of downstream investments. We establish conditions under which it is socially productive to invest in the early years of disadvantaged children. These conditions are supported by evidence from the literature. Later stage remedial interventions are generally less effective, especially if they target IQ. Interventions aimed at disadvantaged adolescents can be effective if they target enhancement of noncognitive capabilities.

The evidence summarized here demonstrates the value of a perspective with multiple skills. An approach based on the dynamic evolution of skills unifies the literature on family economics with the intervention literature.

The role of the timing of the receipt of income and the role of credit constraints in shaping child development is closely examined. We find that the importance of these factors in shaping child outcomes has been exaggerated in the recent literature compared to the importance of parenting and mentoring. Untargeted cash transfers are unlikely to be effective in promoting child skills.

Mentoring, parenting and human interaction are the unifying themes of successful skill development strategies across the entire life cycle. The study of parent-child interactions as an emergent system is a promising approach to human development.

Effective early life interventions promote beneficial changes in parenting. The analysis of parent-child interactions and parental learning, the formalization of the notions of attachment, mentoring and scaffolding and their integration into life-cycle overlapping generational models with dynamic skill accumulation constitute the research frontier in the field.

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