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Abstract

Childhood health affects both future health and skill accumulation, giving rise to disparities in human capital. I estimate flexible production functions of health, cognition and socio-emotional skill between 9 months-14 years of age that capture dynamic relationships between past stocks of human capital, parental human capital and household investments. Using multiple measures of inputs and a latent factor structure, I find that health development is highly self-productive and influenced by parental health, but that skills affect its development in late childhood. Health is important for cognitive development at key early and late stages, and excluding it overstates cognition's role in skill accumulation. Simulations show that interventions aimed at improving the health of children or their parents lead to improvements in health and skills at 14.

Keywords: Human capital, child development, dynamic factor analysis, health, cognitive skills, socio-emotional skills
JEL codes: I12, I14, J13, J24

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1 Introduction

The longlasting social and economic effects of poor childhood health are now well documented - those who suffer from poor health in childhood on average obtain less education, have lower income, and worse health in adulthood than those who enjoy good health over the same period (Case et al., 2005; Currie, 2009). These disparities are, however, not random: a growing body of evidence suggests strong links between early health and socio-economic status, measured by parental income and education levels (Case et al., 2002; Currie, 2009; Conti et al., 2010). However, relatively little is known about the process through which health is "accumulated" over childhood, or how it interacts with other aspects of the early developmental environment to generate disparities in human capital.

The process of human capital development is also complex. For a child, having good health today does not only increase the likelihood of being in good health tomorrow, but also that they develop important cognitive and socio-emotional skills (Currie, 2009).[1] Similarly, a broad range of cognitive and socio-emotional skills develop in tandem over childhood (Cunha and Heckman, 2008; Cunha et al., 2010), at the same time as households make decisions about the allocation of time and resources both in and outside the household. This creates a rich set of interactions that govern how health - and human capital more generally - is built up over children's early years. Understanding how, when, and to what extent health factors into the human capital development process is crucial in understanding how poor health arises and persists in children. Given that health is positively correlated with various cognitive and socio-emotional skills, it is also essential in order to accurately describe how skills develop and interact with one another over childhood.

Using fourteen years of detailed longitudinal data on roughly 11,000 UK-born children, this study makes two contributions to this understanding. Firstly, I estimate flexible health production functions across five stages of childhood between the ages of 9 months and 14 that capture important interactions between health, skills, parents' human capital, and household health investments. Using the detailed nature of the data and recent methodological advances (Agostinelli and Wiswall, 2016a), I estimate these production functions allowing for multiple mis-measured inputs and a latent factor structure. Second, I estimate similar production functions for cognitive and socio-emotional skill, allowing for the impact of health and health investments on their development. To the best of my knowledge this is the first study to do both of these in the context of a high-income country. I then simulate policy interventions and analyse how income transfers, health improvements, and increases to parents' human capital affect accumulation of health and skills. Together, these exercises build on an important and growing body of work on the early origins of inequality to broaden the understanding of human capital development, and how it is affected by health.

[1] Human capital is multidimensional. However, throughout, in line with the literature and in the interest of brevity, I use the term "human capital" to refer to three broad groupings of individual characteristics - "health", "cognitive skills", and "socio-emotional skills" - as these are the focus of this paper.

Over the past two decades, the growing economics literature on human capital development has centered mainly on the understanding how cognitive and socio-emotional skills develop and are determined by household behaviour over childhood (e.g Cunha and Heckman (2008), Cunha et al. (2010), Attanasio et al. (2020b)). The result has been progress towards formalising and quantifying several important aspects of skill accumulation. For example, a central question has been identifying the malleability of skills, when investments in children's development are most productive, and whether their returns are higher in those with low or high levels of skill - what have come to be known as *dynamic complementarities* (Cunha et al., 2010; Agostinelli and Wiswall, 2016a). Only two studies to date have analysed the development of health and skills over childhood, however. By jointly estimating production functions of health and cognition, Attanasio et al. (2017, 2020c) find that health affects early cognitive development, but that there is no impact in the opposite direction. These studies are based on samples of children in developing countries, however, where the health-related environment differs a great deal to that in developed countries.[2] They are also not able to use longitudinal data covering all of childhood or consider health's impact on socio-emotional development (or vice versa).

As a result, there is far less understanding of how, or if, the insights from the literature on skill development extend to health. I find that the development of health - measured for example by long-term illnesses, health conditions, and parents' subjective assessments - is *rigid*. Across all of childhood, health is highly self-productive and unaffected by little other than parents' health. It is also far less malleable than cognitive or socio-emotional skill, which, although in different settings, is broadly in line with the two studies that have estimated the production function of health (Attanasio et al., 2017, 2020c). I do find, however, that cognitive and socio-emotional skills become important determinants of health in the early teenage years. Children's autonomy undoubtedly grows over this period as children increasingly make lifestyle choices of their own, and this suggests children with high levels of skill do so in a manner which positively affects health. In a cross-cohort comparison between the MCS data and a similar, older longitudinal UK survey, Attanasio et al. (2020a) find that socio-emotional skills at age 5 influence BMI and the likelihood a child has tried smoking 14 (16 in the older cohort). The results of this paper add to this evidence, implying that skills in early adolescence begin to affect health more generally.

In estimating the production functions of cognitive and socio-emotional skill, I find that health is an important determinant of cognition in key early and late stages of childhood, between the ages of 9 months and 3, 11 and 14 respectively. This is, in part, similar to the findings of Attanasio et al. (2017, 2020c), who find early health affects cognitive development, but is in contrast to evidence that cognition is largely self-productive at later stages of childhood (Cunha et al., 2010; Agostinelli and Wiswall, 2016a; Attanasio et al., 2020c). Health investments are also important in developing both cognitive and socio-emotional skills, implying that, although they have no direct effect on health, there are spillovers from investing in health. Various studies

[2]See for example, Lu et al. (2016) on the prevalence of poor health in low and middle-income countries, and Peters et al. (2008) on access to health care in developing countries.

have found links between early health or health shocks, parental investment and cognitive skills later in life (e.g Yi et al. (2015),Bharadwaj et al. (2018)), however I find that health investments have an impact on cognitive - and to a lesser extent socio-emotional - skill development across several different stages of childhood. I also find that excluding aspects of health and the healthy environment from the cognitive production function leads to an overstatement of the self and cross-productivity of skills and the impact of cognitive investments at these key stages. This highlights the importance of allowing for the impact of health in a model of skill development, and implies that studies that have not done so have risked overstating elasticities of skill production (e.g Cunha et al. (2010), Agostinelli and Wiswall (2016a), Attanasio et al. (2020b)).

To show the implications of these results, I then use estimates of the distribution of children's initial conditions to simulate the developmental path of health and cognitive and socio-emotional skill. These simulations result in only a small income gradient in health at the end of childhood that appears between the age of 7 and 14 - one that is significantly smaller than might be inferred from using only one as opposed to multiple measures of health. There is a similar gap in socio-emotional skill, however inequality across the income distribution is largest for cognition. A central question in the human capital development literature is whether or not disparities in human capital that perpetuate disadvantage can be closed using policy interventions. To answer this question I then simulate the effect of several policies on health and skill development.

The results show that unconditional income transfers have very little effect on health, but that those aimed at improving children's health directly or the health of their parents result in large effects by the end of childhood. Health improvements also lead to modest improvements in cognitive and socio-emotional skills, and have their largest impact in late childhood. This finding contrasts much of the literature which has so far argued that interventions have their highest returns in late childhood (e.g Cunha et al. (2010), Agostinelli and Wiswall (2016a), Attanasio et al. (2020c)). I estimate that the effects of income or health based interventions fade out as opposed to build over time, however, and that health and skills remain malleable over the early teenage years. This means that improving health late has large effects on health itself as well as cognitive skills, and suggests that there is opportunity for interventions to mediate health and skill gaps in later childhood.

The remainder of this paper has five main components. Section 2 first outlines an empirical model of human capital development and household investment, as well as the methodology used to estimate it. Section 3 then describes the MCS data in more depth, and details the measures of health, cognition, socio-emotional skill, parental human capital and investment it has available. It also shows descriptive evidence as to health inequalities in the sample. Section 4 provides estimates of the parameters of the empirical model, and Section 5 presents results from using these to simulate the developmental paths of health and skills with and without policy interventions. Finally, Section 6 concludes.

2 A Conceptual Framework for Human Capital Development

I follow the conceptual framework of Agostinelli and Wiswall (2016a), but focussing on the evolution of health ($H_{h,t}$) over childhood, from age 9 months to 14 years. I then analyse how health impacts on the development of cognitive ($H_{c,t}$) and socio-emotional skill ($H_{s,t}$) over the same period. While health, cognition, and socio-emotional skill are comprised of complex traits and characteristics, I abstract from analysing the development of specific sub-elements of human capital and focus on these "aggregates".[3]

In this framework, childhood consists of T discrete periods and the accumulation of human capital over these periods is governed by four main features. First, the initial conditions a child faces upon birth. These are comprised of initial stocks of health, cognition and socio-emotional skill - denoted by $H_{h,0}$, $H_{c,0}$, and $H_{s,0}$ - the health, cognitive and socio-emotional skill of their parents - $P_h P_c$, and P_s - and income, Y_0. Second, in each of the T periods there is a function determining how parents' investments in health ($I_{h,t}$) and cognition ($I_{c,t}$) are influenced by children's human capital stocks, endowments, and household income. Thirdly, and again in each of the T periods, there is a function that maps some combination of endowments, children's contemperaneous human capital, and parental investments into human capital in the following period. Lastly, I assume that children's and parents' health and cognitive and socio-emotional skill and investments are unobservable.[4] As such, I specify a measurement system that relates these latent variables with observed measures, denoted by $Z_{\theta,m,t}$ for $\theta_t \in \{H_{h,t}, H_{c,t}, H_{s,t}, P_h, P_c, P_s, I_{c,t}, I_{h,t}\}_{t=0}^{T}$ throughout.

2.1 Initial Conditions

The vector of initial conditions in the initial period (t=0) can be written as:

$$\mathbf{\Omega} = (\ln H_{h,0}, \ln H_{c,0}, \ln H_{s,0}, \ln P_h, \ln P_c, \ln P_s, \ln Y_0)\,, \tag{1}$$

where $H_{k,0}$ and P_k for $k \in \{h, c, s\}$ represent child and parental stock of human capital component k, and Y_0 is family income. I assume that parents' human capital is time invariant and so captured by their stocks of health, cognition and socio-emotional skill in the initial period. In this sense, they can be thought of as capturing wider circumstantial "endowments" that don't vary across childhood.

Further, I assume that

$$\mathbf{\Omega} \sim N(\boldsymbol{\mu}_\Omega, \boldsymbol{\Sigma}_\Omega)\,,$$

[3]This assumption is commonplace in the economics literature on human capital development. For example, Cunha and Heckman (2007, 2008); Cunha et al. (2010), Attanasio et al. (2017, 2020b,c), Agostinelli and Wiswall (2016a) all make similar assumptions, treating components of human capital aggregates or composites of the many underlying dimensions.

[4]Due to data limitations, in the empirical application of this model I do not assume parents' cognition is unobservable. I maintain this asumption here for ease.

where $\boldsymbol{\mu}_\Omega$ and $\boldsymbol{\Sigma}_\Omega$ are the mean vector and covariance matrix of the initial conditions respectively. Importantly, this assumption relates to the joint distribution of the latent variables in the initial period only and not over time. Doing so would mean ex-ante restricting the paramaters - such as the elasticity of substitution - of the human capital production functions (Cunha et al., 2010). I discuss this in more detail when describing these functions in Section 2.3.

2.2 Investment

I do not not embed the production functions in a structural model of household choice (as in e.g Del Boca et al. (2013)), but rather specify a reduced form approximation of a household investment policy function. In each of the T periods of childhood, I assume parents make two distinct types of investment in health and cognitive skill, and that their decisions to invest are determined by contemporaneous stocks of child health, cognitive and socio-emotional skill, their own human capital and household income (Y_t).[5] Investment in $j \in \{h, c\}$ can then be written as:

$$\begin{aligned} \ln I_{j,t} = \beta^j_{1,t} \ln H_{h,t} + \beta^j_{2,t} \ln H_{c,t} + \beta^j_{3,t} \ln H_{s,t} + \beta^j_{4,t} \ln P_h \\ + \beta^j_{5,t} \ln P_c + \beta^j_{6,t} \ln P_s + \beta^j_7 \ln Y_t + \pi_{j,t} , \end{aligned} \tag{2}$$

where $\pi_{j,t}$ is a mean zero shock to investment with variance $\sigma^2_{\pi_{j,t}}$. Equation 2 can be thought of as an approximation to a wide variety of investment functions that might be derived from models of household choice and child development, and have become widely used in similar studies.[6] The flexibility in these functions comes with a cost, as it abstracts from both parental preferences and beliefs about the production technology and the return to their investments (e.g Cunha et al. (2013), Biroli et al. (2018)), as well as from labour supply decisions (Del Boca et al., 2013). This lack of structure means the parameters of Equation 2 have no strict, theoretical interpretation.

Here, however, and as in the literature more generally, I interpret $\beta^j_{i,t} > 0$ for $i = 1, 2, 3$ to broadly indicate reinforcement of skills by parents, and $\beta^j_{i,t} < 0$ for $i = 1, 2, 3$ to indicate compensation. In the former case parents would invest more in their child upon realising they have high stocks of human capital, and in the latter they would invest more upon realising the reverse. The parameters $\beta^j_{i,t}$ for $i = 4, 5, 6$, simply capture how parents' investment decisions are influenced by their own stocks of human capital. In the estimation of this empirical model I consider mainly *time* investments. For example, a health investment may be how often a parent

[5]It is difficult to define investments made specifically in socio-emotional skill, so I define investment types in this way and assume they have spillover effects of socio-emotional development. Cunha et al. (2010), Attanasio et al. (2020c), and Agostinelli and Wiswall (2016a) include one investment type in their estimations. Attanasio et al. (2020b) allows for material and non-material investments in their evaluation of the impact of a Randomized Control Trial (RCT) on the produciton of cognitive and socio-emotional skill. The production function of health over childhood has also been less widely studied than that of cognitive and socio-emotional skill.

[6]For example, Cunha et al. (2010), Attanasio et al. (2017, 2020b,c), and Agostinelli and Wiswall (2016a) all specify similar relationships between investments, child human capital, endowments, and household characteristics.

plays active games outdoors with their child or how often they ensure the child has regular meals. In this case, $\beta^h_{4,t} > 0$ would mean healthier parents invest more time in their child's health by these means.

2.3 Health Production Functions

I assume that in each of the T periods of childhood, a child's future health is a function of their current health, and cognitive and socio-emotional skill, their parent's human capital, and health investments made by their parents ($I_{h,t}$). To allow for flexibility in the relationship between inputs, I specify the following translog health production function:

$$\ln H_{h,t+1} = \ln A_t + \rho^h_{h,t} \ln H_{h,t} + \rho^h_{c,t} \ln H_{c,t} + \rho^h_{s,t} \ln H_{s,t} + \alpha^h_{h,t} \ln P_h + \alpha^h_{c,t} \ln P_c + \alpha^h_{s,t} \ln P_s + \gamma^h_{h,t} \ln I_{h,t} + \kappa^h_{hh,t}(\ln I_{h,t} \times \ln H_{h,t}) + \eta_{h,t}\,, \tag{3}$$

where $\eta_{h,t}$ is a shock to health production assumed to be independent of all the inputs and distributed normally with zero mean and variance $\sigma^2_{\eta_{h,t}}$. The parameter $\rho^h_{h,t}$ indicates the level of *self-productivity* (or *persistence*) of health over time, whereas $\rho^h_{c,t}$ and $\rho^h_{s,t}$ represent the *cross-productivity* of cognitive and socio-emotional skill in health accumulation respectively. The function in Equation 3 can also be expanded to include interactions between any two inputs. Here, I focus on the interaction between health and health investments so admit only the interaction between the two. The elasticity of health production with respect to health investment, $\ln I_{h,t}$, is then given by:

$$\frac{\partial \ln H_{h,t+1}}{\partial \ln I_{h,t}} = \gamma^h_{h,t} + \kappa^h_{hh,t} \ln H_{h,t}$$

When the coefficient on the interaction term is constrained to equal 0, i.e $\kappa^h_{hh,t} = 0$, then the elasticity is simply given by $\gamma^j_{k,t}$, and the production function is Cobb-Douglas. An important feature of the technology in Equation 3 is that it allows these coefficients to be different from 0, and the elasticity of substitution between investments and other inputs to vary across the distribution of skill. More generally, it does not impose that the elasticity of subsitution be constant without further restrictions on the paramaters of the production function. For example, it allows the degree of substitutability between health and investments ($H_{h,t}$ and $I_{h,t}$), and health endowments and investment (P_h and $I_{h,t}$) to differ in the production of health ($\ln H_{h,t+1}$). Assuming a constant elasticity of substitution (CES) function, would mean imposing that, for example, these two elasticities were equal (e.g Cunha et al. (2010) and Attanasio et al. (2017, 2020b,c)).

The interpretation of the elasticity above depends on the sign of each $\kappa^h_{hh,t}$. If, for example, $\kappa^h_{hh,t} > 0$ then health investments are more productive in children who are already in good health. Conversely, if $\kappa^h_{hh,t} < 0$ the opposite is true: investments in health are more efficient when made in children with relatively poorer health. In the former case, these *dynamic complementarities* can contribute to the widening of human capital gaps across childhood (Cunha et al., 2010). In the latter case ($\kappa^h_{hh,t} < 0$), however, it is possible that investments are a channel through which human capital disparities can be reduced. How this elasticty evolves over time also determines the efficacy of investments, and when interventions might have their largest impact. If $\kappa^h_{hh,t} = 0$ then these dynamic relationships do not exist. Similarly, how $\rho^h_{h,t}$ evolves across periods determines the extent to which improvements in health will persist. In combination, it is these features of the developmental process that determine whether the effects of increases in investments or health improvements build over time or fade.

2.4 Health and Skill Development

I again specify a flexible translog technology for the production functions of cognitive and socio-emotional skill, and assume t+1 skills are a function of the same three types of input: lagged human capital, parents' human capital and investments. For skills I include both cognitive ($I_{c,t}$) *and* health investments ($I_{h,t}$) to allow for spillovers from the latter to skill production. The production function of $H_{j,t+1}$ for $j \in \{c, s\}$ can be written as:

$$\begin{aligned} \ln H_{j,t+1} = & \ln A_t + \rho^j_{h,t} \ln H_{h,t} + \rho^j_{c,t} \ln H_{c,t} + \rho^j_{s,t} \ln H_{s,t} + \alpha^j_{h,t} \ln P_h + \alpha^j_{c,t} \ln P_c + \alpha^j_{s,t} \ln P_s \\ & + \gamma^j_{h,t} \ln I_{h,t} + \gamma^j_{c,t} \ln I_{c,t} + \kappa^j_{jh,t}(\ln I_{h,t} \times \ln H_{j,t}) + \kappa^j_{jc,t}(\ln I_{c,t} \times \ln H_{j,t}) + \eta_{j,t} , \end{aligned} \tag{4}$$

where, again, $\eta_{j,t}$ is a shock to production assumed to be fully independent of all inputs and distributed normally with zero mean and variance $\sigma^2_{\eta_j,t}$. All of the parameters of Equation 4 have identical interpretations to their analogues in Equation 3. For example, $\rho^j_{j,t}$ represents self-productivity, $\rho^j_{k,t}$ for $k \neq j$ cross-productivity, and $\kappa^j_{jk,t}$ for $k \in \{h, c\}$ dynamic complementarity between skill j and investment k. Given the focus of this study is health, of particular interest here is $\rho^j_{h,t}$ - the cross-productivity of health in skill production. The elasticity of $\ln H_{j,t+1}$ with respect to, for example, health investment is given by:

$$\frac{\partial \ln H_{j,t+1}}{\partial \ln I_{h,t}} = \gamma^j_{h,t} + \kappa^j_{jh,t} \ln H_{j,t} \tag{5}$$

These give us an indication of the role of the healthy environment in the development of both cognitive and socio-emotional skills. The same interpretation of the elasticities of skills with respect to investments and their self-productivities applies here - together their evolution over time determines how and when skill gaps emerge, as well as how they might be reduced.

2.5 A Measurement System for Unobservables

Given that there are no perfect measures of the inputs into the investment and human capital production functions, they cannot be straightforwardly estimated from data. The data I use to estiate the model contains various imperfect measures, each of which proxies, for example, latent health or household investment with some error. As such, I further assume a relationship between observed variables and unobservable inputs into the human capital production and investment functions. For observable measure $Z_{\theta,m,t}$ and corresponding unobservable variable $\theta_t \in \{H_{c,t}, H_{s,t}, H_{h,t}, P_s, P_h, I_{c,t}, I_{h,t}\}_{t=0}^{T}$ I assume that

$$Z_{\theta,m,t} = \mu_{\theta,m,t} + \lambda_{\theta,m,t} \ln \theta_t + \varepsilon_{\theta,m,t} \qquad m = 1, ..., M_{\theta_t}\ , \tag{6}$$

where $\mu_{\theta,m,t}$ is an intercept, $\lambda_{\theta,m,t}$ a factor loading, and $\varepsilon_{\theta,m,t}$ an idiosyncratic measurement error assumed to be mean zero.[7] The factor loading $\lambda_{\theta,m,t}$ indicates how movements in θ_t are observed in $Z_{\theta,m,t}$. The set of measures of each latent variable, M_{θ_t}, can can vary across time. This means the latent variables can be expressed as a function of error-contaminated measures in a standard errors-in-variables fashion. From 6 I can define:

$$\ln \theta_t \equiv \frac{Z_{\theta,m,t} - \mu_{\theta,m,t}}{\lambda_{\theta,m,t}} - \frac{\varepsilon_{\theta,m,t}}{\lambda_{\theta,m,t}} = \tilde{Z}_{\theta,m,t} - \tilde{\varepsilon}_{\theta,m,t} \tag{7}$$

Given that these latent variables have no inherent origin or scale, normalizations must be imposed on the parameters of Equation 6 to identify their marginal distributions. They are also required in order to identify and interpret the parameters of the human capital production and investment functions. A standard approach is to fix the location and scale of each latent variable in each period by imposing $\lambda_{\theta,m,t} = 1$ and $\mathbb{E}(\ln \theta_t) = 0$ for all t for some arbitrary measure. Agostinelli and Wiswall (2016b) show that these restrictions are unnecessary to separately identify the measurement system and the technologies in Equations 2 and 3 after the initial period, and that they in fact bias estimates of their parameters. These re-normalizations can be avoided and a range of flexible production functions identified, through two broad classes of restrictions: those on the relationship between measurement parameters over time, or those one the parameters of production technology directly (Agostinelli and Wiswall, 2016a).

To capture as much flexibility in their functional form as possible, it is desirable to only restrict the measurement system in the initial period and let the parameters of the production and investment functions be freely estimated. Which set of assumptions can or cannot be imposed partly depends on the properties of the observable measures of their outputs, however. Specifically, in order to avoid renormalisation and imposing restrictions on the structural production and investment parameters, it must be that for one measure $\mu_{H_h,m,t} = \mu_{H_h,m,t'}$ and $\lambda_{H_h,m,t} = \lambda_{H_h,m,t'}$

[7] I have omitted the t subscript from θ when indexing the measures and their parameters to save on notation. I have also omitted parental cognitive skill here (P_c) since it is treated as observable in estimating the model due to limitations in the data.

for all $t' \neq t$. This means assuming that, for example, a child who is equally healthy at two points in time be expected to have the same observable value of $Z_{H_h,m,t}$ and $Z_{H_h,m,t'}$ respectively, a property of a measure Agostinelli and Wiswall (2016a) define as *age invariance*. If this condition is met, it is possible to normalise onto this measure in the initial period, and then freely estimate the parameters of the health production functions in all periods. I create one measure of health that meets this criteria across all periods, and after the initial period there is at least one for socio-emotional skill. For health, I therefore impose the initial period normalisations, $\lambda_{H_h,1,0} = 1$ and $\mathbb{E}(\ln H_{h,0}) = 0$, on this age-invariant measure. For socio-emotional skill I impose normalisations in both the initial and first period i.e $\lambda_{H_s,1,t} = 1$ and $\mathbb{E}(\ln H_{s,t}) = 0$ for $t = 0, 1$. Although re-normalising onto the age-invariant measure might restrict the technology in this period, it allows me to estimate flexible production functions of socio-emotional skill and health at all ages.

For cognition, there are no age-invariant measures available. In fact, whereas the set of measures of health and socio-emotional skill are consistent over time, those of cognitive skill differ substantially across periods. In this case, re-normalisation is even less desirable as it would limit comparisons of parameter estimates over time. In order to avoid this, I restrict the parameters of the cognitive skill production functions directly. I discuss these restrictions in the following subsection. Parental stocks of human capitalare assumed to be time-invariant so I fix their location and scale to one arbitrary initial measure[8], and I re-normalise investments in every period.

With regards to the measurement errors $((\varepsilon_{\theta,m,t}))$, I assume they are fully independent:

1. across alternative measures at a point in time, $Cov(\varepsilon_{\theta,m,t}, \varepsilon_{\theta,m',t}) = 0 \, \forall \, m' \neq m$;
2. across all measures at all other points in time, $Cov(\varepsilon_{\theta,m,t}, \varepsilon_{\theta,m',t'}) = 0 \, \forall \, m'$ and $t' \neq t$; and
3. across all latent skills at every point in time, $Cov(\varepsilon_{\theta,m,t}, \theta'_{t'}) = 0 \, \forall \, \theta'$ and t'.

These assumptions are stricter than what is required to identify the distribution of the latent variables in the initial period, however they are exhaustive of the assumptions required to obtain consistent estimates of the investment and production functions using the methodology I employ. I discuss this in more detail in the next sub-section.

An auxiliary feature of Equation 6 is that it assumes any variation in $Z_{\theta,m,t}$ can be straightforwardly decomposed into contributions from either the latent variable -the *signal* - or measurement error - the *noise*. That is, it implies

$$V(Z_{\theta,m,t}) = \lambda^2_{\theta,m,t} V(\ln \theta_t) + V(\varepsilon_{\theta,m,t})$$

As a result, signal $(s_{\theta,m,t})$ in each measure, can be given by ratio:

[8]Again, in the application of this model to data I do not treat parental cognition as unobservable due to data limitations. I maintain the assumption when outlining the model for completeness.

$$s_{\theta,m,t} = \frac{\lambda^2_{\theta,m,t} V(\ln\theta_t)}{\lambda^2_{\theta,m,t} V(\ln\theta_t) + V(\varepsilon_{\theta,m,t})},$$

with the noise being calculated as $(1 - s_{\theta,m,t})$. This allows for a simple analysis of how well the observable measures capture variation in the underlying latent variables they proxy.

2.6 Specification and Estimation

I estimate Equations 2, 3 and 4 across five periods covering the ages of 9 months-3 years (period 1), and 3-5 (2), 5-7 (3), 7-11 (4), and 11-14 (5). Below, I outline the restrictions I impose on these equations given the assumptions about the measurement parameters outlined above.

2.6.1 Structural parameter restrictions

For the health production functions, given the initial normalisation and the the assumption of age-invariant measurement parameters for one measure - i.e $\mu_{H_h,m,t} = \mu_{H_h,m,t'}$ and $\lambda_{H_h,m,t} = \lambda_{H_h,m,t'}$ for all t' - it is possible to estimate Equation 3 with no restrictions in any period. They therefore include a TFP term (A_t) and their Returns to Scale (RTS) is freely estimated. This is also the case for the socio-emotional skill production function, although the first period re-normalisation onto the age-invariant measure means the production function in this initial period might be ex-ante restricted. Re-normalising investments in every period also means it is possible to estimate these functions with no restrictions despite the absence of an age-invariant measure. When considering cognitive production, however, age-invariance cannot be assumed between for any measure or period. This is because of both inconsistencies in the measures of cognition across time and the construction of the measures themselves. I therefore assume the the cognitive production functions have Constant Returns to Scale (CRS) and omit TFP, which implies the following restriction on its parameters:

$$\sum_{k\in\{h,c,s\}} \rho^c_{k,t} + \sum_{k\in\{h,c,s\}} \alpha^c_{k,t} + \gamma^c_{h,t} + \gamma^c_{c,t} + \kappa^c_{ch,t} + \kappa^c_{cc,t} = 1$$

$$\ln A_t = 0$$

In the following subsection I provide an example of the algorithm used to estimate the production functions to make clear the relationship between the measurement and production function parameter restrictions. As a baseline, I estimate all of the production technologies as Cobb-Douglas, which requires restricting $\kappa^j_{jh,t} = \kappa^j_{jc,t} = 0$ for $j \in \{h, c, s\}$. Including interactions between investments and skills terms then allows me to test this restriction.

Since the scale of the latent variables depends on the initial period normalisations, so does the interpretation of the parameters of the investment and production. As a result, there is no clear way to interpret their meaning if the normalizing measure is not cardinal, given that any order preserving transformation of a measure could be consistent with a given stock of human capital. Cunha et al. (2010) "anchor" their test results in adult outcomes - such as years of education or earnings - to give the parameters a cardinal interpretation. The data used in this paper began with children born in the year 2000 and, as a result, do not yet contain information on adult or even intermediate outcomes. For health the normalizing measure is of the number of illnesses a child has, and so can plausibly be seen as cardinal. It is slightly less clear that observable cognitive and socio-emotional measures capture "how much" skill children have, however, partly because it is difficult to measure skills cardinally at such a young age. For cognition, the normalising measure is of the number of developmental milestones reached, and for socio-emotional skills of the number of symptoms children display that indicate certain traits indicative of mood regularity or conduct problems, and I also take these as cardinal. The next section describes the measures in detail.

2.6.2 Estimating the Model

As an example of my application of the estimation algorithm of Agostinelli and Wiswall (2016a), consider a simple model of the joint evolution or health and cognition with one household investment. With three measures of health and cognitive skill in the initial period, the measurement parameters can be recovered by the ratio of their covariances:

$$\lambda_{\theta,m,0} = \frac{\text{Cov}(Z_{\theta,m,0}, Z_{\theta,m',0})}{\text{Cov}(Z_{\theta,1,0}, Z_{\theta,m',0})} = \frac{\lambda_{\theta,m,0}\lambda_{\theta,m',0}Var(\theta)}{\lambda_{\theta,m',0}Var(\theta)} \qquad \text{for } \theta \in \{H_{h,0}, H_{c,0}\}$$

The measurement means are simply estimated by the unconditional mean of the measures under the normalisation $\mathbb{E}(\theta) = 0$. Latent health and cognition can then be defined as in Equation 7:

$$\ln \theta_0 \equiv \frac{Z_{\theta,m,0} - \mu_{\theta,m,0}}{\lambda_{\theta,m,0}} - \frac{\varepsilon_{\theta,m,0}}{\lambda_{\theta,m,0}} = \tilde{Z}_{\theta,m,0} - \tilde{\varepsilon}_{\theta,m,0} \qquad \text{for } \theta \in \{H_{h,0}, H_{c,0}\}$$

Substituting an investment function into one investment measurement equation, using the definition of θ_0 above, and rearranging gives the following reduced form investment equation:

$$Z_{I,m,0} = \mu_{I,m,0} + \lambda_{I,m,0}\big(\beta_1 \ln H_{h,0} + \beta_2 \ln H_{c,0} + \beta_3 Y_0 + \pi_0\big) + \varepsilon_{I,m,0}$$

$$Z_{I,m,0} = \mu_{I,m,0} + \lambda_{I,m,0}\big(\beta_1(\tilde{Z}_{H_h,m,0} - \tilde{\varepsilon}_{H_h,m,0}) + (\beta_2\tilde{Z}_{H_c,m,0} - \tilde{\varepsilon}_{H_c,m,0}) + \beta_3 Y_0 + \pi_0\big) + \varepsilon_{I,m,0}$$

$$Z_{I,m,0} = \delta_{0,0} + \delta_{1,0}\tilde{Z}_{H_h,m,0} + \delta_{2,t}\tilde{Z}_{H_c,m,0} + \nu_0$$

where:

$$\delta_{0,0} = \mu_{I,m,0}$$

$$\delta_{i,0} = \lambda_{I,m,0}\beta_{i,0} \quad \text{for} \quad i = 1, 2$$

$$\nu_0 = \varepsilon_{I,m,0} + \lambda_{I,m,0}\big(\pi_0 - \beta_1\tilde{\varepsilon}_{H_h,m,0} - \beta_2\tilde{\varepsilon}_{H_c,m,0}\big)$$

Estimating the above reduced form equation by ordinary least squares will result in inconsistent estimates of the δ_is since:

$$\mathbb{E}(\tilde{Z}_{\theta,m,0}\nu_0) = \mathbb{E}\Big(\big(\ln\theta + \tilde{\varepsilon}_{H_\theta,m,0}\big)\big(\varepsilon_{I,m,0} + \lambda_{I,m,0}\big(\pi_0 - \beta_1\tilde{\varepsilon}_{H_h,m,0} - \beta_2\tilde{\varepsilon}_{H_c,m,0}\big)\big)\Big)$$
$$= \mathbb{E}(\tilde{\varepsilon}_{\theta,m,0}\beta_i\tilde{\varepsilon}_{\theta,m,0}) = \beta_i\sigma^2_{\varepsilon_{\theta,m,0}} \quad \text{for} \quad \theta \in \{H_{h,0}, H_{c,0}\},$$

where all other expected cross-products are zero based on the assumptions that latent measurement errors and production shocks are fully independent. This former assumption also means that the remaining measures of latent inputs are valid instruments, and they can be used to consistently estimate the reduced form investment parameters. With the normalisation that $\lambda_{I,m,0} = 1$, the reduced form and structural parameters become equivalent, i.e $\beta_{i,0} = \delta_{i,0}$, and the scale of latent investment is defined by the scale of the observable measure $Z_{I,m,0}$. A residual investment measure can be constructed by simply de-meaning this observable measure. An identical process can then be followed to estimate the parameters of the production functions. Substituting a simplified, Cobb-Douglas health and cognitive production functions into one $t+1$ health and cognition measurement equation and further using the fact that $\ln I_0 = \tilde{Z}_{I,m,0} - \tilde{\varepsilon}_{I,m,0}$, the following reduced form health and cognitive skill production function equations can be expressed:

$$Z_{H_j,m,1} = \tau^j_{0,0} + \tau^j_{1,0}\tilde{Z}_{H_h,m,0} + \tau^j_{2,0}\tilde{Z}_{H_c,m,0} + \tau^j_{3,t}\tilde{Z}_{I,m,0} + \upsilon_{j,1} \quad \text{for } j \in \{h, c\}$$

Where now:

$$\tau^j_{i,0} = \lambda_{H_j,m,1}\rho^j_{i,0} \quad \text{for} \quad i = 1, 2$$

$$\tau^j_{3,0} = \lambda_{H_j,m,1}\gamma^j_0$$

$$\upsilon_{j,1} = \varepsilon_{H_j,1} + \lambda_{H_j,m,1}\left(\eta_{j,0} - \rho^j_{1,0}\tilde{\varepsilon}_{H_h,m,0} - \rho^j_{2,0}\tilde{\varepsilon}_{H_c,m,0} - \gamma^j_0\tilde{\varepsilon}_{I,m,0}\right)$$

$$\tau^j_{0,0} = \mu_{h_j,m,1} + \ln A_0$$

Again, the assumption of independent measurement errors mean alternative measures of the inputs can be used as instruments to obtain consistent estimates of the reduced form production parameters. To recover the structural health production parameters, the restrictions on the measurement parameters can be exploited. Since the assumption that $Z_{H_h,m,1}$ is age-invariant implies that $\lambda_{H_h,m,0} = \lambda_{H_h,m,1}$ and $\mu_{H_h,m,0} = \mu_{H_h,m,1}$, the structural parameters of the health production function can be calculated as:

$$\begin{aligned}
\rho^h_{i,0} &= \frac{\tau^h_{i,0}}{\lambda_{H_h,m,0}} = \frac{\lambda_{H_h,m,1}\rho^h_{i,0}}{\lambda_{H_h,m,0}} \quad \text{for} \quad i = 1, 2 \\
\gamma^h_0 &= \frac{\tau^h_{3,0}}{\lambda_{H_h,m,0}} = \frac{\lambda_{H_h,m,1}\gamma^h_0}{\lambda_{H_h,m,0}} \\
\ln A_0 &= \tau^h_{0,0} - \mu_{H_h,m,0} \\
\text{RTS} &= \sum_i \frac{\tau^h_{i,0}}{\lambda_{H_h,m,0}}
\end{aligned}$$

For cognitive skill production, without the assumption of age-invariance I restrict the structural cognitive production to have CRS and no TFP. The structural parameters can then be separately identify from the measurement parameters as:

$$\begin{aligned}
\lambda_{H_h,m,1} &= \sum_i \tau^c_{i,0} = \sum_i \lambda_{H_c,m,1}\rho^c_{i,0} + \lambda_{H_c,m,1}\gamma^c_0 \quad \text{since RTS} = \rho^c_{1,0} + \rho^c_{2,0} + \gamma^c_0 \equiv 1 \\
\rho^c_{i,0} &= \frac{\tau^c_{i,0}}{\sum_i \tau^c_{i,0}} = \frac{\lambda_{H_c,m,1}\rho^c_{i,0}}{\lambda_{H_c,m,1}} \quad \text{for} \quad i = 1, 2 \\
\gamma^c_0 &= \frac{\tau^c_{3,0}}{\sum_i \tau^c_{i,0}} = \frac{\lambda_{H_c,m,1}\gamma^c_0}{\lambda_{H_c,m,1}} \\
\tau^c_{0,0} &= \mu_{H_c,m,1} \quad \text{since } \ln A_t = 0
\end{aligned}$$

The estimation procedure requires that a "lead" measure be used as the outputs/inputs of the investment and production functions, leaving the remaining measures to be used as instruments. I use the age-invariant measures of health and socio-emotional skill as the lead measures. For cognition, where this is not an option, I use the measure which ex-ante appears to be most highly correlated with its latent cognitive skill as the lead measure. For investment, which I re-normalise every period, I use the same approach.

This simplified example also highlights how omitting health from an analysis of skill development might lead to over or under-estimating their production parameters. If, for example, having good health leads to higher levels of cognition, then $\rho^c_{c,0}$ above will be biased upwards to they extent that $H_{c,0}$ is correlated with $H_{h,0}$. The same will be true in all periods in which health is not considered. Given that the magnitude of $\rho^c_{c,t}$ shows how malleable cognition is at any point, this upward bias might incorrectly lead to the conclusion that cognitive skill is highly self-productive when in fact it can be increased through health improvements or health investments. I return to this point when discussing the results in Section 4.

3 Sample and Observable measures

I use data from the first six waves - covering the ages of 9 months, 3, 5, 7, 11 and 14 - of the Millennium Cohort Study (MCS), a longitudinal survey tracking the physical, socio-emotional and circumstantial development of a sample of children born in the United Kingdom between 2000 and 2002. Its first wave took place between June 2001 and January 2003 when the children were aged 9 months, and oversampled children from disadvantaged backgrounds.[9] As a result, the baseline MCS sample is not nationally representative by design. The study includes a wide variety of information on the mental and physical health of the cohort members as well as detailed information regarding their family circumstances. The MCS does not explicitly survey the mother as the main respondent to the survey, meaning the parental interview can be completed by either the mother or the father of a child at each wave. In practice, mothers almost exclusively answered the surveys as the main respondent - 99.85% and 94% of main respondents were the mothers at ages 9 months and 14 years respectively.

Appendix Table D1 provides a statistical description of the MCS households at baseline and each follow-up round. An important feature of the MCS is the large rate of attrition: there are roughly 8,000 fewer individuals present in the sample at age 14 than there are at age 3. This attrition is also not random, and is concentrated among low-income households. In Table D1, average income of the sample increases across rounds, and the spread of the sample across income quintiles changes as a result. This is, in part, a result of increases in parents' income as they gain 14 years of experience in the labour market, however it is also a result of higher attrition among low-income families. Appendix Table D2 shows the proportion of families in each income quintile when children are aged 14 based on their income quintile at age 9 months. In the last column it shows that those in the bottom of the income distribution were far more likely to drop out of the sample by age 14. It also suggests that those who remained in the sample were more likely to move up the income distribution than down. This suggests that not only is the attrition non-random, but that those who have taken part in all six rounds of the survey are also relatively high-achieving families. In my analysis, to allow for comparability of results over time I restrict the sample used to estimate the model to children present in all five rounds of the

[9]MCS sampling was carried out so as to sample children of the same age at interview. There are some exceptions to this. The age of cohort members at wave 1 ranges from 6-12 months, however the average age is 9.2 months with a standard deviation of only 0.5 months - 16,500 out of 18,552 cohort members are aged 9 or 10 months. For simplicity in all that follows I will refer to the waves by the corresponding target age at which they were carried out.

survey, leaving a maximum of 11,714 observations in each of the five rounds. A central interest in this study is whether or not there is inequalities in health across the income distribution. In light of the features of the restricted sample discussed above, it is possible that any results will understate the relationship between health, or human capital more generally, and income.

3.1 Measurements

The MCS contains many potential measures on each of the unobservable inputs/outputs of investment and production. However, the measurement system outlined in Section 2.5 posits that each measures is *dedicated* to only one unobservable. Prior to "assigning" measures to unobservables, I used an Exploratory Factor Analysis (EFA) the verify the two assumptions underpinning this system: that observable measures contain rich enough variation to capture unobservables; and that each observable measures only one unobservable. With regards to the latter, measures that were estimated to be highly correlated with more than one unobservable were discarded, as were those that shared little variation with their corresponding latent variable. Appendix C describes the two components of this EFA in detail, and below I describe the measures retained to be used in estimations.

Child Health: The detailed nature of the MCS allows measures of children's physical health to be constructed consistently across ages. At each age, I use measures of the number of long-term illnesses and health conditions from which a child suffers. Long term illnesses are defined according to the World Health Organization's (WHO) International Classification of Diseases (ICD), and health conditions as symptoms a child has displayed that are not necessarily chronic or indicative of a long-standing illness (WHO, 2018). For example, a health condition might be diarrhea whereas a long-term illness would be eczema. I use the number of health conditions at 9 months as the normalising measure for child health. At the same age I also make use of information on the length of a child's gestation period and the number of complications the mother experienced during pregnancy.[10] At ages 3, 5, 7, 11 and 14 I also use a count of the number of times cohort members have had to visit the hospital for treatment over and above regular check-ups. At ages 7, 11, and 14, I also use parent's subjective evaluation of the child's health on a scale of 1 (poor) to 5 (excellent). Appendix Table D5 provides a statistical summary of the health measures at each age.

Child Cognitive Skill: Because it covers ages of 9 months to 14 years, the MCS has not administered a consistent set of cognitive assessments. At 9 months old, cognitive skill is measured by parental questionnaire. At this age, I use parental responses to a subset of questions from the Denver Developmental Screening Test (DDST) and the MacArthur-Bates Communicative Development Inventory (CDI), alongside a measure of the number of concerns the respondent has about their child's cognitive development. I interpret the normalising measure,

[10]There is a large literature, reviewed by Almond and Currie (2011), on the "fetal origins" hypothesis and the implications of in-utero conditions for health at birth and lifetime outcomes.

the DDST, as cardinal as it measures how many developmental milestones a child has reached and measures fine and gross motor-skill development (Frankenburg and Dodds, 1967).[11] From age 3 onward I use childrens' scores on assessments of recognition/understanding of colours, letters, numbers and patterns, as well as assessments of their language, mathematics and working memory skills. At age 3, the assessment instruments are questions from the Bracken School Readiness (BSR) and British Ability Scales (BAS) tests. BAS tests are administered again at ages 5, 7, 11, alongside A National Foundation for Education Research (NFER) numerical skills test (age 7), Cambridge Neurophysical Test Automated Battery (CANTAB) gambling and spatial working memory tasks (age 11 and 14), and a word recognition assessment (age 14). Appendix B.1 provides detail on the cognitive assessments used from the MCS survey across ages and Appendix Table D6 summarises them statistically.

Child socio-emotional Skill: Socio-emotional assessments are administered more consistently across the MCS rounds. At 9 months I use responses to questions from the Carey Infant Temperament Scale mood, regularity, and adaptability and withdrawal assessments. The normalising measure here is a child's score on the "mood" scale which indicates the degree of positivity towards interactions such as feeding, being changed, and arriving in new environments. At age 3, I then use sub-scales from a Strengths and Difficulties Questionnaire (SDQ) indicating how many symptoms of conduct problems, hyperactivity, emotional instability, peer problems and pro-socialty children display. I re-normalise onto the conduct problems sub-scale which measures the extent to which a child displays behaviours such as stealing, lying, fighting, disobeying and having tantrums. I also use sub-scales from the Child Social and Behavioural Questionnaire (CSBQ) which are aimed at measuring the degree of emotional (in)stability children display. The SDQ is administered to parents again at ages 5, 7, 11 and 14, and the CSBQ questions at ages 5 and 7. Appendix B.2 provides detail on the socio-emotional measures used from the MCS data and Appendix Table D7 summarises them statistically.

Investments: To measure investments, I exploit questions from the MCS regarding how frequently parents take part in certain activities with their children, or encourage them to do so. Such measures capture how much *time*, as opposed to *resources*, parents invest in their children. Whilst these two forms of investment are distinct, they are jointly determined alongside parental labour supply in models of household choice and child development - a result of the intrinsic relationship between time, labour supply and income (Bernal, 2008; Del Boca et al., 2013, 2016; Aizer and Cunha, 2012). Here, however, I focus on time investments as there is no information on material investments in the MCS. There is growing evidence that time spent on child care is an important determinant of their human capital development (Cunha et al., 2010; Boneva and

[11]For example, it assesses how often the child performs actions which indicate the development of either fine or gross motor skills such as smiling, clapping their hands, holding small objects, or passing toys when asked to. It is difficult to measure cognitive development at 9 months of age, however there is evidence that these skills are strongly linked to future cognitive development - Diamond (2000) discusses in detail the evidence on the interrelation between cognitive development and early motor skills. Johnson et al. (2015) describes in detail the sub-set of questions the MCS uses from both the DDST and MacArthur-Bates CDI.

Rauh, 2016; Attanasio et al., 2020b), and that large portions of the impact of early interventions based on cash transfers on this process come through mothers' substitution of their time from work to childcare (Del Boca et al., 2013, 2016; Agostinelli and Sorrenti, 2018).

I assume the activities about which parents of the MCS subjects are asked belong to two distinct categories - those aimed at fostering cognitive skills, and those that are intended to improve health or promote a healthy lifestyle. This structure was confirmed as part of the preliminary EFA, outlined in Appendix A, and I define these categories as cognitive and health investments respectively. For cognitive investments, at ages 3, 5, and 7 I use the parents' responses to questions regarding how often they read, write, sing/play music and practice maths with the child in a week. At ages 11 and 14, I use their responses when asked how often they help the child with homework, how often they check the child's homework, the number of hours per week a child spends studying and how often they talk to the child about important subjects. As measures of health investments, I make use of a range of questions the parents are asked about their child's lifestyle. Across all ages I use some combination of measures of how frequently the child has regular meals and regular bed times, how often they take part in a sport or the parents plays sports/active games with them, the portions of fruit they eat in day, and the number of days a week they have breakfast. Appendix Tables D8 and D9 provide a statistical summary of the health and cognitive investment measures used across ages.

Parental human capital: Given the assumption that parents' human capital is time-invariant and a proxy for wider environmental ednowments, I measure their cognitive and socio-emotional skill and health based on information from the main respondent when children are aged 9 months.[12] There are not explicit measures of parents' cognition at 9 months, so I use the parents' highest level of qualification as a proxy and do not treat cognition as unobservable.[13] The implications of this assumption for interpreting its associated elasticity is discussed in the next section. For socio-emotional skill I make use of four measures - the Rosenberg self-esteem scale, the Rutter Malaise psychological distress scale and a measure of the respondent's locus of control. To measure health, I use the main respondent's subjective health, a variable indicating whether or not they have and long-standing illnesses, and a measure of the number of health conditions from which they suffer. Again, Appendix Table D10 gives a statistical summary of these measures.

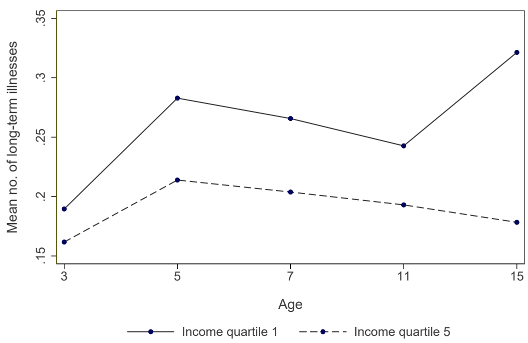
[12]Many of the MCS questions are also administered to the secondary parent, however the survey does not require partners to be present, meaning response rates to these questions are low. Requiring a combination of both parents' skills as a proxy for endowments would require a large non-random reduction in the sample. At 9 months 99.9% of main partner interviews were achieved in full or partial in person. This contrasts to only 71.3% of partner interviews being achieved at least in partial in person - a difference of 5,307 observations. The approach of using only one parent's, typically the mother's, skills at the earliest survey is common in the human capital development literature (e.g Cunha et al. (2010), Agostinelli and Wiswall (2016a), and Boneva and Rauh (2016))

[13]There are several questions on whether or not parents have difficulty reading and writing when children are 9 months, however they vary very little across parents. There is also a word score test given to parents when children are aged 14, however this was very highly correlated with socio-emotional measures. Although they are assumed time-invariant, sing measures from 9 months maintains consistency.

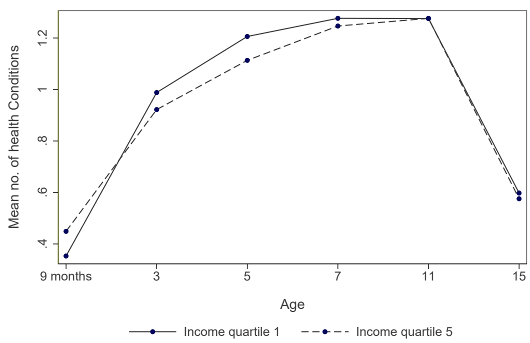
3.2 Observable Health and Investment Gradients

As an initial look at gradients in observable health measures in the MCS, Figure 1 plots the evolution of health along two dimensions in the bottom and top quartile of the MCS sample income distribution: the average number of long-term illnesses (panel (a)) and health conditions (panels (b)). Whilst the number of health conditions at each end of the income distribution track each other closely over time, there are differences in the development of health in terms of long-term illnesses. Figure 1(a) shows that, on average, children in the lowest quartile of the income distribution suffer from more long term illnesses than those in the top quartile at all ages. By age 3, this gap begins to widen and, although it narrows slightly between ages 5 and 7, this difference becomes stark at age 14.

Figure 1: Observable health measures over time for those in the top and bottom income quartiles in the MCS



(a)



(b)

Note: Panel (a) show sthe mean number of long-term illnesses and Panel (b) the number of health conditions among children in the top (dashed line) and bottom (solid line) income quartiles of the MCS sample family income distribution at each age. Family income is equivalised to adjust for household composition using the OECD equivalisation scales (Hansen et al., 2014). Quartiles are calculated based on family income at each age. Section 3 describes the variables in each panel.

Appendix tables D3 and D4 provide summaries of the health and cognitive investment measures used in period 1 - between the ages of 9 months and 3 years - respectively, by quartile of the income distribution. In both tables there are small gradients investments. For example, Table D3 shows that the proportion of parents who say their child has fruit or vegetables once a day, or who report to play sport with their child increases across income quartiles. Similarly, those in the top quartile of the income distribution are more likely to report their child having regular meals and bed times *usually* or *always* than those in the bottom. The gradients in Table D4 are generally less pronounced, however there are still large differences in the proportion of parents who report reading to their child every day across the income distribution.

4 Results

4.1 Measurement System

Appendix tables D16-D13 report estimates of the measurement system, which show the informational content of measures across unobservables and ages. Tables D11, D12 and D13 contain the measurement parameters and signal/noise ratios for measures of health, cognition and socio-emotional skill respectively. It is clear from the Table D11 that health is measured relatively well by the observable data, other than in the first and last periods. For example, at 9 months the signal in measures ranges from 5% to 12%, whereas at age 5 they range from 30% to 56%. There is similar pattern across measures of cognition (Table D12) socio-emotional skill (Table D13), with first and last period measures being, on average, the noisiest. This highlights the importance of counting for measurement error in estimating the process of human capital development. If the raw measures were used as proxies of the inputs of the investment and production functions, the corresponding parameters would be biased downwards in proportion to the signal/noise ratios. It also shows that it is perhaps more difficult to measure human capital at the "extreme" ends of childhood.

Table D14 shows that the signal in health investment measures also varies both across and within periods. At age 7, the measures are particularly noisy, with the largest signal being roughly 13%, however in all other periods at least one measure has over one-quarter of its variation shared with latent health investment. The measures of cognitive investment are generally less noisy than those of health investment. At three ages (5, 11, and 14) one measure of cognitive investment has a signal of less than 10%, however the signal in the other measures in these periods are relatively large. Table D16 shows that observable measures of the parent's human capital appear to measure health and socio-emotional skill well - across the two, the smallest signal is 23%. I note here again that I use only parents' education as a proxy for cognitive skill, this means that estimates of its corresponding elasticty in the investment and production functions that follow may in fact be downward biased.

4.2 The Determinants of Household Investment

Whilst it is not possible to know the underlying mechanism that maps parental characteristics into investment, the parameters of the investment functions provide insight as to the investment behaviours of parents.

4.2.1 Health Investment

Table 1 shows the estimates of the parameters of the health investment functions. Family income, is positively associated with health investment in all period. The relative strength of this relationship is in fact increasing with children's age, implying that family income becomes increasingly important in determining health investents over time. Similar empirical studies of human capital development have found family income and/or resources to be an important determinant of educational and recreational investment in a variety of contexts.[14] However, that a similar gradient exists in the health investments of families highlights a further aspect of the early environment affected by income.

Similarly, the results in Table 1 also indicate a positive gradient in health investments across parents' education and socio-emotional skill in three of the five periods. The former influence investment decisions early and late (9 months-5, and 11-15), whereas the latter do so through the middle of childhood (3-11). These effects come over and above the influence of family income, suggesting it is not only finances that constrain parental investments but also information, education and perhaps understanding of child development process.

Parental responses to children's revealed human capital in Table 1 differ substantially across periods. There are responses to cognitive skill that are statistically different from zero in all but one period. By far the largest of these is a compensatory effect in the earliest period, between 9 months and 3 years of age. In this period, a 1% increase in cognition is associated with a 1.2% decrease in health investment. In the same period, the opposite is true for socio-emotional skill, with their being a large reinforcing response. Parents' responses to socio-emotional skills remain reinforcing, albeit to a much smaller extent, throughout childhood. Conversely, cognition affects health investments alternating directions across periods, suggesting how parents make health investments based on their children's human capital differs across stages of childhood. Children's health only influences health investments in the last period, covering the early teenage years, when there is a large compensatory effect with respect to health. Table 1 suggests that, overall, parental health investment decisions are influenced most by children's human capital at the earliest and latest stages of childhood; a finding that is perhaps unsurprising given they cover key developmental phases, when children are in their pre-school years or in the early stages of high school.

4.2.2 Cognitive Investment

Estimates of the cognitive investment functions are provided in Table 2. They show a less pronounced income effect than was estimated for health investment, suggesting that income plays a relatively smaller role in determining cognitive investments. Parents' education is not estimated to be a strong determinant of cognitive investment at any age, however socio-emotional endowments are in periods 2 (3-5), 4 (7-11) and 5 (11-14), albeit to a small extent.

[14] Attanasio et al. (2020c,b, 2017)and Agostinelli and Wiswall (2016a) all find that investments are strongly responsive to either family income or wealth relative to their estimates of the investment function parameters. These studies predominantly measure investments with the reported educational and recreational inputs of families. Attanasio et al. (2017) do include two health investments in their aggregate, however they do not separately include health investment in their empirical model. It should also be noted that Attanasio et al. (2020c,b, 2017) are all studies of human capital development in developing countries, and so the results may not be directly applicable to those from a model using UK data.

Table 1: Estimates of health investment function parameters

	Period 1 *Ages 9 months-3*	Period 2 *Ages 3-5*	Period 3 *Ages 5-7*	Period 4 *Ages 7-11*	Period 5 *Ages 11-15*
Lagged human capital					
$\ln H_{h,t-1}$	0.021	0.005	0.022	-0.024	-0.453***
	(0.234)	(0.105)	(0.067)	(0.059)	(0.116)
	[-0.364,0.406]	[-0.167,0.177]	[-0.088,0.132]	[-0.121,0.073]	[-0.644,-0.263]
$\ln H_{c,t-1}$	-1.192***	0.136***	-0.014	-0.081**	0.057***
	(0.243)	(0.048)	(0.049)	(0.032)	(0.021)
	[-1.592,-0.792]	[0.057,0.215]	[-0.094,0.066]	[-0.133,-0.029]	[0.023,0.092]
$\ln H_{s,t-1}$	0.855***	0.013	0.014	0.041**	0.183***
	(0.128)	(0.013)	(0.019)	(0.018)	(0.032)
	[0.644,1.067]	[-0.008,0.033]	[-0.017,0.046]	[0.011,0.070]	[0.131,0.236]
Parental human capital (fixed over time)					
$\ln P_h$	0.064	0.014	0.014	0.007	0.097*
	(0.039)	(0.033)	(0.039)	(0.039)	(0.058)
	[-0.001,0.128]	[-0.041,0.068]	[-0.050,0.079]	[-0.058,0.072]	[0.001,0.192]
$\ln P_c$	0.295***	0.079***	0.054	0.020	0.277***
	(0.041)	(0.030)	(0.040)	(0.043)	(0.051)
	[0.228,0.362]	[0.030,0.129]	[-0.012,0.120]	[-0.051,0.090]	[0.193,0.361]
$\ln P_s$	0.004	0.086***	0.138***	0.097***	0.000
	(0.022)	(0.022)	(0.022)	(0.019)	(0.029)
	[-0.031,0.040]	[0.049,0.122]	[0.102,0.175]	[0.065,0.128]	[-0.047,0.048]
Income					
$\ln Y_t$	0.070***	0.088***	0.043	0.216***	0.525***
	(0.022)	(0.025)	(0.029)	(0.048)	(0.058)
	[0.035,0.105]	[0.047,0.130]	[-0.006,0.091]	[0.136,0.295]	[0.429,0.621]
$\sigma^2_{\pi_h}$	0.222***	0.050***	0.657***	0.203***	1.289***
	(0.010)	(0.011)	(0.021)	(0.019)	(0.052)
	[0.205,0.239]	[0.032,0.069]	[0.622,0.692]	[0.172,0.234]	[1.204,1.375]
N	8,237	6,976	7,824	7,729	7875

Notes: Standard errors in parentheses and 90% confidence intervals in square brackets are calculated using 100 bootstrap replications. The outcome in each equation column is health investment measured by the observables in Appendix Table D14. $t-1$ = ages 9 months and ages 3, 5, 7, and 11 years for the five columns respectively. The inputs in the left column are are lagged child health, cognitive skill and socio-emotional skill; parental health cognitive skill and socio-emotional skill; and family income, respectively. All with the exception of parental cognitive skill and family income are treated as unobservable. Section 2.5 describes the observables used as measures of each input, and estimates of their measurement parameters are shown in Tables D11-D16.

Children's health significantly affects cognitive investments between the ages of 9 months and 5. In the first period, there is a strong compensatory effect with a 1% reduction in health estimated to increase investment by around 1.47%. Although also compensatory, the response in the following period is about one-eighth of the magnitude, and its effect fades thereafter. This is slightly different to recent evidence from Nicoletti and Tonei (forthcoming), who find that parental investments are compensatory with respect to health up until age 9. Cognitive skill affects cognitive investment behaviours in every period, again to different extents and in different directions. In the first period, there is an large reinforcement effect. This is in the same period in which there is a large compensatory effect of cognition on *health* investment, meaning parents in the sample invest more resources into their child's cognitive development upon realising they have high levels of cognition, but try to make up for deficits they observe by making healthy lifestyle choices. The response to cognition remains reinforcing in the next period, but switches to being compensatory from period 3 onward when children enter primary school. Socio-emotional skills have a positive effect on cognitive investments in all but one period, between the age of 5-7. In general, this period stands out from the rest in that the only statistically significant determinant of investment is cognition. The estimated variance of shocks is also very large in this period, suggesting that there are substantially more external factors influencing cognitive investment behaviours during it than across all others that covering school years.

Table 2: Estimates of cognitive investment function parameters

	Period 1 *Ages 9 months-3*	Period 2 *Ages 3-5*	Period 3 *Ages 5-7*	Period 4 *Ages 7-11*	Period 5 *Ages 11-15*
Lagged human capital					
$\ln H_{h,t-1}$	-1.467***	-0.181	-0.052	0.011	0.024
	(0.391)	(0.111)	(0.080)	(0.049)	(0.064)
	[-2.110,-0.825]	[-0.364,0.001]	[-0.183,0.080]	[-0.070,0.092]	[-0.082,0.130]
$\ln H_{c,t-1}$	2.188***	0.117**	-0.416***	-0.094***	-0.055***
	(0.519)	(0.050)	(0.064)	(0.021)	(0.014)
	[1.334,3.041]	[0.035,0.199]	[-0.521,-0.311]	[-0.129,-0.059]	[-0.078,-0.033]
$\ln H_{s,t-1}$	0.794***	0.040***	0.053	0.061***	0.051***
	(0.201)	(0.010)	(0.033)	(0.011)	(0.016)
	[0.464,1.125]	[0.023,0.057]	[-0.001,0.107]	[0.043,0.078]	[0.024,0.078]
Parental human capital (fixed over time)					
$\ln P_h$	-0.021	-0.003	-0.080	-0.014	-0.010
	(0.070)	(0.030)	(0.055)	(0.026)	(0.025)
	[-0.137,0.094]	[-0.053,0.047]	[-0.171,0.010]	[-0.056,0.028]	[-0.052,0.031]
$\ln P_c$	0.046	0.049*	0.050	0.007	-0.014
	(0.083)	(0.030)	(0.052)	(0.026)	(0.028)
	[-0.090,0.183]	[0.000,0.097]	[-0.036,0.137]	[-0.036,0.049]	[-0.060,0.031]
$\ln P_s$	-0.004	0.067***	-0.029	0.050***	0.034**
	(0.037)	(0.017)	(0.033)	(0.015)	(0.015)
	[-0.066,0.057]	[0.040,0.095]	[-0.083,0.025]	[0.025,0.075]	[0.010,0.059]
Income					
$\ln Y_t$	0.111**	0.045*	0.014	0.067**	0.043
	(0.045)	(0.024)	(0.038)	(0.028)	(0.032)
	[0.038,0.185]	[0.006,0.084]	[-0.048,0.076]	[0.020,0.113]	[-0.010,0.095]
$\sigma^2_{\pi_c}$	3.293***	0.044***	1.958***	0.411***	0.066***
	(0.096)	(0.005)	(0.037)	(0.023)	(0.011)
	[3.136,3.451]	[0.036,0.052]	[1.897,2.018]	[0.373,0.449]	[0.048,0.083]
N	8,236	6,901	7,817	7,707	8079

Notes: Standard errors in parentheses and 90% confidence intervals in square brackets are calculated using 100 bootstrap replications. The outcome in each equation column is cognitive investment measured by the observables in Appendix Table D15. $t-1$ = ages 9 months and ages 3, 5, 7, and 11 years for the five columns respectively. The inputs in the left column are are lagged child health, cognitive skill and socio-emotional skill; parental health cognitive skill and socio-emotional skill; and family income, respectively. All with the exception of parental cognitive skill and family income are treated as unobservable. Section 2.5 describes the observables used as measures of each input, and their estimated measurement parameters are shown in Tables D11-D16.

4.3 Health Production Functions

The production function estimates lend themselves to a more structural interpretation than those of the investment equations. Each elasticity illustrates the malleability of health - and later cognitive and socio-emotional skill - with respect to its corresponding input. These measures capture not only the long-term health accumulated over childhood, but also some aspects of transitory health experienced over the period in question.

To compare the contribution of each of the inputs of health production, I first show estimates of a baseline Cobb-Douglas production function. Table 3 highlights the persistence of health across childhood: in all stages health is highly self-productive and there is very little evidence it is affected by investments. The elasticity of health with respect to lagged stocks of itself is never estimated to lower than 0.45, and is as high as 1.2 between the ages of 3 and 5.

Perhaps intuitively, there is no evidence of cross-productivities between skills and health in early childhood. There is evidence that both cognitive and socio-emotional skills affect health at later stages, however. Socio-emotional skills are estimated to positively influence the production of health in between the ages of 7-11 and 11-14, as are cognitive skills between 7-11. At these later ages, it is plausible that cognitive and socio-emotional skills enable children to make health-conscious decisions or self-invest in their health. This is in line with recent evidence that socio-emotional skills are important in determining health and health behaviour among children in both the MCS and an older UK cohort born in 1970 (Attanasio et al., 2020a). If it is the case that cognitive and socio-emotional skills promote good health as early a adolescence, one way in which to reduce health inequality is through ensuring children are equipped with the necessary skills to understand the health implications of their behaviour and/or lifestyle choices.

Moving to the role of parental human capital, parents' health is estimated to positively affect health to much the same, relatively small, extent in all periods. Between the ages of 9 months-3, 3-5 and 7-11 these elasticities are statistically different from zero, with a 1% increase in log health endowment being associated with a 0.034%, .06% and 0.066% increase in health respectively. There is not any consistent pattern in the role of parents' education or socio-emotional skill in the production of health. Both only enter significantly into the health production function between the ages of 7 and 11, when their elasticities are small and negative. It appears then that the most important parental characteristic in health development across childhood is the past health of children themselves and parents' health. Table 3 also shows that health investments do not influence health development in any period.[15] This lack of an investment effect speaks to the high level of self-productivity in health across all ages, suggesting investments of the type measured here - for example, having regular meals, healthy diet and exercising frequently - do not have an impact on overall health as it is measured by illnesses and health conditions. This leaves open

[15] Although they are statistically not different from zero, the point estimates are negative. It is again worthwhile bearing in mind that some of the measures of health investments used measure children's engagement in sports, and relationships like this might pick up any accidents, injuries, or hospital visits that were experienced as a result.

Table 3: Estimates of Cobb-Douglas health production function

	Period 1 *Ages 9 months-3*	Period 2 *Ages 3-5*	Period 3 *Ages 5-7*	Period 4 *Ages 7-11*	Period 5 *Ages 11-15*
Lagged human capital					
$\ln H_{h,t-1}$	0.466^{***}	1.221^{***}	0.810^{***}	0.539^{***}	0.819^{***}
	(0.137)	(0.080)	(0.035)	(0.042)	(0.056)
	[0.241,0.691]	[1.089,1.354]	[0.752,0.868]	[0.470,0.608]	[0.726,0.912]
$\ln H_{c,t-1}$	0.091	0.036	0.003	0.089^{***}	0.005
	(0.113)	(0.025)	(0.015)	(0.015)	(0.007)
	[-0.095,0.277]	[-0.005,0.077]	[-0.022,0.028]	[0.065,0.113]	[-0.007,0.016]
$\ln H_{s,t-1}$	0.030	-0.002	0.002	0.063^{***}	0.061^{***}
	(0.056)	(0.008)	(0.008)	(0.011)	(0.015)
	[-0.062,0.123]	[-0.014,0.011]	[-0.011,0.015]	[0.045,0.081]	[0.036,0.086]
Parental human capital (fixed over time)					
$\ln P_h$	0.034^{*}	0.060^{***}	0.023	0.066^{***}	0.034
	(0.018)	(0.021)	(0.016)	(0.020)	(0.022)
	[0.005,0.064]	[0.026,0.094]	[-0.003,0.049]	[0.033,0.098]	[-0.002,0.070]
$\ln P_c$	0.026	-0.005	-0.008	-0.049^{***}	-0.011
	(0.019)	(0.021)	(0.013)	(0.018)	(0.018)
	[-0.005,0.057]	[-0.039,0.030]	[-0.031,0.014]	[-0.079,-0.019]	[-0.040,0.019]
$\ln P_s$	0.014	-0.005	0.000	-0.018^{*}	0.007
	(0.009)	(0.011)	(0.008)	(0.011)	(0.012)
	[-0.001,0.029]	[-0.023,0.013]	[-0.014,0.014]	[-0.037,-0.000]	[-0.013,0.026]
Investments					
$\ln I_{h,t-1}$	0.014	0.005	-0.013	-0.038	-0.010
	(0.020)	(0.046)	(0.012)	(0.035)	(0.013)
	[-0.019,0.047]	[-0.071,0.081]	[-0.034,0.007]	[-0.095,0.020]	[-0.031,0.011]
$\ln A_t$	0.227^{***}	0.160^{***}	0.181^{***}	0.212^{***}	0.166^{***}
	(0.020)	(0.023)	(0.016)	(0.018)	(0.019)
	[0.194,0.260]	[0.123,0.198]	[0.155,0.207]	[0.182,0.243]	[0.135,0.198]
RTS	0.676^{***}	1.311^{***}	0.817^{***}	0.652^{***}	0.905^{***}
	(0.121)	(0.081)	(0.035)	(0.049)	(0.048)
	[0.477,0.875]	[1.179,1.444]	[0.758,0.875]	[0.571,0.733]	[0.825,0.984]
$\sigma^2_{\eta_h}$	0.025^{***}	0.056^{***}	0.031^{***}	0.037^{***}	0.027^{***}
	(0.006)	(0.005)	(0.004)	(0.006)	(0.010)
	[0.015,0.035]	[0.048,0.064]	[0.024,0.038]	[0.026,0.047]	[0.011,0.043]
N	8,300	7,012	7,947	7,716	7,823

Notes: Standard errors in parentheses and 90% confidence intervals in square brackets are calculated using 100 bootstrap replications. The outcome in each column is children's health measured by the observables in Appendix Table D11. $t-1$ = ages 9 months and ages 3, 5, 7, and 11 years for the five columns respectively. The inputs in the left column are are lagged child health, cognitive skill and socio-emotional skill; parental health, cognitive skill and socio-emotional skill; and health investment, respectively. All with the exception of parental education are treated as unobservable. Section 2.5 describes the observables used as measures of each input, and their estimated measurement parameters are shown in Tables D14-D13.

the possibility that there are other types of health investment these measures do not capture that might in fact be associated with better health. For example, the measures used are of healthy behaviours and time spent in healthy activities, but do not capture many aspects of the home environment and parental choice such as cleanliness, handling of sickness/illness, vaccinations or nutrition. The self-productivity of health production is further highlighted by the relatively small TFP estimates, and the fact the RTS are estimated to be small or close to constant in all but one period - a period, between the ages of 3 and 5, in which health development is driven entirely by health itself. The estimated variance of shocks is also small across all periods, but statistically different from zero and larger than the impact of, for example, health endowments. This suggests that there are factors other than those captured by the inputs of the health production function that consistently influence the development of health.

Given that there might be higher returns to investment in children with poorer health, it could be that the investment elasticities shown in Table 3 are close to zero as they represent a simple average across the sample distribution of health. To test this, Appendix Table D19 shows estimates of the health production function with interacted health investment and child health at each age. It is not possible to reject that that these interaction effects are equal to zero in any period, however, suggesting that no such complementarity exists. This further confirms the results of Table 3 that investments have no strong effect on health accumulation, even when it is allowed to vary across the distribution of health.

4.4 Health and Skill Accumulation

4.4.1 Cognitive Skill Production Functions

Table 4 shows estimates of the baseline Cobb-Douglas cognitive skill production function, with its RTS constrained to equal one. Cognitive skill is estimated to be self-productive to varying extents across childhood. Over the first 4 periods, between the ages of 9 months and 11, cognition becomes increasingly persistent, with its self-productivity being close to one by age 11. In the last period however, between 11-14, this reduces to around one-sixth of its size in the previous period. This is in contrast to much of the literature on skill development, in which evidence has consistently found that cognition is increasingly or highly self-productive across all of the ages covered in this study (e.gCunha et al. (2010), Agostinelli and Wiswall (2016a), Attanasio et al. (2020c)). In the first period, when the self-productivity of cognition is at its lowest, health is estimated as a important determinant of cognitive development, with an elasticity of roughly 0.26. Although the effect of health on cognitive development fades over the next 3 periods, it becomes important to its development again in the final period, between 11-14, when cognitive self-productivity drops from its peak at age 11. This suggests that during these ages, good health is important in developing cognitive skill and that the impact of health of cognitive development is felt both early and late in childhood - again, important phases in skill accumulation. There is also evidence of cross productivities between socio-emotional skill and cognition in the first two periods, between 9 months and 5.

Health investments are estimated to factor significantly in the production of cognitive skill in four of the five periods, albeit marginally in one (between 3-5). Cognitive investments affect cognitive development positively in between 9 months-3 and 11-14, but negatively in periods covering 3-11. This negative effect is driven by parents' strong, compensatory response to cognition when making cognitive investments across these periods not being matched by increases in cognitive skill (Table 2).[16] To examine whether the impact of investment might vary across the distribution of skill, Tables D20 and D21 show estimates of the cognitive production function with interactions of cognitive skill with health and cognitive investments respectively. In neither is there any strong evidence that the efficacy of investments in producing cognition depends on contemporaneous levels of skill. The only interaction effect that is statistically different from zero is between health investments and cognition in the final period (Table D20). In this period, the interaction effect is positive, suggesting that health investments are more productive in producing cognition when made in children with already high levels of skill. This is points to the importance of the health-related environment in this period in determining the divergence of cognitive skill.

4.4.2 Socio-emotional Skill Production Functions

Table 5 shows estimates of the baseline Cobb-Douglas socio-emotional production parameters. Like health and cognition, socio-emotional skill is self-productive across childhood. In the last period, and similar to cognition, its self-productivity is low in comparison to the preceding periods, however. Health enters positively into the socio-emotional production function in all periods, however its 90% confidence interval only does not contain zero marginally in one, between 5-7.

Parental education and socio-emotional skill have a similar impact in the production of socio-emotional skill across all of childhood. Both have a positive effects on its development, particularly in the earliest periods, between 9 months and 5. Parents' health on the other hand has little effect in any period. Health investments positively affect socio-emotional development in all periods, and their elasticity is large and statistically different from zero in first and fourth periods. In the first period, when children are aged between 9 months and 3 years old, health investments are in fact the strongest determinant of next period skill behind socio-emotional skill itself. The same is true for cognitive investments in the following period, meaning that early socio-emotional skill appears to be particularly influenced by household investment behaviours. Appendix Tables D22 and D23 also show estimates of the socio-emotional production function with interactions of socio-emotional skill with health and cognitive investments respectively. In neither table is there evidence of dynamic complementaries between skills and investments.

[16]It is not possible to rule out is is not partly a result of the methodology used. Despite minimising the extent to which measures capture variation in more than one latent variable, using many instruments for many endogenous regressors means counterintuitive results like this might be driven by correlations across measures of different unobservables. I discuss this in more detail at the end of the section.

Table 4: Estimates of Cobb-Douglas cognitive skill production function

	Period 1 *Ages 9 months-3*	Period 2 *Ages 3-5*	Period 3 *Ages 5-7*	Period 4 *Ages 7-11*	Period 5 *Ages 11-15*
Lagged human capital					
$\ln H_{h,t-1}$	0.258***	0.150	-0.047	-0.043	0.240**
	(0.098)	(0.106)	(0.063)	(0.094)	(0.120)
	[0.096,0.419]	[-0.023,0.324]	[-0.151,0.057]	[-0.198,0.112]	[0.042,0.438]
$\ln H_{c,t-1}$	0.138	0.643***	0.884***	0.931***	0.154***
	(0.141)	(0.104)	(0.053)	(0.124)	(0.028)
	[-0.094,0.370]	[0.472,0.815]	[0.797,0.971]	[0.727,1.136]	[0.108,0.200]
$\ln H_{s,t-1}$	0.173**	0.044***	0.028	0.012	-0.045
	(0.068)	(0.017)	(0.018)	(0.028)	(0.034)
	[0.061,0.285]	[0.017,0.072]	[-0.002,0.058]	[-0.035,0.059]	[-0.102,0.012]
Parental human capital (fixed over time)					
$\ln P_h$	-0.015	0.027	-0.004	-0.059	-0.035
	(0.025)	(0.034)	(0.030)	(0.053)	(0.051)
	[-0.056,0.025]	[-0.029,0.083]	[-0.053,0.046]	[-0.147,0.029]	[-0.120,0.049]
$\ln P_c$	0.284***	0.066*	0.142***	0.103**	0.310***
	(0.036)	(0.037)	(0.029)	(0.046)	(0.060)
	[0.226,0.342]	[0.005,0.127]	[0.094,0.190]	[0.027,0.180]	[0.211,0.409]
$\ln P_s$	0.012	-0.033	0.013	0.035	0.029
	(0.011)	(0.021)	(0.018)	(0.034)	(0.023)
	[-0.007,0.031]	[-0.067,0.001]	[-0.017,0.042]	[-0.020,0.090]	[-0.009,0.066]
Investments					
$\ln I_{h,t-1}$	0.082***	0.203*	0.015	0.286**	0.176***
	(0.024)	(0.106)	(0.025)	(0.118)	(0.038)
	[0.044,0.121]	[0.029,0.377]	[-0.026,0.056]	[0.093,0.480]	[0.113,0.239]
$\ln I_{c,t-1}$	0.068***	-0.101	-0.032***	-0.266**	0.172*
	(0.012)	(0.107)	(0.011)	(0.110)	(0.096)
	[0.049,0.087]	[-0.277,0.075]	[-0.050,-0.013]	[-0.448,-0.084]	[0.013,0.331]
$\sigma^2_{\eta_c}$	0.451	0.103***	0.082***	2.062***	0.120***
	(1.155)	(0.024)	(0.022)	(0.776)	(0.032)
	[-1.449,2.352]	[0.065,0.142]	[0.045,0.118]	[0.785,3.339]	[0.067,0.172]
N	7,998	6,898	7,853	7,373	7,404

Notes: Standard errors in parentheses and 90% confidence intervals in square brackets are calculated using 100 bootstrap replications. The outcome in each column is children's cognitive skill measured by the observables in Appendix Table D12. $t-1$ = ages 9 months and ages 3, 5, 7, and 11 years for the five columns respectively. The inputs in the left column are are lagged child health, cognitive skill and socio-emotional skill; parental health, cognitive skill and socio-emotional skill; and health and cognitive investment, respectively. All with the exception of parental cognitive skill are treated as unobservable. Section 2.5 describes the observables used as measures of each input, and their estimated measurement parameters are shown in Tables D11-D16.

Socio-emotional skill is considerably more malleable than health. The estimates of its RTS are far larger than that of health in each period. Its RTS are actually estimated to be statistically greater than one across the first four periods, and in the first period they are estimated to be greater than 2 - a 1% increase in each of its inputs are associated with a 2.7% increase in socio-emotional skill at age 3. The estimates of TFP are also substantially higher across all but the last period.

4.4.3 How Does Excluding Health Affect Estimates of Skill Production Functions?

To show the implications of excluding health in an analysis of skill development, Appendix Tables D25 and D26 show estimates of the cognitive and socio-emotional skill production functions respectively, excluding health. Whilst the qualitative results remain unchanged, excluding children's and parents' health and health investments from the production functions results in several significant changes to parameter estimates. For example, in Table D25, the elasticity of cognition with respect to socio-emotional skill in the first period almost doubles, and in the second period its self-productivity increases by one-third. Omitting health investments also increases the estimated effect of cognitive investments in the first and last periods, when they were estimated to affect cognitive development.

This also highlights a result of the previous section as it relates to health investments - cognitive investments affect cognitive development negatively in periods 2, 3 and 4 as compensatory investments are not met with increases in cognition. When excluding health investments, the magnitude of these negative effects increase in absolute terms due to the negative correlation between investments - likely a product of parents trading off investments for one another.

For socio-emotional skill, Table D26 shows that excluding health also results in its self-productivity more than doubling in the first period. In the same period, it also results in effect of cognition reversing to to be *negative*. Taken at face-value, this would suggest babies with high level of cognition at 9 months have lower stocks of socio-emotional skill at age 3 - a conclusion that, again, might not be entirely counterintuitive given I measure socio-emotional skill with symptoms relating to behavioral and social difficulties. Here, however, this relationship arises due to the exclusion of health investments from the socio-emotional skill production function. In Table 1, there is a very large compensatory investment response to cognition in the first period, and in Table 5 these investments have a large positive effect on socio-emotional skill production in the same period. As a result, excluding health investments results in the appearance of a negative relationship between cognitive and socio-emotional skills in this key early stage. The conclusions about the process of socio-emotional development are broadly unchanged thereafter, again suggesting that cognitive development is tied more to health.

5 Simulating Counterfactual Development Paths

In this section I explore the implications of the estimated model for health and skill development. I then simulate the short and long-term impacts of three types of intervention aimed at improving

Table 5: Estimates of Cobb-Douglas socio-emotional skill production function

	Period 1 *Ages 9 months-3*	Period 2 *Ages 3-5*	Period 3 *Ages 5-7*	Period 4 *Ages 7-11*	Period 5 *Ages 11-15*
Lagged human capital					
$\ln H_{h,t-1}$	0.233	0.117	0.125*	0.022	0.109
	(0.289)	(0.144)	(0.070)	(0.075)	(0.077)
	[-0.243,0.709]	[-0.121,0.354]	[0.009,0.240]	[-0.102,0.145]	[-0.019,0.236]
$\ln H_{c,t-1}$	0.295	0.033	0.006	0.071**	0.017
	(0.412)	(0.054)	(0.037)	(0.032)	(0.011)
	[-0.383,0.972]	[-0.056,0.122]	[-0.054,0.067]	[0.019,0.123]	[-0.001,0.035]
$\ln H_{s,t-1}$	0.438**	0.409***	0.788***	0.678***	0.313***
	(0.204)	(0.015)	(0.022)	(0.022)	(0.023)
	[0.102,0.774]	[0.385,0.434]	[0.753,0.824]	[0.642,0.715]	[0.276,0.350]
Parental human capital (fixed over time)					
$\ln P_h$	0.006	-0.015	-0.009	0.049	0.047
	(0.059)	(0.045)	(0.035)	(0.040)	(0.033)
	[-0.091,0.103]	[-0.090,0.060]	[-0.067,0.048]	[-0.017,0.114]	[-0.006,0.101]
$\ln P_c$	0.524***	0.044	0.139***	0.076*	0.084***
	(0.070)	(0.048)	(0.035)	(0.040)	(0.029)
	[0.408,0.640]	[-0.036,0.123]	[0.082,0.197]	[0.010,0.142]	[0.036,0.132]
$\ln P_s$	0.396***	0.097***	0.058**	0.044	0.035*
	(0.037)	(0.025)	(0.023)	(0.027)	(0.020)
	[0.335,0.457]	[0.056,0.138]	[0.020,0.096]	[-0.000,0.088]	[0.002,0.069]
Investments					
$\ln I_{h,t-1}$	0.714***	0.137	0.048	0.325***	0.026
	(0.083)	(0.122)	(0.029)	(0.088)	(0.017)
	[0.577,0.850]	[-0.064,0.339]	[-0.000,0.097]	[0.181,0.469]	[-0.001,0.054]
$\ln I_{c,t-1}$	0.061***	0.469***	-0.011	0.021	0.074
	(0.018)	(0.102)	(0.012)	(0.069)	(0.080)
	[0.031,0.092]	[0.301,0.637]	[-0.030,0.009]	[-0.091,0.134]	[-0.058,0.206]
$\ln A_t$	-0.471***	1.089***	1.127***	1.138***	0.156***
	(0.065)	(0.055)	(0.049)	(0.046)	(0.037)
	[-0.577,-0.364]	[0.999,1.178]	[1.047,1.208]	[1.063,1.214]	[0.096,0.217]
RTS	2.667***	1.291***	1.146***	1.286***	0.705***
	(0.338)	(0.156)	(0.072)	(0.107)	(0.098)
	[2.111,3.223]	[1.034,1.548]	[1.027,1.265]	[1.110,1.462]	[0.544,0.866]
$\sigma^2_{\eta_n}$	0.919***	0.349***	0.384***	0.384***	0.152***
	(0.085)	(0.032)	(0.033)	(0.029)	(0.011)
	[0.780,1.059]	[0.297,0.401]	[0.329,0.439]	[0.337,0.432]	[0.134,0.171]
N	8,195	6,908	7,892	7,578	7,619

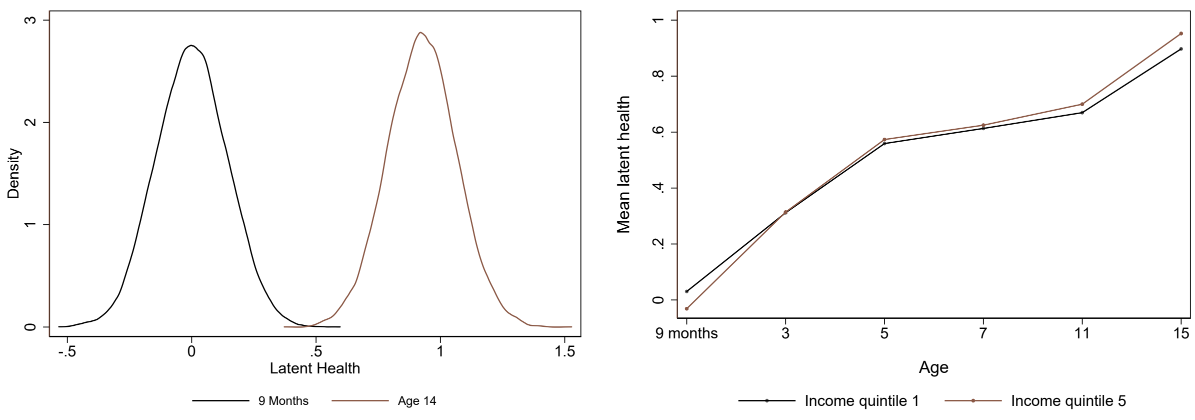
Notes: Standard errors in parentheses and 90% confidence intervals in square brackets are calculated using 100 bootstrap replcations. The outcome in each column is children's socio-emotional skill measured by the observables in Appendix Table D13. $t-1$ = ages 9 months and ages 3, 5, 7, and 11 years for the five columns respectively. The inputs in the left column are are lagged child health, cognitive skill and socio-emotional skill; parents' health, cognitive skill and socio-emotional skill; and and health and cognitive investment, respectively. All with the exception of parental cognitive skill are treated as unobservable. Section 2.5 describes the observables used as measures of each input, and their estimated measurement parameters are shown in Tables D11-D16.

health and skills, and reducing human capital disparities. First, I evaluate the impact of income transfers at different stages of childhood on the development of health, as well as cognitive and socio-emotional skill. Secondly, I examine how an intervention aimed at improving children's health might affect its development, as well as the development of cognitive and socio-emotional skill. Lastly, I estimate how improving the early environment through increasing the health and education of parents might affect the developmental path of health and skills. To do so, I draw a sample of 10,000 observations from the estimated joint distribution of initial conditions - shown in Appendix Tables D17 and D18 - and simulate the developmental paths of health and skills with and without these interventions using estimates of the production and investment functions from section 4.

5.1 The Estimated Developmental Path of Health and Skills

Figure 2 shows this estimated development path of health in the absence of any intervention from two perspectives. Firstly, Panel (a) shows its simulated distribution at 9 months and age 14 - the initial and end period of the model. As might be expected given its estimated persistence, the distribution of latent health stays similar over time. This also makes clear that I have modeled health as a stock of human capital that builds across childhood, a conceptual approach that differs from the view of health production of, for example, Grossman (1972) in which health is viewed a stock that depreciates over time, and "improves" only through investments. This approach is focussed on human capital in adulthood, however, and is less suitable here given that the phase of life being studied is one in which children grow and develop into young adults.

Figure 2: The estimated path of health capital over time



(a) **(b)**

Note: Panel (a) the simulated distribution of health at 9 months and age 14, and panel (b) shows the simulated evolution of mean latent health in the top and bottom quintiles of the income distribution. Both were estimated by simulating the developmental path of 10,000 observations randomly drawn from the estimated initial conditions.

Figure 2(b) then plots the mean level of log latent health at the top and bottom of the simulated income distribution over time. This shows that children's health is not dissimilar across the income distribution over much of childhood, but by age 14 there is a small income inequality in health that is equal to roughly one-half of a standard deviation of its distribution. This implies that although health is persistent over time, small differences across the income distribution emerge mainly in the latter stages of childhood. Bearing in mind the results of the previous section, it is likely that this is driven by disparities in cognitive and socio-emotional skills. Comparing the gradient here with that in the observables measures in Figure 1 also highlights the importance of using multiple measures to back out latent health - using either of the two panels of the figure to draw conclusions about health might lead to the under or overstating the extent of the relationship between health and income.

Appendix Figure D1 provides analogous plots for cognitive and socio-emotional skills. It shows that health and health inequalities evolve differently to those in skills. The distribution of socio-emotional skill becomes narrower over time, and early inequalities across the income distribution reduce in later childhood. The resulting income gradient is similar to that of health.[17] On the other hand, the distribution of cognition flattens over time, and there is a much larger difference in the average level of cognitive skill at the top and bottom of the income distribution.

5.2 Short and Long-Term Effects of Interventions

Before presenting the estimated developmental path when transfers are given to families, it is first useful to consider their short (i.e immediate effect in t) and long-term effects (i.e at the end of childhood) in terms of the parameters of the production and investment functions. Here I outline these effects using the example of income transfer, however the intuition can then be applied to all interventions considered.

The effects of income transfers will initially come through the effects of changes in investment. Any increases in human capital induced by these changes will then be propagated through childhood. Formally, given endowments, child human capital and income, the immediate, marginal impact of a one-time income transfer in any of the t periods on next period's $(t+1)$ health can be expressed as:[18]

$$\Delta^{Y}_{h,t+1}(\mathbf{\Omega}_t) = \frac{\partial \ln H_{h,t+1}}{\partial Y_t} = \frac{\partial \ln H_{h,t}}{\partial \ln I_{h,t}} \frac{\partial \ln I_{h,t}}{\partial Y_t},$$

where $\mathbf{\Omega}_t = \{H_{h,t}, H_{c,t}, H_{s,t}, P_h, P_c, P_s, Y_t\}$ is the vector of state variables which are observed at the beginning of the period. In the baseline, Cobb-Douglas form of the health production function this marginal effect is equivalent to:

[17] The decline in socio-emotional skill in the last period is driven by the very low RTS and TFP estimates between 11 and 14.

[18] This presentation of the marginal effects of an income transfer follows from Agostinelli and Wiswall (2016a)

$$\Delta^Y_{h,t+1}(\mathbf{\Omega}_t) = \frac{\partial \ln H_{h,t}}{\partial Y_t} = \gamma^h_{h,t} \times \frac{\beta^h_{7,t}}{Y_t} \tag{8}$$

Given that this effect can vary with household income, it is possible to analyse how the impact of transfers would differ depending on family resources.[19] The results in Section 4 showed that investment did not enter significantly (statistically or economically) into the health production function, however. As a result, these short-term effects will be (or be very close to) zero. Cognitive and socio-emotional skills can impact health development, meaning it is possible that income transfers have an impact on health in the long-run. Too see how, the impact of income transfers on health at the end of childhood can be written as a function of all short term impacts up until that point:

$$\begin{aligned}\Delta^Y_{h,L}(\mathbf{\Omega}_t) = & \underbrace{\Delta^Y_{h,L-1}(\mathbf{\Omega}_t) \times \left(\frac{\partial \ln H_{h,L}}{\partial \ln H_{h,t+L-1}} + \frac{\partial \ln H_{h,L}}{\partial \ln I_{h,L-1}} \frac{\partial \ln I_{h,L-1}}{\partial \ln H_{h,L-1}} \right)}_{\text{effect of the change in } \textit{lagged} \text{ health induced by transfer}} \\ & + \underbrace{\sum_{j \in \{c,s\}} \Delta^Y_{j,L-1}(\mathbf{\Omega}_t) \times \left(\frac{\partial \ln H_{h,L}}{\partial \ln H_{j,L-1}} + \frac{\partial \ln H_{h,L}}{\partial \ln I_{h,L-1}} \frac{\partial \ln I_{h,L-1}}{\partial \ln H_{j,L-1}} + \frac{\partial \ln H_{h,L}}{\partial \ln I_{c,L-1}} \frac{\partial \ln I_{c,L-1}}{\partial \ln H_{j,L-1}} \right)}_{\text{effect of the change in } \textit{lagged} \text{ cognitive and socio-emotional skill induced by transfer}},\end{aligned} \tag{9}$$

where $t + L = t + (T - t)$; the end of childhood.[20] Above, implicit in $\Delta_{k,t+\tau-1}$ for $k \in \{h, c, s\}$ is the full history of marginal effects on on skill accumulation up until that point. For example, if childhood had only 3 periods (i.e $L = 3$), the long-term impact of a transfer in period 1 on health is given by:

$$\begin{aligned}\Delta^Y_{h,3}(\mathbf{\Omega}_1) = & \left[\gamma^h_{h,t} \times \frac{\beta^h_{7,t}}{Y_1} \right] \times \left(\rho^h_{h,2} + \gamma^h_{h,2}\beta^h_{1,2} \right) \\ & + \left[\left(\gamma^c_{h,t} \times \frac{\beta^h_{7,t}}{Y_1} \right) + \left(\gamma^c_{c,t} \times \frac{\beta^c_{7,t}}{Y_1} \right) \right] \times \left(\rho^h_{c,2} + \gamma^h_{h,2}\beta^h_{2,2} + \gamma^h_{c,2}\beta^c_{2,2} \right) \\ & + \left[\left(\gamma^s_{h,t} \times \frac{\beta^h_{7,t}}{Y_1} \right) + \left(\gamma^s_{c,t} \times \frac{\beta^c_{7,t}}{Y_1} \right) \right] \times \left(\rho^h_{s,2} + \gamma^h_{h,2}\beta^h_{3,2} + \gamma^h_{c,2}\beta^c_{3,2} \right)\end{aligned} \tag{10}$$

The transfer initially has an impact on health through increased investments. Increased

[19] If an interaction of health with health investment was included in the production function, the short-term effect would also capture dynamic complementarities through an additional term: $\kappa^h_{hh,t} \times \frac{\beta^h_{7,t}}{Y_t} \times H_{h,t}$. Given the results provided no evidence of these relationships, I exclude them here.

[20] Note here that the cognitive and socio-emotional skill cross-productivity components of Equation 9, have an additional term as both are affected by health *and* cognitive investments

income in period 1 then has two effects at the end of childhood. Firstly, there is a direct effect on the accumulation of health, realised through self-productivity ($\rho^h_{h,2}$) and any investment response ($\gamma^h_{h,2}\beta^h_{1,2}$). Secondly, there is an indirect impact that comes through the cross productivity of cognitive and socio-emotional skill in the development of health ($\rho^h_{c,2}, \rho^h_{s,2}$), as well as any investment response in period 2 to changes in their stocks ($(\gamma^h_{h,2}\beta^h_{2,2} + \gamma^h_{c,2}\beta^c_{2,2})$). The short and long-term effects on cognitive and socio-emotional skill can be expressed in an identical manner.

5.3 The Effects of Income Transfers Across Childhood

Appendix Figure D2(a) plots the average effect of a one-time £5,000 transfer - equivalent to around one-third of median equivalised annual income in sample - to all children based on the period in which it is given.[21] It shows that income transfers are estimated to have the largest long-term impact on cognitive and socio-emotional skill when given late (7-11; 11-14), and that they have no effect on health when given in any period.[22] Focussing on the age at which its impact is largest, Figure D2 also shows that the effect of an income transfer at age 11 on skills at 14 is similar across the distribution of income (panel (b)) and health (panel (c)), although they do affect cognition to a slightly greater extent for low-income children. This is because, as shown in Equation 8, the marginal effect of investments can vary across the income distribution. Appendix Table D27 also shows estimates of the short and long-term effects by period of transfer.[23]

It is also possible to estimate the effects of income transfers targeted to those in the poorest families. Given the effects of un-conditional transfers were constant across the income and health distribution (Figure D2), the effects of these transfers will be no different in magnitude to those the result from a transfer to the whole sample. Figure 3(a) confirms this. However, a policy concern of targeted transfers such as this is whether or not they can reduce inequalities. Figure 3(b) shows the overall change in the composition of skills among *all* children in ventiles of the health distribution at 14 given a transfer to only the 25% poorest children at age 11 (again the period when their effect is largest). It shows that this targeted transfer affects the composition of skills most at the lower end of the health distribution: because poorer children have lower health on average by age 11, these transfers have the largest effect on average cognitive and, to a lesser extent, socio-emotional skill among those in the bottom of the health distribution. Still, however, there is no effect on health. Appendix Table D28 shows both the short and long-term effect of these targeted transfers on the children who benefited by the period in which they were given.

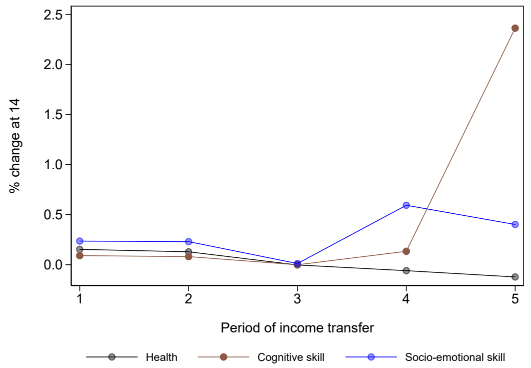
The effects of income transfers on cognitive and socio-emotional skill are small due to

[21] An implicit asumption in the simulation is that all of the income is spent in the same period.

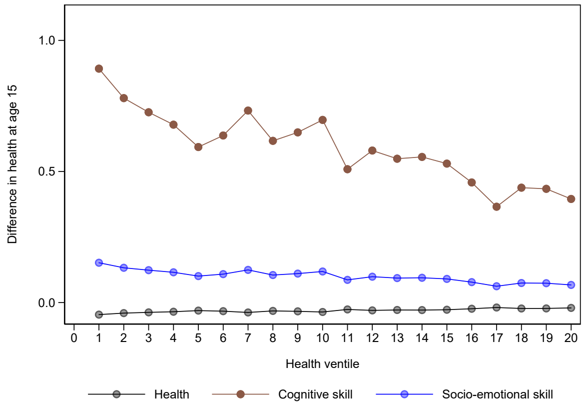
[22] For health, the short-term effect is negative in all but the first period because investments were estimated to have a small, statistically insignificant negative elasticity in health production. All estimated parameters are used to forward simulate the model regardless of their statistical significance.

[23] Each row/column combination shows the average percent change in the human capital in either the short or long-term given a transfer in the period indicated by the column. The short-term effects equal the long-term effects in the last period

Figure 3: The long-term human capital impacts of a £5, 000 increase in income across childhood for these in the bottom quartile of the income distribution



(a) Long-term effects on transfer recipients by round of transfer



(b) Overall change in average human capital among health ventiles given a targeted income transfer at age 11

Note: Panel (a) shows the % increase in health and cognitive and socio-emotional skill at 14 given an income transfer of £5,000 to those in the bottom 25% of the income distribution at the age shown on the x-axis. Panel (b) shows the % increase in each component of human capital at 14 among all children in each health ventile given an income transfer at age 11 to those in the bottom 25% of the income distribution. The effects were calculate by drawing 10,000 observations from the estimated initial conditions and forward simulating the child development path with and without directed income transfers in each period. It is assumed that the transfers are spent fully in the period they are given.

two features of the estimated model. Firstly, the effect of income on investments was often relatively small, meaning increases in income are not necessarily translated into large increases in investment. This is perhaps intuitive given the measures used are of *time* as opposed to *material* investments. Second, long-term effects are driven by self-productivities, and there are no dynamic complementarities present between skills and investments. The result is that any small short-term impacts fade over time.

That income transfers later in childhood affects skills to a greater extent than those early is in contrast to Agostinelli and Wiswall (2016a), who find that they have their largest effect on when given as early as age 5. This is driven by the fact they estimate cognition to have high returns to scale in early childhood, and its technology to displays dynamic complementarities between cognition and investments. Attanasio et al. (2020c) also simulate income transfers and find that they have a larger impact when given before 5 for cognition and between 5-8 for health. They find that their measures of investments do impact health production, however. Overall, this is evidence that it is difficult to impact health, or cognitive and socio-emotional development simply using one-off, unconditional income transfers. This echoes the findings of similar studies that have sought to estimate the impact of income transfers on child development or adult outcomes as they act through increased levels of household investment (Del Boca et al., 2013, 2016).

5.4 The Effect of Health Improvements Across Childhood

As opposed to income transfers, the idea of "health improvements" as an intervention are somewhat abstract. Such policies would not be straightforward to design. *How* they were conducted would also require an clear definition of the aspects of health they sought to improve. As discussed in Section 3, I measure health by long-term illnesses and short-term health conditions. A health-improving intervention in this context would therefore require reductions in both of these things, perhaps through home-visitation or additional health care for children in the poorest health. Such supplemental health care programmes have been implemented in England and Germany, and there is evidence they have improved children's health both directly an indirectly.[24]

The short-term effects of health improvements differ from those of an income transfer due to their direct effect in health (and skill) production in the period of the improvement. This immediate increase in health then gives rise to a long-term effect in an identical manner as shown in Equation 9.[25] Appendix Figure D3(a) shows the long-term effects (age 14) of a one standard deviation health improvement by the period in which it occurs. Again, these improvements have the largest effect when made in the final period, between the ages of 11 and 14. For example, a one standard deviation increase in health at age 11 improves health at 14 by 10%, and cognitive and socio-emotional skills by 2% and 1.2% respectively. As in the case of income transfers, the relatively large effects of this late health improvements are a consequence of short-term effects fading out. Appendix Table D29 shows estimates of both the short and long-term effects.[26]

Improving health at age 11 increases cognition at 14 because it becomes an important determinant in cognitive production in late childhood. Similarly, although it did not enter significantly into the socio-emotional skill production function, the two are still highly correlated. Not considering health in the analysis of policy interventions therefore bypasses an important channel through which skills can be affected in late childhood. Appendix Figures D3(b) and D3(c) show that the effects of a health improvement in the final period are constant across the income an health distributions. The results of this simulation are differ slightly from those in Attanasio et al. (2020c). Although in a different setting, they estimate that health improvements have their largest long-term effect on cognition at 12 when they are received between 5-8. This is because they find health does not effect cognition in the latter period of their model, between 8-12. As I find here, however, they find that health improvements have their largest effect on health when given in this last period, due to its high self-productivity.

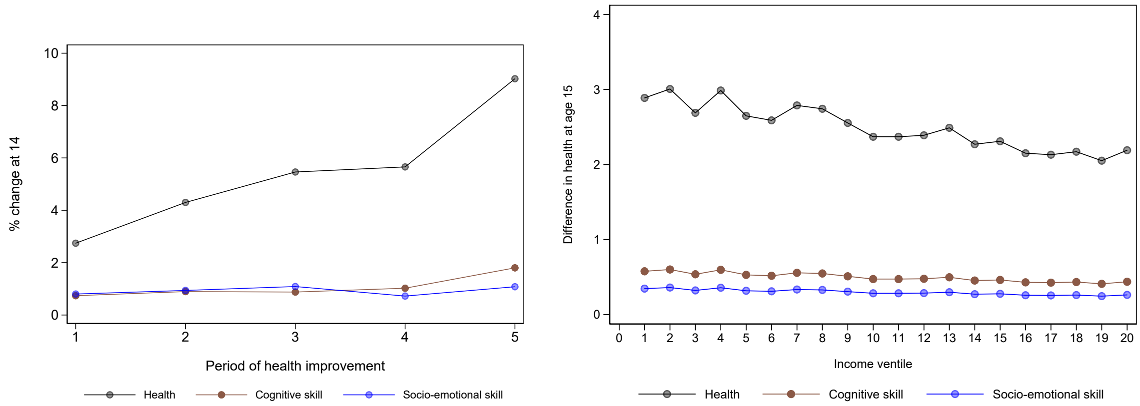
Again, it is possible to evaluate the effects of directing these improvements to children who

[24] Cattan et al. (2019) outline and analyse the effects of England's "Sure Start" policy, and Sandner et al. (2018) do the same for Germany's "Pro Kind" intervention.

[25] Formally, conditional on $\boldsymbol{\Omega}_t$, the short-term effect is: $\frac{\partial \ln H_{h,t+1}}{\partial \ln H_t} = \frac{\partial \ln H_{h,t+1}}{\partial \ln H_{h,t}} + \frac{\partial \ln H_{h,t+1}}{\partial \ln I_{h,t}} \frac{\partial \ln I_{h,t}}{\partial \ln H_{h,t}}$. This differs to the short-term effect of an income transfer by the first term.

[26] Some of the short-term the effects of a health improvement on cognition are negative - i.e in periods 3 and 4 (5-7; 7-11) - because there is a negative, statistically insignificant effect of health on cognition in these periods. Again, all estimated parameters are used to forward simulate the model regardless of their statistical significance.

Figure 4: The long-term human capital impacts of a one standard deviation improvement in health across childhood for those in the bottom quartile of the health distribution



(a) Long-term effects on those whose health improved by round of transfer

(b) Overall change in average human capital among income ventiles given a health improvement at age 11

Note: Panel (a) shows the % increase in health and cognitive and socio-emotional skill at 14 given one standard deviation improvement in health for those in the bottom 25% of the health distribution at the age shown on the x-axis. Panel (b) shows the % increase in each component of human capital at 14 among all children in each income ventile given a health improvement at age 11 to those in the bottom 25% of the health distribution. The effects were calculate by drawing 10,000 observations from the estimated initial conditions and forward simulating the child development path with and without directed income transfers in each period. It is assumed that the transfers are spent fully in the period they are given.

are in the poorest health, and whether they affect inequalities. Once more, given the effects of health improvements are homogeneous across income and health levels, the impact of these improvements will be the same as when given to the whole sample. This is shown in Figure 4(a). Figure 4(b) shows, however, that improving health for the unhealthiest 25% of children at age 11 (when the effects of improvements are largest) affects the composition of health at 14 in the lower end of the income distribution to a larger extent. The is also true for the skill composition, however the magnitude of these changes is much smaller. Again, this is because low-income children are more likely to have poor health and less skill at age 11. Appendix Table D30 shows estimates of the short and long-term effects of these directed health improvements.

5.5 The Effects of Increases in Parental Health and Education

Finally, I simulate the developmental path of health and skills given increases to two components of parental human capital; a one standard deviation improvement to their health, and in increase in educational attainment. The increase in education is equivalent to moving parents up one level in the UK's National Vocational Qualification (NVQ) scale. For example, if a parent obtained failing grades in lower high school exams (ages 14-16), the intervention would increase their attainment to having passed these exams. Similarly, if they had obtained an undergraduate degree, they would be up-skilled to masters level attainment.[27] These types of "interventions" can be seen as attempting to reduce the intergenerational link between parental characteristics and children's health. For improvements to parents' health, such improvements might come through the home-visitation style programmes discussed when outlining the effects of improvements to children's health. These increases to parental human capital influence short-term development through their effect on both investments and the production process. As I have assumed they are time-invariant, the initial increases in parental human capital affect development through the same channels in all subsequent periods.

Table 6 shows the effects of these increases at 9 months on human capital at each age. Each major-column represents the relevant component of children's human capital and each sub-column the component of parental human capital increased. Parents' education has the largest impact on cognitive and socio-emotional development, and little effect on health. By age 14, cognition and socio-emotional skill are 3.7% and 2% higher than in the absence of the increase to parents' education, whereas health is only 0.36% higher. Similarly, improving parental health has the largest effect on children's health - at 8.7%, the effect on health by 14 is in fact almost as large as when improving children's health itself at age 11 (Table D27). This effect builds over time from an initial change in health at age 3 of only 2.2%. Socio-emotional skill at 14 also increases as a result of improving parents' health, and is just under 5% higher than it otherwise would have been. There is little effect on cognition.[28]

Appendix Figure D4 shows that the long-term effects of increases in parents' education are larger for children in the lower end of the income and health distributions (panels (a) and (b)), but that the effects of improvements to parents health are constant (panels (c) and (d)). This is because parents are estimated to make investments independently of their health, but not their education. As a result, increases in their attainment impact development through two channels, whereas those to health do so only through one. Second, the marginal effect of investments can vary across the income distribution (Equation 8), and investments impact cognitive but not health production.

Turning again to directed interventions, Figure D5(a) shows the change in the composition of health and skills at 14 is more pronounced among those in lower end of the income distribution when parental health is only improved for the unhealthiest 25% of children. Similarly, Figure D5(b) shows that targeting health of parents in the *poorest* 25% of families results in the largest changes in health and skill composition among the unhealthiest children. Again, this is an artifact of the negative relationship between skills, health and parents health at age 11.

[27]There are 8 NVQ levels in total. See https://www.gov.uk/what-different-qualification-levels-mean/list-of-qualification-levels for a full list of NVQ qualification levels in England, Wales and Northern Ireland. Sottish qualifications are converted by the MCS to their NVQ equivalents.

[28]There is a small negative effect at 14 due to the small, statistically insignificant negative elasticity on parents' health in the production of cognition. See Table 4.

Table 6: The impacts on human capital of increases in parents' human capital across childhood

Outcome:	**Health**		**Cognition**		**Socio-emotional.**	
	Parental edu.	*Parental health*	*Parental edu.*	*Parental health*	*Parental edu.*	*Parental health*
Age 3	0.2554	2.1751	2.6119	-0.6960	6.1862	3.1119
	(0.1125)	(0.0000)	(1.1507)	(0.0000)	(2.7254)	(0.0000)
Age 5	0.3619	6.3300	2.6635	1.9098	3.5417	0.4409
	(0.1594)	(0.0000)	(1.1734)	(0.0000)	(1.5603)	(0.0000)
Age 7	0.2316	6.5451	3.6449	1.3896	4.0489	0.6960
	(0.1020)	(0.0000)	(1.6058)	(0.0000)	(1.7838)	(0.0000)
Age 11	0.2913	7.7631	4.3185	-2.3240	3.6722	3.7797
	(0.1283)	(0.0000)	(1.9026)	(0.0000)	(1.6178)	(0.0000)
Age 14	0.3605	8.6578	3.6877	-0.3516	2.0300	4.9764
	(0.1588)	(0.0000)	(1.6246)	(0.0000)	(0.8944)	(0.0000)
N	10,000	10,000	10,000	10,000	10,000	10,000

Note: Each cell shows $100 * E[\ln H_{j,t}^{H_h} - \ln H_{j,t}]$, the average change in human capital component j - indicated by the master column - given an increase in the component of parents' human capital indicated by each sub-column at 9 moths of age. Parents' health is increased by one standard deviation and their education increase by one National Vocation Qualification level. For example, if a parent reports to have obtained lower higher school level qualifications, their education will be incresed to having obtained upper high school qualifications. The differences are calculated by simulating the developmental path of 10,000 observations randomly drawn from the estimated initial conditions, with and without the increases to parents' human capital at 9 months. Standard errors of the difference are in parentheses.

6 Conclusions

This study analysed health development between the ages of 9 months and 14, and how it affects the accumulation of two important components of human capital; cognitive and socio-emotional skills. Using detailed longitudinal data on a large sample of children born at the turn of the millennium in the UK, I have estimated investment and human capital production functions across childhood, correcting for mis-measurement of health, skills and household investments.

The results highlight several important features of health development and its role in skill accumulation. First, I find that health is highly persistent and mainly affected by past and parental health, but that in later childhood, cognitive and socio-emotional skills begin to influence its development. Cognitive and socio-emotional skills are affected by investments at various stages of childhood, and so there is a small socio-economic gradient in health by age 14. Second, I found that health affects the accumulation of cognitive skills early and late in childhood, crucial periods of development before school entry and during early high-school years. Further, my the results show that excluding health from human capital production functions results in overstating the the self and cross productivities of skills in the developmental process.

Gaining a broader perspective of child development is essential to understanding if and how early disparities in human capital emerge. A growing policy concern in many high-income countries is equality of opportunity, and ensuring that children's future opportunities are not predetermined by early circumstances. I therefore simulate the effect of several policies across different stages of childhood to analyse how they might affect health and skills at 14.

Improving parents' health has a large and persistent effect on child health by the end of childhood, and increasing their education results in small gains. Cash transfers have almost no impact on health development, and very little effect on cognitive and socio-emotional skill. The effects of improvements to children's health are more sizable on all three components of human capital, and are largest when given in late childhood. This is in contrast to results in the literature so far which have found dynamic complementarities between skills and investments, high-persistence of human capital in late-childhood or increasing returns to scale in skill production mean interventions have their highest returns when made early. I find no evidence of dynamic complementarities in the production of any component of human capital and that health and skills are malleable between 11-14. As a result, early interventions are note estimated to build over time. For all interventions, targeting them towards the unhealthiest/poorest children changes the health and skill composition to a greater extent at the lower end of the income/health distribution. This suggests policies aimed at reducing socioeconomic disparities in human capital can be effective when targeted to early adolescence - a finding that contradicts the viewpoint that interventions in the teenage years are inefficient, and provides evidence supporting the design of policy that considers all stages of development.

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A Estimation Algorithm

To estimate the human capital production and investment functions I follow the sequential algorithm developed by Agostinelli and Wiswall (2016a). The algorithm first requires identification of the measurement parameters and joint distribution of the initial conditions. Agostinelli and Wiswall (2016a) then show the restrictions on the measurement system or structural parameters under which the functions can be identified in the first and each subsequent period.

Given the restrictions/normalizations on the measurement system laid out in 2, estimation has four main steps: 1) Estimation of the joint distribution of the initial conditions; 2) Estimation of the investment function and investment measurement parameters in $t = 0$; 3) Estimation of the production function and measurement parameters for health and cognitive and socio-emotional skill in period t=1; 4) Repeat steps 2 and 3 for $t = 2, 3, 4, 5$. The next five subsections outline this process in full, focusing on the production function of health.

A.1 The joint distribution of initial conditions

The factor loading of each of the latent initial conditions can be retrieved by simply taking the ratio of covariances between different observed measurements. For example, for unobservable $\theta \in \{\ln H_{h,0}, \ln H_{c,0}, \ln H_{s,0}, \ln P_h, \ln P_s\}$:

$$\lambda_{\theta,m,0} = \frac{\text{Cov}(Z_{\theta,m,0}, Z_{\theta,m',0})}{\text{Cov}(Z_{\theta,1,0}, Z_{\theta,m',})} \quad \forall m' \neq m \tag{A1}$$

Next, under the assumption that the initial conditions are mean zero the intercepts, $\mu_{\theta,m,0}$, can be estimated by $\mathbb{E}(Z_{\theta,m,0})$, and residual measures are constructed:

$$\tilde{Z}_{\theta,m,0} = \frac{Z_{\theta,m,0} - \mu_{\theta,m,0}}{\lambda_{\theta,m,0}} = \ln\theta_0 + \frac{\varepsilon_{\theta,m,0}}{\lambda_{\theta,m,0}} = \ln\theta_0 + \tilde{\varepsilon}_{\theta,m,0} \quad \forall m \tag{A2}$$

The latent variables are equivalent to:

$$\tilde{Z}^*_{\theta,m,0} = \tilde{Z}_{\theta,m,0} - \tilde{\varepsilon}_{\theta,m,0} = \ln\theta_0 \tag{A3}$$

The diagonal and off-diagonal elements of Σ_Ω can be estimated by

$$\frac{\text{Cov}(Z_{\theta,1,0}, Z_{\theta,2,0})\text{Cov}(Z_{\theta,1,0}, Z_{\theta,3,0})}{\text{Cov}(Z_{\theta,2,0}, Z_{\theta,2,0})} = \frac{\lambda_{\theta,2,0}\lambda_{\theta,3,0}\text{Var}(\ln\theta_0)^2}{\lambda_{\theta,2,0}\lambda_{\theta,3,0}\text{Var}(\ln\theta_0)} = \text{Var}(\ln\theta_0) \tag{A4}$$

and

$$\text{Cov}(Z_{\theta,1,0}, Z_{\theta',1,0}) = \text{Cov}(\ln\theta_0, \ln\theta'_0) \tag{A5}$$

respectively. Since $\ln Y_0$ and P_c are assumed to me measured without error, their mean and variance are easily computed, and their covariance with the latent initial conditions is simply:

$$\text{Cov}(\ln Y_0, \ln \theta_0) = \text{Cov}(\ln Y_0, Z_{\theta,1,0})$$
$$\text{Cov}(\ln P_c, \ln \theta_0) = \text{Cov}(\ln P_c, Z_{\theta,1,0})$$

Given the assumption that unobservables are mean zero in the initial period, the mean vector is

$$\mu_\Omega = (0, 0, 0, 0, \mu_{\ln P_c}, 0, \mu_{\ln Y,0})$$

A.2 Investment Functions

Substituting a structural investment equation in to one measurement equation for investment in human capital component $j \in \{c, h\}$ in period zero gives:

$$\begin{aligned} Z_{I_j,1,0} = \mu_{I_j,1,0} + \lambda_{I_j,1,0}(\beta^j_{1,0} \ln H_{c,t} + \beta^j_{2,0} \ln H_{s,0} + \beta^j_{3,0} \ln H_{h,0} + \beta^j_{4,0} \ln P_c \\ + \beta^j_{5,0} \ln P_s + \beta^j_{6,0} \ln P_h + \beta^j_7 \ln Y_0 + \pi_{j,0}) + \varepsilon_{I_j,1,0} \end{aligned} \tag{A6}$$

Then, substituting the corresponding $\tilde{Z}^*_\theta = \tilde{Z}_{\theta,m,0} - \tilde{\varepsilon}_{\theta,m,0}$ in to this in place of the relevant θ Equation A6 can be re-written as:

$$\begin{aligned} Z_{I_j,1,0} = \mu_{I_j,1,0} + \lambda_{I_j,1,0}(\beta^j_{1,0} \tilde{Z}^*_{H_c,m,0} + \beta^j_{2,0} \tilde{Z}^*_{H_s,m,0} + \beta^j_{3,0} \tilde{Z}^*_{H_h,m,0} + \beta^j_{4,0} \ln P_c \\ + \beta^j_{5,0} \tilde{Z}^*_{P_s,m} + \beta^j_{6,0} \tilde{Z}^*_{P_h,m} + \beta^j_7 \ln Y_0 + \pi_{j,0}) + \varepsilon_{I_j,1,0} \end{aligned} \tag{A7}$$

Expanding and rearranging this equation gives the following reduced form investment equation for $I_{j,0}$:

$$\begin{aligned} Z_{I_j,1,0} = \delta^j_0 + \delta^j_{1,0} \tilde{Z}_{H_c,m,0} + \delta^j_{2,0} \tilde{Z}_{H_s,m,0} + \delta^j_{3,0} \tilde{Z}_{H_h,m,0} + \delta^j_{4,0} \ln P_c \\ + \delta^j_{5,0} \tilde{Z}_{P_s,m} + \delta^j_{6,0} \tilde{Z}_{P_h,m} + \delta^j_{7,0} \ln Y_0 + \nu_{j,0} \end{aligned} \tag{A8}$$

where

$$
\begin{aligned}
\tilde{Z}_{\theta,m,0} =& \ln\theta_0 + \tilde{\varepsilon}_{\theta,m,0} \quad \text{for}\, \theta \in \{\ln H_{h,0}, \ln H_{c,0}, \ln H_{s,0}, \ln P_h, \ln P_s\} \\
\delta_0^j =& \mu_{I_j,1,0} \\
\delta_{i,0}^j =& \lambda_{I_j,1,0}\beta_{i,0}^j \quad \text{for} \quad i = 1,..,7 \\
\nu_{j,0} =& \varepsilon_{I_j,1,0} + \lambda_{I_j,1,0}(\pi_{j,0} - \beta_{1,0}^j\tilde{\varepsilon}_{H_c,m,0} - \beta_{2,0}^j\tilde{\varepsilon}_{H_s,m,0} - \beta_{3,0}^j\tilde{\varepsilon}_{H_h,m,0} \\
& - \beta_{5,0}^j\tilde{\varepsilon}_{P_s,m,0} - \beta_{6,0}^j\tilde{\varepsilon}_{P_h,m,0})
\end{aligned}
$$

In Equation A8, $\mathbb{E}(\tilde{Z}_{\theta,m,0}\nu_{j,0}) \neq 0$ since both contain $\tilde{\varepsilon}_{\theta,m,0}$. To consistently estimate the reduced form parameters in Equation A8 all other available measures of each latent input are used as instrumental variables for the error contaminated $\tilde{Z}$s. Under the assumption that measurement errors are independent of one another and all latent variables, the condition that $\mathbb{E}(Z_{\theta,m',0}\nu_{j,0}) = 0 \quad \forall\,\theta_0$ and $m' \neq m$ is satisfied and so these alternative measures are valid instruments. With the normalsation that $\lambda_{I_{j,0},m,0} = 1$ and $\mathbb{E}(\ln I_{j,0}) = 0$, the parameters of the investment function be recovered straightforwardly as:

$$
\begin{aligned}
\beta_{i,0}^j &= \delta_{1,0}^j \quad \text{for} \quad i = 1,..,7 \\
\delta_0^j &= \mu_{I_j,1,0}
\end{aligned}
$$

A residual investment measure is then constructed as:

$$
\tilde{Z}_{I_j,1,0} = Z_{I_j,1,0} - \mu_{I_j,1,0} = \ln I_{j,0} + \varepsilon_{I_j,1,0} \quad j \in \{c,h\} \tag{A9}
$$

and latent investment is therefore equal to:

$$
\tilde{Z}^*_{H_h,m,0} = \tilde{Z}_{I_j,1,0} - \varepsilon_{I_j,1,0} = \ln I_{j,0} \quad j \in \{c,h\} \tag{A10}
$$

A.3 Production Functions

An identical procedure is then used used to estimate the production functions health, cognition, and socio-emotional skill. Focusing on the production function of health, substituting Equation 3 in to an arbitrary measurement equation for period 1 stock of health gives:

$$
\begin{aligned}
Z_{H_h,1,1} = \mu_{H_h,1,1} + \lambda_{H_h,1,1}\big(&\rho^h_{h,t}\ln H_{h,t} + \rho^h_{c,t}\ln H_{c,t} + \rho^h_{s,t}\ln H_{s,t} \\
&+\alpha^h_{h,t}\ln P_h + \alpha^h_{c,t}\ln P_c + \alpha^h_{s,t}\ln P_s \\
&+ \gamma^h_{h,t}\ln I_{h,t} + \kappa^h_{hh,t}(\ln I_{h,t}\ln H_{h,t}) + \eta_{h,t+1}\big) + \varepsilon_{H_h,1,1}
\end{aligned} \tag{A11}
$$

Once more using the fact that $\tilde{Z}^*_{\theta,m,0} = \tilde{Z}_{\theta,m,0} - \tilde{\varepsilon}_{\theta,m,0} = \ln\theta_0$ for $\theta_0 \in \{H_{c,0}, H_{s,0}, H_{h,0}, P_{c,0}, P_{s,0}, P_{h,0}, I_{c,0}, I_{h,0}\}$, this can be written as:

$$
\begin{aligned}
Z_{H_h,1,1} = \mu_{H_h,1,1} + \lambda_{H_j,m,1}\big(&\rho^h_{k,0}\tilde{Z}^*_{H_h,m,0} + \rho^h_{c,0}\tilde{Z}^*_{H_c,m,0} + \rho^h_{s,0}\tilde{Z}^*_{H_s,m,0} \\
&+\alpha^h_{h,0}\tilde{Z}^*_{P_h,m} + \alpha^h_{c,0}P_c + \alpha^h_{s,0}\tilde{Z}^*_{P_s,m} \\
&+ \gamma^h_{h,0}\tilde{Z}^*_{I_h,m,0} + \kappa^h_{hh,0}\tilde{Z}^*_{H_h,m,0}\tilde{Z}^*_{I_h,m,0} + \eta_{h,1}\big) + \varepsilon_{H_h,1,1}
\end{aligned} \tag{A12}
$$

Then expanding the $\tilde{Z}^*$s and rearranging gives the reduced form production function:

$$
\begin{aligned}
Z_{H_h,1,1} = \omega_{h,0} + &\tau^h_{h,0}\tilde{Z}_{H_h,m,0} + \tau^h_{c,0}\tilde{Z}_{H_c,m,0} + \tau^h_{s,0}\tilde{Z}_{H_s,m,0} \\
&+\sigma^h_{h,0}\tilde{Z}_{P_h,m} + \sigma^h_{c,0}P_c + \sigma^h_{k,0}\tilde{Z}_{P_s,m} \\
&+ \phi^h_{h,0}\tilde{Z}_{I_h,m,0} + \psi^h_{hh,0}\tilde{Z}_{H_h,m,0}\tilde{Z}_{I_h,m,0} + \upsilon_{j,1}
\end{aligned} \tag{A13}
$$

where

$$
\begin{aligned}
\tilde{Z}_{\theta,m,0} &= \ln\theta_0 + \tilde{\varepsilon}_{\theta,m,0} \quad \text{for } \theta \in \{\ln H_{h,0}, \ln H_{c,0}, \ln H_{s,0}, \ln P_h, \ln P_s, \ln I_{h,0}\} \\
\omega_{h,0} &= \mu_{H_h,1,1} + \ln A_t \\
\tau^h_{k,0} &= \lambda_{H_h,1,1}\rho^h_{k,0} \quad \text{for} \quad k \in \{h, c, s\} \\
\sigma^h_{k,0} &= \lambda_{H_h,1,1}\alpha^h_{k,0} \quad \text{for} \quad k \in \{h, c, s\} \\
\phi^h_{k,0} &= \lambda_{H_h,1,1}\gamma^h_{h,0} \\
\psi^h_{hh,0} &= \lambda_{H_h,1,1}\kappa^h_{hh,0}
\end{aligned}
$$

and

$$\begin{aligned}\upsilon_{h,1} =& \varepsilon_{H_h,1,1} + \lambda_{H_h,1,1}\Bigg[\eta_{h,1} - \sum_{k\in\{h,c,n\}} \rho^h_{k,0}\tilde{\varepsilon}_{H_k,m,0} - \sum_{k\in\{h,n\}} \alpha^h_{k,0}\tilde{\varepsilon}_{P_k,m,0} \\ &- \gamma^h_{h,0}\tilde{\varepsilon}_{I_h,m,0} - \kappa^h_{hh,0}\left(\tilde{Z}_{I_h,m,0}\tilde{\varepsilon}_{H_h,m,0} + \tilde{Z}_{H_h,m,0}\tilde{\varepsilon}_{I_h,m,0} - \tilde{\varepsilon}_{I_h,m,0}\tilde{\varepsilon}_{H_h,m,0}\right)\Bigg]\end{aligned} \tag{A14}$$

As in estimation of the investment functions, all alternative measures of the inputs are used as instrumental variables with their validity implied by the assumption that measurement errors are fully independent. I assume that the measurement parameters of $Z_{H_h,1,1}$ are age-invariant, implying that $\lambda_{H_h,m,0} = \lambda_{H_h,m,1}$ and $\mu_{H_h,m,0} = \mu_{H_h,m,1}$. The structural parameters of the health production function can then be recovered as:

$$\begin{aligned}\rho^h_{k,0} =& \frac{\tau^h_{k,0}}{\lambda_{H_h,1,0}} = \frac{\lambda_{H_h,1,1}\rho^h_{k,0}}{\lambda_{H_h,1,1}} \quad \text{for} \quad k \in \{h,c,s\} \\ \alpha^h_{k,0} =& \frac{\sigma^h_{k,0}}{\lambda_{H_h,1,0}} = \frac{\lambda_{H_h,m,1}\alpha^j_{k,0}}{\lambda_{H_h,1,0}} \quad \text{for} \quad k \in \{h,c,s\} \\ \gamma^j_{k,0} =& \frac{\phi^j_{k,0}}{\lambda_{H_h,1,0}} = \frac{\lambda_{H_h,m,1}\gamma^j_{k,0}}{\lambda_{H_h,1,0}} \\ \kappa^j_{hh} =& \frac{\psi^j_{hh}}{\lambda_{H_h,1,0}} = \frac{\lambda_{H_h,m,1}\kappa^j_{hh,0}}{\lambda_{H_h,1,0}}\end{aligned}$$

Its TFP and RTS can then be backed out by:

$$\begin{aligned}RTS &= \sum_k \frac{\tau^h_{k,0}}{\lambda_{H_h,1,0}} + \sum_k \frac{\sigma^h_{k,0}}{\lambda_{H_h,1,0}} + \frac{\phi^h_{h,0}}{\lambda_{H_h,1,0}} + \frac{\psi^h_{hh,0}}{\lambda_{H_h,1,0}} \\ \ln A_t &= \omega_{h,0} - \mu_{H_h,1,0}\end{aligned}$$

These expressions simplify even further when the age-invariant measure is also the normalising measure, since $\lambda_{H_h,1,0} = \lambda_{H_h,1,1} = 1$ and $\mu_{H_h,1,0} = \mu_{H_h,1,1} = \mathbb{E}(Z_{H_h,1,0})$. A period 1 residual health measure can be constructed as:

$$\tilde{Z}_{H_h,1,1} = \frac{Z_{H_h,1,1} - \mu_{H_h,1,1}}{\lambda_{H_h,1,1}} = \ln H_{h,1} + \tilde{\varepsilon}_{H_h,1,1} \tag{A15}$$

This once more allows the following definition of latent health in the next period:

$$\tilde{Z}^*_{H_h,m,1} = \tilde{Z}_{H_h,m,1} - \tilde{\varepsilon}_{H_h,m,1} = \ln H_{h,1} \tag{A16}$$

The parameters of the socio-emotional skill measurement and production function parameters are estimated identically with one difference. I re-normalise socio-emotional skill in onto an age-invariant measure at $t = 1$. This means imposing $\mathbb{E}(\ln H_{s,1}) = 0$ and $\lambda_{H_s,1,1} = 1$ to fix the location and scale of latent socio-emotional skill to the age-invariant measure.

As outlined in the main body of the paper, the process for disentangling the structural production production parameters from the measurement parameters is different in the case of cognitive skill. It is not possible to assume age-invariance for any of the measures available meaning restrictions have to be place on the structural cognitive production function parameters. The reduced form version of Equation A13 for cognitive skill production (with only one investment and interaction for simplicity) is given by:

$$\begin{aligned} Z_{H_c,m,1} = \omega_{c,0} + \tau^c_{h,0}\tilde{Z}_{H_h,m,0} + \tau^c_{c,0}\tilde{Z}_{H_c,m,0} + \tau^c_{s,0}\tilde{Z}_{H_s,m,0} \\ +\sigma^c_{h,0}\tilde{Z}_{P_h,m} + \sigma^c_{c,0}P_c + \sigma^c_{k,0}\tilde{Z}_{P_s,m} \\ + \phi^c_{h,0}\tilde{Z}_{I_c,m,0} + \psi^c_{cc,0}\tilde{Z}_{H_c,m,0}\tilde{Z}_{I_c,m,0} + \upsilon_{j,1} \end{aligned} \tag{A17}$$

where, again, the reduced form parameters can be written as a combination of the structural and measurement parameters of cognition in the next period:

$$\begin{aligned} \tilde{Z}_{\theta,m,0} &= \ln\theta_0 + \tilde{\varepsilon}_{\theta,m,0} \quad \text{for } \theta \in \{\ln H_{h,0}, \ln H_{c,0}, \ln H_{s,0}, \ln P_h, \ln P_s, \ln I_{h,0}\} \\ \omega_{c,0} &= \mu_{H_c,m,1} + \ln A_t \\ \tau^c_{k,0} &= \lambda_{H_c,m,1}\rho^c_{k,0} \quad \text{for} \quad k \in \{h, c, s\} \\ \sigma^c_{k,0} &= \lambda_{H_c,m,1}\alpha^c_{k,0} \quad \text{for} \quad k \in \{h, c, s\} \\ \phi^c_{k,0} &= \lambda_{H_c,m,1}\gamma^c_{c,0} \\ \psi^c_{cc,0} &= \lambda_{H_c,m,1}\kappa^c_{cc,0} \end{aligned}$$

In this case, however, it is not the case that $\lambda_{H_c,m,0} = \lambda_{H_c,m,1}$ or $\mu_{H_c,m,0} = \mu_{H_c,m,1}$, meaning the measurement parameters must be directly estimated. In order to do so, the restriction of CRS and no TFP must be imposed on the technology, which implies :

$$\lambda_{H_c,n,1} = \sum_k \tau^c_{k,0} + \sum_k \sigma^c_{k,0} + \phi^c_{c,0} + \psi^c_{cc,0}$$

$$\mu_{H_c,n,1} = \omega_{c,0}$$

$$\rho^c_{k,0} = \frac{\tau^c_{k,0}}{\lambda_{H_c,m,1}} \quad \text{for} \quad k \in \{h, c, s\}$$

$$\alpha^c_{k,0} = \frac{\sigma^c_{k,0}}{\lambda_{H_c,m,1}} \quad \text{for} \quad k \in \{h, c, s\}$$

$$\gamma^c_{k,0} = \frac{\phi^c_{c,0}}{\lambda_{H_c,m,1}}$$

$$\kappa^c_{k,0} = \frac{\psi^c_{cc,0}}{\lambda_{H_c,m,1}}$$

Once the the parameters of the period 1 health, cognitive and socio-emotional production functions are estimated, $\tilde{Z}^*_{H_h,m,1}$, $\tilde{Z}^*_{H_c,m,1}$ and $\tilde{Z}^*_{H_s,m,1}$ can be used alongside $\tilde{Z}^*_{P_h,m}$, P_c and $\tilde{Z}^*_{P_s,m}$ to estimate the structural and measurement parameters of investment at $t = 1$, then the production functions of health and human capital in an identical manner. The same process is then followed in all subsequent periods.

A.4 Variance of shocks

The variance of the shocks to production and investment are estimated by the covariance between the residual from equations the reduced form investment ($\nu_{j,0}$) and production ($\upsilon_{j,1}$) functions (A8 and A13) and an alternative residual measure, $\tilde{Z}_{H_j,m',1}$ and $\tilde{Z}_{I_j,1',1}$. The assumption that measurement errors are independent means that:

$$\text{Cov}\left(\frac{\nu_{j,0}}{\lambda_{I_j,m,0}}, \tilde{Z}_{I_j,m',1}\right) = Var(\pi_{j,t}) = \sigma^2_{I_j,0} \quad \text{for} \quad j \in \{h, c\}, \tag{A18}$$

and

$$\text{Cov}\left(\frac{\upsilon_{j,0}}{\lambda_{H_j,m,1}}, \tilde{Z}_{H_j,m',1}\right) = Var(\eta_{j,1}) = \sigma^2_{\eta_j,1} \quad \text{for} \quad j \in \{h, c, s\} \tag{A19}$$

A.5 Signal to noise ratios

The variance of each measure of each latent variable can be easily decomposed into a portion caused by the latent variable - the signal - and a portion caused by measurement error. The signal of measure $Z_{\theta,m,t}$ is calculated by the ratio:

$$s_{\theta,m,t} = \frac{\lambda^2_{\theta,m,t}\text{Cov}\left(\tilde{Z}_{\theta,m,t}, \tilde{Z}_{\theta,m',t}\right)}{V(Z_{\theta,m,t})} = \frac{\lambda^2_{\theta,m,t}V(\ln\theta_t)}{\lambda^2_{\theta,m,t}V(\ln\theta_t) + V(\varepsilon_{\theta,m,t})}\,, \tag{A20}$$

and the noise by $(1 - s_{\theta,m,t})$, where $\theta \in \{\ln H_{h,t}, \ln H_{c,t}, \ln H_{s,t}, \ln P_h, \ln P_s, \ln I_{h,t}, \ln I_{c,t}\}_{t=0}^{T}$.

B Additional data description

B.1 Details of the child cognitive assessments used from the MCS

Denver Developmental Screening Test (DDST):

At 9 months of age, the MCS ask the main respondent 8 questions from the DDST aimed at assessing the level of gross (G) and fine (F) motor skill development in infants. The 8 questons have three possible responses: “Not Yet”, “Once or Twice”, and “Often” to questions about wheher nor not the child can

- Sit up with support (G);
- Stand up while holding onto something such as furniture (G);
- Walk a few steps on his/her own (G);
- Move around between places if placed on the floor (G);
- Put his/her hands together (F);
- Grab objects using the whole hand (F);
- Pick up small objects using forefinger and thumb only (F);
- Pass a toy back and forth between hands (F),

See Frankenburg and Dodds (1967) for full details of the devleopment and purpose of the DDST.

MacArthur-Bates Communicative Development Inventory (CDI):

Also at 9 months of age, the MCS asks the main respondent 5 questions from the MacArthur-Bates CDI assessing the child’s which assess the cohort members’ development of receptive and productive vocabulary. The 5 questons have three possible responses: “Not Yet”, “Once or Twice”, and “Often” to questions about wheher nor not the child

- Smiles when smiled at;
- Reaches out to gives a toy or object he/she is holding;
- Waves bye-bye on his/her own when someone leaves;
- Extends his/her arms to show they want to be picked up;
- Nods his/her head for yes.

Fenson et al. (1986) provides full details of the MacArthur Bates CDI.

Bracken School Readiness (BSR) Assessments:

At age 3 the MCS children are administered 6 BSR assessments of the following concepts:

- **Colours:** recognition of both primary colours and basic colour terms.
- **Letters:** recognition of both upper and lower case.
- **Numbers/Counting:** recognition of single- and doubl-digit numbers, and the ability to assign a number value to a set of objects
- **Sizes:** recognition of concepts describing one, two, and three dimensions
- **Comparisons:** the ability to match/differentiate objects based on salient characteristics
- **Shapes:** recognition of one-, two-, and three-dimensional shapes.

In total these 6 tests contain 88 questions, a child's answer to which is either correct or incorrect. Each assessment has two scores available: the raw total number of correct answers and the percent of questions answered correctly. I use the former in estimation production functions.

British Ability Scales (BAS) Assessments:

Table B1 shows the BAS assessments used at each age in the MCS and how they are administered. Each assessment has several scores available, including the raw total number of correct answers and the total number of correct answers adjusted for the specific question set administered - the *ability* score. I use the ability scores in estimation of the cognitive production functions.

National Foundation for Education Research (NFER) number skills:

At age 7 the National Foundation for Education Research (NFER) number skills test was administered as part of the MCS survey. All children were required to first complete an initial assessment that assigned them to an "easier", "medium", or "harder" test. Th NFER number skills assessment is nt normally administered in this two-step manner, hoever it was done so in the MCS to save survey and administration time. It also meant the cohort members answered half of the total number of questions in the full assessment.

The test to which they were routed based on this initial assessment comprised of various number problems, each of which was answered either correctly or incorrectly by the cohort members. Item Response Throery was used to scale the sub-set of questions administered in to an equivalent raw score from a fully administered test.

Cambridge Neurophsyical Test Automated Battery (CANTAB) Tasks:

At ages 11 and 15 the computerised CANTAB Gambling Task was administered.

Table B1: British Ability Scales by age in the MCS

Assessment	Age	Test
Naming Vocabulary	3 & 5 years	Cohort members are shown colored pictures one-by-one and asked to identify what they depict.
Picture Similarity	5 years	Cohort members are given a card and asked to place it underneath the picture to which it is most similar from a group of four images
Pattern Construction	5 & 7 years	Cohort members are given squares and asked to recreate a coloured pattern they are shown
Word Reading	7 years	Records how many words out of a group of ninety, arranged in nine blocks of ten in ascending order of difficulty, a cohort member can pronounce. If a child makes 8 errors in a block of 10 words, then the assessment stops
Verbal Similarities	11 years	The interviewer reads out three words to the child who must then say how the three things are similar. After 12 questions, the test stops unless the child has less than 3 failures on *all* questions until that point. If so they progress to answer 5 more questions.

In the gambling task, children are shown a row of ten boxes coloured either red or blue at the top of the screen and two rectanlges containing the words “Red” and “Blue” at the bottom. They are told that there is a token hidden in one of these boxes. By pressing the corresponging rectangle, cohort members must indicate whether they think the token is in a red or blue box. Additionaly, they are asked to gamble 5%, 25%, 50%, 75%, or 95% of an endowment of 100 points on their choice. The proportions were displayed on the right-hand side of the screen in either descending or ascending order. Six outcomes are measured:

- Overall proportional bet: mean proportion of points gambled across trials
- Deliberation time: mean time to respond to the questions
- Quality of decision making: proportion of trials in which the most likely option was chosen
- Risk taking: mean points bet on the most likely outcome
- Risk adjustment: the degree to which a cohort member alters their proportional bet in accordance with the odds of the token being in each color of box.
- Delay aversion: a measure of the tendency to bet large proportions when the possible proportions were displayed in descending order, and vice versa.

At age 11 the the CANTAB spatial working memory task was administered. This test was also computerised.

The spatial working memeory task tested cohort members' ability to retain spatial information and manipulate remembered items in working memory, as well as their ability to us strategy. In the task, the children were shown a number of coloured boxes in the middle and an empty column on the right-hand side of the screen. They are asked to find a number of blue tokens in the coloured boxes and fill up the column with them. To do so, they must select a box by touching it and if a blue token is revealed move across and in to the column. Touching a box that has already been searched is an error, and the number of boxes is gradually increased from 3 to 8 with the colour and order of boxes altering between trials.

Three different aspects of performance are measured:

- **Errors:** the number of times a cohort member revisits a box
- **Strategy:** the order in which a cohort member searches the boxes
- **Latency:** mean time, in milli-seconds, to first touch the screen, to touch the screen again after placing a token in the column, and to find the final token from the beginning of the trial.

Word Recognition:

At age 15 the cohort members word recognition is assessed through testing their famaliarity with words and their meaning. The cohort members were shown a list of 20 *target* words, each with 5 other words written next to them. From these 5 words, the children were asked to select that which was most like the target word. A child's score in this assessment indicates in how many of the 20 trialsthey correctly identified the most similar word from the group of 5 alternatives.

The words used were a subset of those from the standard vocabulary tests developed by the Applied Psychology Unit at the University of Edinburgh in 1976. A similar test was administered to the members of the 1970 British Cohort Study.

B.2 Details of the child socio-emotional assessments used from the MCS

Carey Infant Temperament Scales (CIT):

At 9 months of age the MCS administered 14 questions from CIT scale to the respondents. The questions were aimed at assessing 4 areas of cohort members' tempremental and behavioural development: regularity (R), approachability and withdrawl (AW), adaptability(A), and mood (M). The questions had 5 responses - "Almost never", "Rarely", "Usually does not", "Often", and "Always" - with regards to how often the cohort member:

- Makes happy sounds when having his/her nappy changed (M)
- Is pleasant (smiles, laughs) when he/she first arriving in unfamiliar places (M)
- Is pleasant (coos, smiles) during procedures like hair brushing (M)
- Is content (smiles, coos) during interruptions of milk or solid feeding (M)
- Remains pleasant or calm with minor injuries (M)
- Objects to being bathed in a different place of by a different person (AW)
- Is still wary or frightened of strangers after 15 minutes (AW)
- Is shy (turns away or clings) on you meeting another child for the first time (AW)
- Is fretful for the first few minutes in a new place (A)
- Appears bothered (cries/squirms) when first put down in a different sleeping place (A)
- Wants and takes milk feeds at about the same time (within one hour)from day to day (A)
- Gets sleepy about the same time (within 30 minutes) each evening (R)
- Naps are abput the same length from day to day (R)
- Wants to take solid food at about the same time (within one hour) from day to day (R)

Carey and McDevitt (1978) provides details of the original CIT and outlines the revisions made that resulted in the questionanaire from which the questions asked in the MCS were taken.

Child Social and Behavioural Questionnaires (CSBQ):

Sub-sets of questions from the CSBQ were asked at 3, 5, 7, and 11 years of age. These questions aimed to measure the extent to which cohort members displayed Independence and Self Regulation (ISR), Emotional Dysregulation (ED), and Cooperation (C). Table B2 shows the CSBQ items administered, the age at which they were asked, and which domian of child bahviour they measure.

Table B2: Child Social and Behavioural Questionnaire Items by age in the MCS

Item	Age	Domain
Likes to work things out for self	3,5 & 7 years	ISR
Does not need much help with tasks	3,5 & 7 years	ISR
Chooses activities on their own	3,5 & 7 years	ISR
Persists in the face of difficult tasks	3,5 & 7 years	ISR
Moves to a new activity after finishing a task	3,5& 7 years	ISR
Shows mood swings	3,5 & 7 years	ED
Gets over excited	3,5 & 7 years	ED
Easily frustrated	3,5 & 7 years	ED
Gets over being upset quickly	3,5& 7 years	ED
Acts impulsively	3,5 & 7 years	ED
Is calm and easy going	5 & 7 years	C
Works/plays easily with others	5 & 7 years	C
Says please and thank you when reminded	11 years	C
Waits his/her turn in games/activities	11 years	C
Co-operates with requests	11 years	C

Strengths and Difficulties Questionnaires (SDQ):

At ages 3, 7, 11, and 15, 25 questions from the SDQ were administered to cohort members' parents. The 25 questions asked questions regarding whether ot not the children displayed behaviours indicative 0f 5 traits: emotional symptoms (E), conduct problems (C), hyperactivity/inattention (H), peer problems (P), and being pro-social (PS). Table B3 shows the SDQ questions administered and which of these traits the behaviour about which they ask is deemed to indicate.

Table B3: Strength and Difficulties Questions in the MCS

Item	Age	Trait
Complains of headaches/stomach-aches/sickness	3, 5, 7 & 11 years	E
Often seems worried	3, 5, 7 & 11 years	E
Often unhappy	3, 5, 7 & 11 years	E
Nervous or clingy in new situations	3, 5, 7 & 11 years	E
Many fears, easily scared	3, 5, 7 & 11 years	E
Often has temper tantrums	3, 5, 7 & 11 years	C
Generally obedient	3, 5, 7 & 11 years	C
Fights with or bullies other children	3, 5, 7 & 11 years	C
Often argumentative with adults	3, 5, 7 & 11 years	C
Can be spiteful to others	3, 5, 7 & 11 years	C
Restless, overactive, cannot stay still long	3, 5, 7 & 11 years	H
Constantly fidgeting	3, 5, 7 & 11 years	H
Easily distracted	3, 5, 7 & 11 years	H
Can stop and think before acting	3, 5, 7 & 11 years	H
Sees tasks through to the end	3, 5, 7 & 11 years	H
Has at least one good friend	3, 5, 7 & 11 years	P
Generally liked by other children	3, 5, 7 & 11 years	P
Tends to play alone	3, 5, 7 & 11 years	P
Picked on or bullied by other children	3, 5, 7 & 11 years	P
Gets on better with adults	3, 5, 7 & 11 years	P
Considerate of others' feelings	3, 5, 7 & 11 years	PS
Shares readily with others	3, 5, 7 & 11 years	PS
Helpful if someone is hurt, upset or ill	3, 5, 7 & 11 years	PS
Kind to younger children	3, 5, 7 & 11 years	PS
Often volunteers to help others	3, 5, 7 & 11 years	PS

In each of the five categories - emotional symptoms, conduct problems, hyperactivity/inattention, peer problems, and being pro-social - cohort members' scores were the total number of symptoms displayed. Johnson et al. (2015) gives details of all the socio-emotional assessments administered to the children of the MCS between the ages of 9 months and 11 years, and Fitsimons et al. (2017) provides analogous descriptions for the age 15 survey

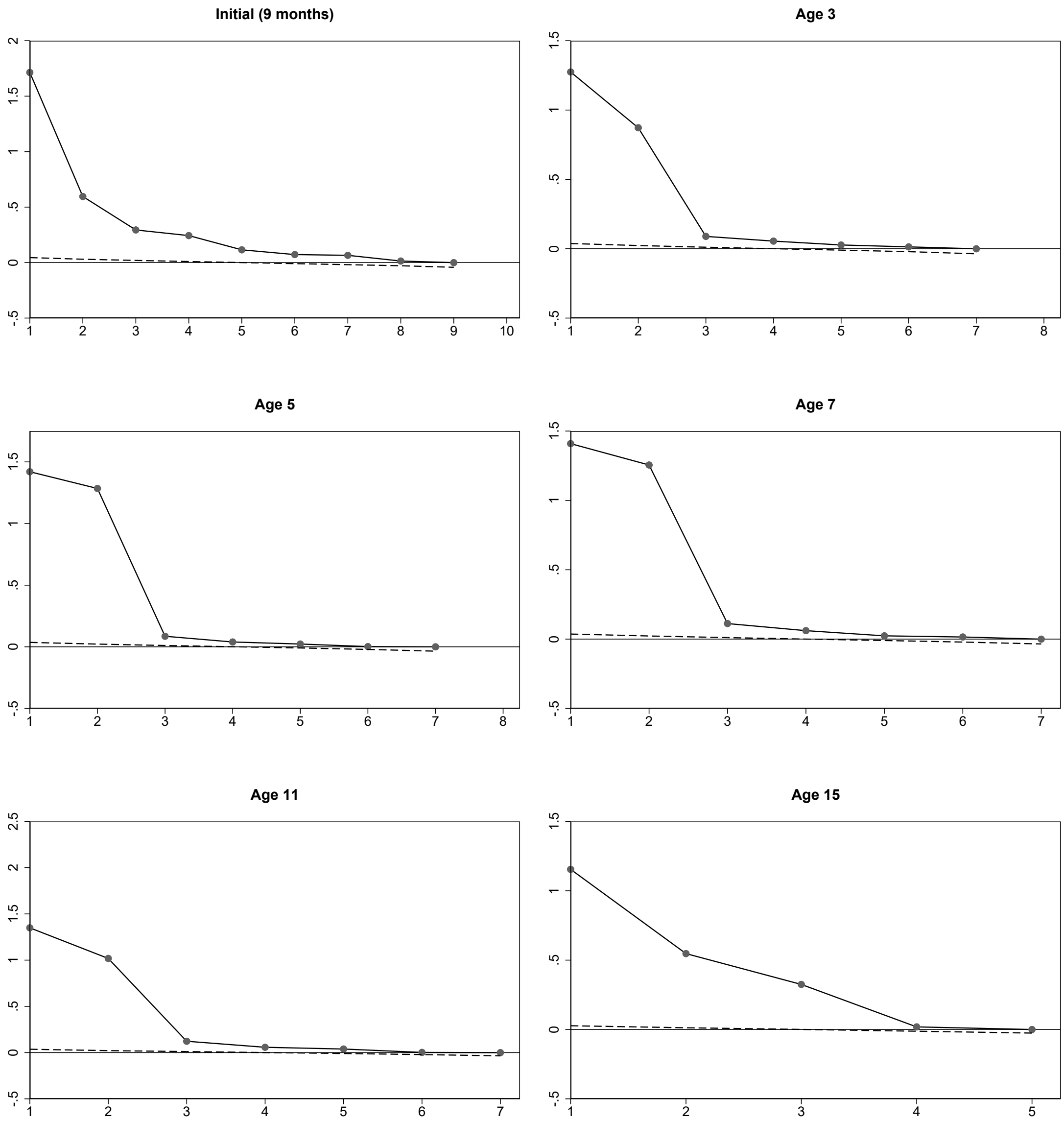
C Exploratory Factor Analysis

C.1 Verifying and selecting the number of latent factors

The first step in "confirming" the structure of the measurement system was to verify that the observable measures shared enough variation to meaningfully exploit their correlations in estimating the investment and production functions. To do this, I first group the measures into four broad categories based on ex-ante beliefs about what they proxy: (1) health; (2) cognitive and socio-emotional skills; (3) Investments; and (4) endowments. I then examine how much variation they share and along how many dimensions - in others words, are the health measures highly correlated and, if so, is it only in one direction? Similarly, I would like to know if the cognitive and socio-emotional skill measures are highly correlated, and if this correlation is sufficiently strong along two dimensions. To do this, it it possible to simply examine the eigenvalues of the correlation matrix of the groups of observable measures and use some general rules of thumb as to what their magnitude imply about the number of latent variables underlying them. For example, Kaiser (1960) suggests only keeping a number of factors greater or equal to the number of eigenvalues greater than 1. Cattell (1966) on the other hand proposes a graphical solution, recommending that by plotting the latent factors against their eigenvalues the number of factors to be retained can be shown by the decrease in eigenvalues begins to smooth. I consider both these criteria, while at the same time using a parallel analysis (Horn, 1965). This analysis involves generating correlation matrices from randomly generated data of the same dimension as the actual data (hence *parallel*), and calculating and comparing their eigenvalues. Horn (1965) suggests keeping factors whose eigenvalues are larger than that of its randomly generated counterpart.

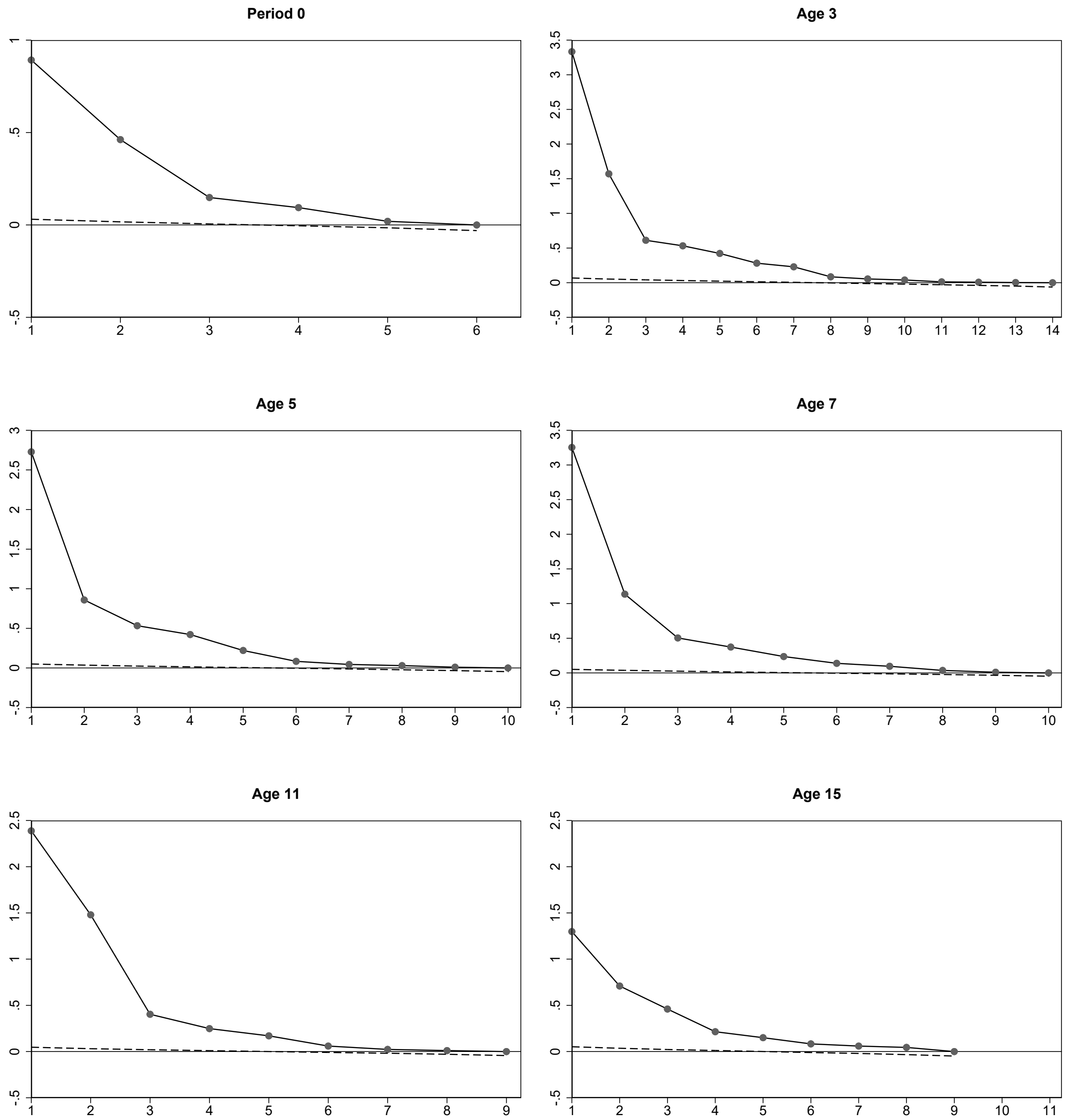
To combine these three rules of thumb, Figures C1, C2, C3, and C4 plot the eigenvalues of the correlation matrices of the four groupings of observable variables listed above in order of size, alongside their counterparts from randomly simulated data. They show that using a combination of the rules described above, the data supports extracting between 1 and 3 latent health (Figure C1) and skill (Figure C2) factors in each period, and somewhere between 1 and 4 investment factors in each period. For parental human capital the data similarly support the extraction of up to 3 factors. With this considered, it appears the data are rich enough to estimate a model with latent health, cognition, socio-emotional skill, parents' human capital and two types of investment. However, because there appear to be more latent factors underlying the data, I retain up to three factors across periods, and next analyse the extent to which different measures are correlated with the various latent factors.

Figure C1: Scree Plots of factors and their eigenvalues from an exploratory factor analysis of health measures in each period



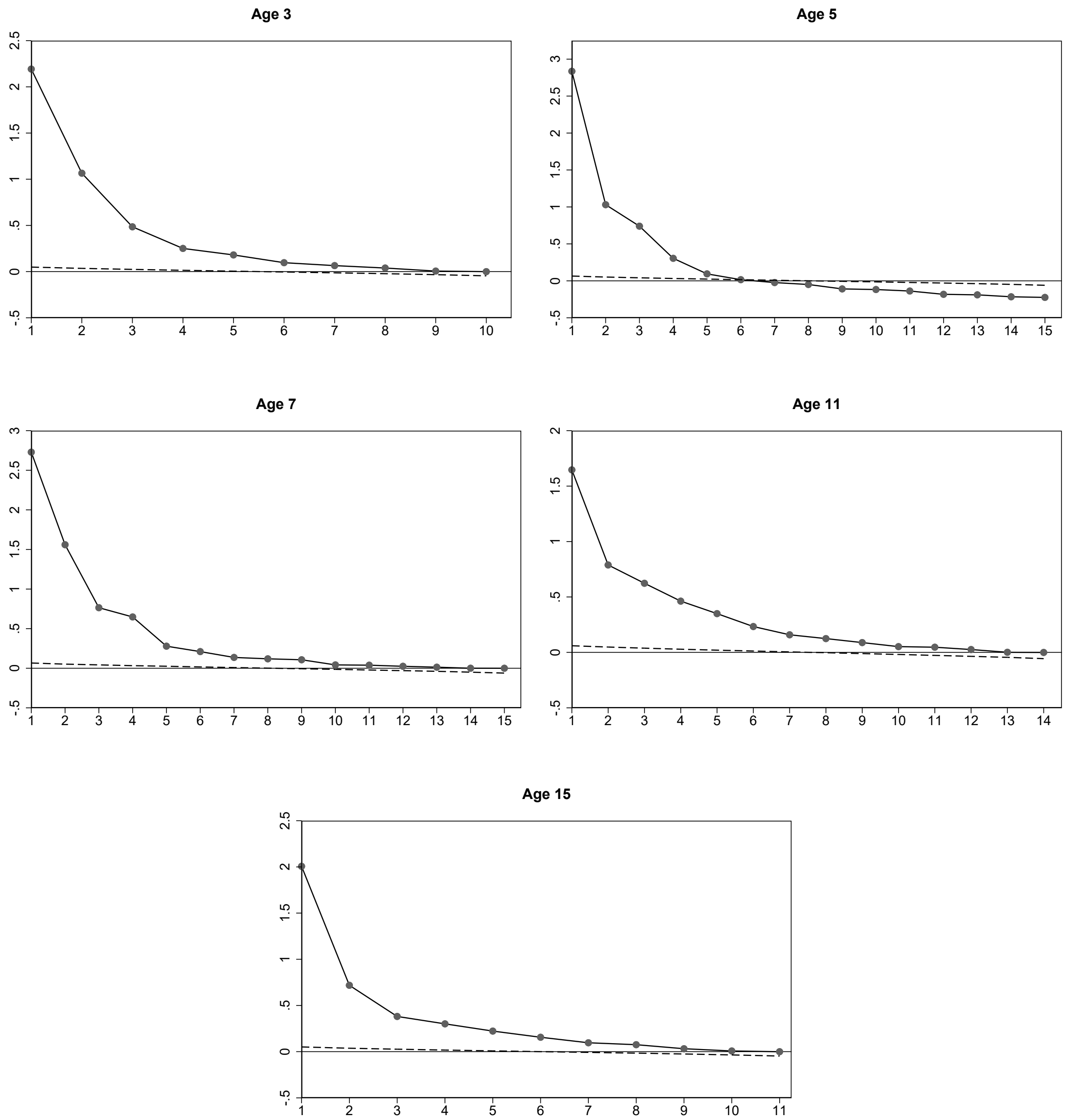
Note: The solid line connects the eigenvalues of the factors underlying k measures of health at each age. The dotted line connects the eigenvalues of the factors underlying randomly simulated data of the same dimension (i.e $N \times k$). This figure was generated using Philip B. Ender's *-fapra-* package in Stata.

Figure C2: Scree Plots of factors and their eigenvalues from an exploratory factor analysis of both cognitive and socio-emotional skill measures in each period



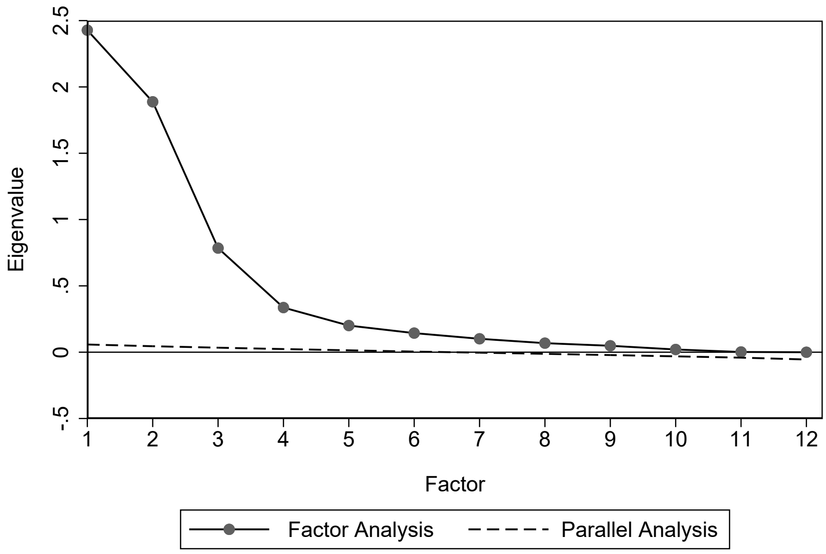
Note: The solid line connects the eigenvalues of the factors underlying k measures of cognitive and socio-emotional skill at each age. The dotted line connects the eigenvalues of the factors underlying randomly simulated data of the same dimension (i.e $N \times k$). This figure was generated using Philip B. Ender's -*fapra*- package in Stata.

Figure C3: Scree Plots of factors and their eigenvalues from an exploratory factor analysis of both cognitive and health investment measures in each period



Note: The solid line connects the eigenvalues of the factors underlying k measures of health and cognitive investments at each age. The dotted line connects the eigenvalues of the factors underlying randomly simulated data of the same dimension (i.e $N \times k$). This figure was generated using Philip B. Ender's *-fapra-* package in Stata.

Figure C4: Scree Plots of factors and their eigenvalues from an exploratory factor analysis of parent human capital measures in the initial period



Note: The solid line connects the eigenvalues of the factors underlying k measures of each parent's health and socio-emotional skill. The dotted line connects the eigenvalues of the factors underlying randomly simulated data of the same dimension (i.e $N \times k$). This figure was generated using Philip B. Ender's *-fapra-* package in Stata.

C.2 Selecting and excluding individual measures

Given the initial analysis of the shared variation in measures showed there to be numerous factors underlying the data, it was then necessary to exclude measures that were correlated with either more than one factor, or with the "wrong" factor based on their purpose. For example, after retaining two latent health factors, if one health measure was correlated strongly with both - either in the same or opposite directions - then it was excluded from the analysis. Similarly if a socio-emotional skill measure appeared to measure cognitive skill then it was not used, nor was a health investment measure if it was highly correlated with a cognitive investment measure. I then retained measures based on the extent of their signal - how much of their variation is explained by variation in the latent variable. Excluding or retaining measures in this manner is important given the methodology employed to estimate the investment and production functions. It maximises the likelihood that the measures used as instruments have two features: they predominantly explain variation in the measure used as an input/output, and that they do not only do so weakly. The former of these two qualities is important to reduced the incidence of cross-correlations between measures giving misleading results, and the latter so that estimates of the structural parameters are not biased by using weak instruments in the first stage of the methodology.

Tables C1, C2a and B2b, and B3a and B3b show the results of an exploratory factor analysis of the measures of health, cognitive and socio-emotional skills and investments respectively. The factor loadings presented are obtained through an *oblique quartimin* rotation, to allow for factors to be correlated and to accurately depict the how measures load on common factors. In each table, the highlighted rows (either in gray or red) show the measures selected to be used in estimating the investment and production functions. Looking at Table C1 highlights the process of measure selection, and the importance of ex-ante establishing the loadings of measures. For example, at 9 months, the number of health conditions, and complications during pregnancy and first week of life load heavily on a different factor to birthweight. At the same time, gestation length loads heavily on both factors and complications during labor load negatively on on the factor associated with birthweight but positively on that associated with health conditions. I choose to select the measures of health conditions, and complications during pregnancy and the first week of life for two reasons. Firstly, and most importantly, health conditions arguably measures health in an cardinal way, and it is available at each age. I use it as an age-invariant measure which enables me to estimate flexible production functions with limited restrictions on their parameters Agostinelli and Wiswall (2016a). Second, complications during pregnancy and the first week of life are the only measures that load heavily on the factor on which the measure of health conditions loads and none other. In each subsequent period, the choice of measures comes down to a similar choice of which measures load most strongly on the factor associated with health conditions. In some periods I don't retain measures that meet this criteria simply because they are relatively noisy. For example, at ages 5, 7 and 11 I do not use a measure of non-regular hospital visits despite them loading heavily only on the relevant factor because it is consistently less that 10% signal.

I follow an identical process for selecting measures of cognitive and socio-emotional skill. In Table C2a and B2b the rows highlighted in gray indicate the measures retained for cognition and those in red the measures retained for socio-emotional skill. The table shows that the process of selection is straightforward at all ages in that all variables, with only one or two exceptions, load on the factor they were ex-ante assumed to measure. There is one caveat here in that I do not include all measures of cognition at age 15. This is because when doing so, there are two measures that skew the correlations between variables to be somewhat misleading. For example if considering all cognitive measures available at this age, four of the six load heavily on socio-emotional skill, and two load negatively on the factor I assume to be latent cognition. This is undoubtedly due in part to the nature of the measures. The CANTAB gambling task is meant to measure both problem solving *and*risk aversion. It is perhaps intuitive then that some of these measures be correlated with a bundle of socio-emotional skills. Two measures strongly load on what might be labeled the cognitive factor, however, and have almost 100% of their variance shared with the latent variables. These are measures of a children's overall proportional bet and their risk taking. Respectively, these two measures are of the overall average bet a child makes and the average bet the child makes when they have selected the most likely outcome. It is not possible to say with that these two strictly measure cognition, and they likely capture some aspect of risk attitudes. They are also highly correlated by construction given that the latter is contained within the former. I therefore present results of the EFA in Table B2b excluding these measures. The cognitive measure with the least noise in this last period is the *risk adjustment* measure, which records how children adjust their bets when they the odds are highly in their favour. I take this as measure of their problem solving skills, and less so as a measure of risk attitudes.

Moving to investments, the pattern in loadings differs somewhat from what was expected ex-ante based on assumptions about the type of investments variables measure. For example, in all periods many measures load on both or the "wrong" latent factors - at age 3 helping a child playing a sport is highly correlated with measures defined as proxies of cognitive investment, and a measure of the frequency with which a parent reads to the child loads heavily on both investments. Similarly, while measures of helping children with writing and maths load heavily on the latent cognitive investment factor at age 5, they are also highly negatively correlated with the health investment factor. As a result, although they are intuitively appealing measures of cognitive investment, I exclude them in this period. The results in Table B3b also show that it is more difficult to separate investments from one another in later period, between 11 and 15. For example, three measures defined as proxies health investment in the other periods load on the cognitive investment factor at age 15, and the majority of measures are correlated to the same extent with both types of latent investment. the same is true at age 11, meaning at these ages it is more difficult to make a clear cut selection of measures. Instead I select measures in order to minimize the extent to which these cross-correlations occur.

Table C1: EFA of observable health measures at each age

	Factor 1	Factor 2	Factor 3	Uniqueness
Initial (9 months)				
Health conditions	-0.130	0.219		0.960
First week complications	0.047	0.510		0.716
Pregnancy complications	-0.047	0.317		0.910
Birthweight (Kilos)	0.888	-0.014		0.223
Length of gestation	0.509	0.319		0.495
Complications during labor	-0.188	0.333		0.909
Age came home from hospital	0.132	0.351		0.818
Weight z-score	0.441	-0.151		0.842
Non-regular hosptial visits	-0.011	0.150		0.979
N	10,525			
Age 3				
Health conditions	-0.034	0.580		0.664
Long-term illnesses	0.039	0.554		0.690
Non-regular hosptial visits	-0.007	0.351		0.877
Accidents	-0.037	0.097		0.990
Emergency health problems	0.027	0.245		0.939
Weight z-score	0.834	-0.020		0.305
Height z-score	0.751	0.028		0.433
N	9,848			
Age 5				
Health conditions	-0.028	0.601		0.639
Long-term illnesses	-0.005	0.724		0.477
General health	0.048	0.550		0.694
Non-regular hosptial visits	-0.003	0.308		0.905
Accidents	0.001	0.078		0.994
Weight z-score	0.921	-0.024		0.152
Height z-score	0.746	0.046		0.439
N	10,724			
Age 7				
Health conditions	-0.032	0.582		0.663
Long-term illnesses	0.007	0.719		0.482
General health	0.023	0.554		0.691
Non-regular hosptial visits	-0.004	0.248		0.939
Accidents	-0.014	0.056		0.997
Weight z-score	0.761	-0.049		0.423
Height z-score	0.900	0.030		0.187
N	10,450			
Age 11				
Health conditions	-0.003	0.502		0.748
Long-term illnesses	0.041	0.577		0.668
General health	-0.049	0.560		0.681
Non-regular hosptial visits	0.003	0.242		0.941
Accidents	-0.039	0.069		0.993
Weight z-score	1.152	-0.014		-0.329
Height z-score	0.569	0.113		0.671
N	10,606			
Age 15				
Health conditions	-0.004	0.359		0.871
Long-term illnesses	0.002	0.579		0.665
General health	-0.059	0.164		0.969
Weight z-score	3.373	-0.000		-10.374
Height z-score	0.150	0.089		0.970
N	10,655			

Note: The columns represent the observable measures of health, their factor loadings on retained factors, and their unique variance respectively. All we obtained from an exploratory factor analysis using an oblique quartimin rotation of the factor loading matrix. The number of factors retained was determined as outlined in Appendix C.1. The rows highlighted in gray represent the variables selected as measures of health to be used in estimating the production and investment functions.

Table C2a: EFA of observable cognitive and socio-emotional skill measures at each age

	Factor 1	Factor 2	Factor 3	Uniqueness
Initial (9 months)				
Denver Developmental Screening Test	0.771	-0.018		0.407
Communicaitve Development Inventories	0.505	0.064		0.736
Number of developmental concerns	0.188	0.021		0.964
Carey Infant Temperament: Mood	0.000	0.738		0.455
Cary Infant Temperament: Regularity	-0.030	0.176		0.969
Cary Infant Temperament: Adaptability and Withdrawl	0.001	0.223		0.950
N	10,791			
Age 3				
Bracken School Readiness: Numbers	0.617	-0.097		0.653
Bracken School Readiness: Colours	0.640	0.075		0.551
Bracken School Readiness: Letters	0.473	-0.116		0.802
Bracken School Readiness: Sizes	0.610	0.028		0.615
Bracken School Readiness: Comparisons	0.518	-0.004		0.733
Bracken School Readiness: Shapes	0.765	-0.010		0.419
Naming Vocabulary score	0.612	0.081		0.584
SDQ: Conduct Problems	-0.017	0.727		0.480
SDQ: Emotional regulation	0.037	0.396		0.831
SDQ: Hyperactivity/Inattention	0.032	0.652		0.558
SDQ: Peer problems	0.035	0.408		0.822
SDQ: Pro-sociality	-0.027	0.444		0.811
CSR: Independence	0.049	0.278		0.910
CSBQ: Emotional Dysregulation	-0.003	0.595		0.648
N	8,783			
Age 5				
Picture Similarities	-0.043	0.601		0.656
Naming Vocabulary	0.051	0.545		0.680
Pattern construction	0.013	0.622		0.607
SDQ: Conduct Problems	0.752	-0.045		0.457
SDQ: Emotional regulation	0.421	0.029		0.813
SDQ: Hyperactivity/Inattention	0.678	0.064		0.504
SDQ: Peer problems	0.452	0.047		0.778
SDQ: Pro-sociality	0.488	-0.004		0.763
CSR: Independence	0.407	0.127		0.780
CSBQ: Emotional Dysregulation	0.659	-0.043		0.585
N	10,302			

Note: The columns represent the observable measures of cognitive and socio-emotional skill, their factor loadings on retained factors, and their unique variance respectively. All we obtained from an exploratory factor analysis using an oblique quartimin rotation of the factor loading matrix. The number of factors retained was determined as outlined in Appendix C.1. The rows highlighted in gray and red represent the variables selected as measures of cognitive and socio-emotional skill to be used in estimating the production and investment functions.

Table B2b: EFA of observable cognitive and socio-emotional skill measures at each age (cont.)

	Factor 1	Factor 2	Factor 3	Uniqueness
Age 7				
NFER Maths score	-0.030	0.865		0.269
Word Reading Ability	0.092	0.575		0.623
Pattern construction	0.033	0.550		0.683
SDQ: Conduct Problems	0.770	-0.052		0.432
SDQ: Emotional regulation	0.470	0.036		0.766
SDQ: Hyperactivity/Inattention	0.698	0.092		0.460
SDQ: Peer problems	0.495	0.033		0.743
SDQ: Pro-sociality	0.521	-0.060		0.747
CSR: Independence	0.442	0.188		0.711
CSBQ: Emotional Dysregulation	0.788	-0.035		0.398
N	9,903			
Age 11				
BAS verbal similarities	0.242	0.149		0.905
Spatial working Memory: Strategy	0.010	0.594		0.644
Spatial working Memory: Four-box errors	0.014	0.472		0.774
Spatial working Memory: Eight-box errors	-0.003	1.103		-0.215
SDQ: Conduct Problems	0.735	-0.021		0.466
SDQ: Emotional regulation	0.561	-0.006		0.686
SDQ: Hyperactivity/Inattention	0.693	0.057		0.500
SDQ: Peer problems	0.580	-0.016		0.667
SDQ: Pro-sociality	0.507	-0.060		0.752
N	9,980			
Age 15				
Word activity score	0.095	0.274		0.906
CANTAB gambling: Risk adjustent	-0.015	0.648		0.584
CANTAB gambling: decision quality	0.054	0.332		0.880
CANTAB gambling: delay aversion	-0.007	-0.385		0.850
SDQ: Conduct Problems	0.479	0.075		0.751
SDQ: Emotional Symptoms	0.711	-0.015		0.498
SDQ: Hyperactivity/Inattention	0.309	0.004		0.904
SDQ: Peer Problems	0.431	-0.037		0.819
SDQ: Pro-sociality	0.199	0.025		0.958
N	8,262			

Note: The columns represent the observable measures of cognitive and socio-emotional skill, their factor loadings on retained factors, and their unique variance respectively. All we obtained from an exploratory factor analysis using an oblique quartimin rotation of the factor loading matrix. The number of factors retained was determined as outlined in Appendix C.1. The rows highlighted in gray and red represent the variables selected as measures of cognitive and socio-emotional skill to be used in estimating the production and investment functions.

Table B3a: EFA of observable health and cognitive investment measures at each age

	Factor 1	Factor 2	Factor 3	Uniqueness
Age 3				
Regular bed times	-0.061	0.682		0.551
Regular meal times	-0.010	0.614		0.626
Portions of fruit	0.133	0.325		0.856
Someone helps child learn sport	0.287	0.043		0.910
S2 MAIN How often do you read to the child C1	0.317	0.404		0.676
How often helps child learn alphabet	0.545	-0.044		0.713
How often helps child with numbers/counting	0.776	-0.061		0.416
How often child visits library	0.107	0.284		0.894
How often helps child with songs/poems/rhymes	0.663	0.093		0.522
How often paints/draws with the child	0.397	-0.001		0.842
N	10,569			
Age 5				
Days per week child eats breakfast	-0.042	0.558		0.698
Portions of fruit	0.102	0.400		0.810
Regular bed times	-0.030	0.550		0.705
Regular meal times	0.031	0.498		0.743
How often plays sports with child	0.286	0.210		0.846
How often child plays non-club/class sports	0.081	0.343		0.862
How often plays active games with child	0.468	0.183		0.708
How often helps child learn reading	0.467	0.081		0.758
How often helps child with writing	0.646	-0.102		0.603
How often helps child with maths	0.653	-0.123		0.596
How often child visits library	0.131	0.236		0.913
How often helps child with songs/poems/rhmyes	0.460	0.098		0.758
How often draws/paints with child	0.564	0.033		0.672
How often tells the child stories	0.465	0.041		0.773
How often plays games/toys with child	0.552	0.103		0.658
N	10,686			
Age 7				
Days per week child eats breakfast	0.218	-0.029		0.955
Portions of fruit	0.285	-0.043		0.924
Regular bed times	0.188	-0.026		0.967
Frequency child does physical activities with family	0.546	-0.045		0.713
How often child does physical activity	0.249	-0.092		0.942
How often plays active games with child	0.659	-0.038		0.578
How often helps child learn alphabet	0.048	0.710		0.475
How often helps child with writing	-0.022	0.893		0.213
How often helps child with numbers/counting	0.000	0.783		0.387
How often child visits library	0.172	0.048		0.964
How often sings songs/plays music with child	0.466	-0.003		0.783
How often paints/draws with child	0.546	0.085		0.669
How often reads/tells stories to child	0.405	0.095		0.806
How often plays games with child	0.649	0.010		0.575
Hours per week doing homework	0.123	0.031		0.982
N	10,310			

Note: The columns represent the observable measures of health and cognitive investment, their factor loadings on retained factors, and their unique variance respectively. All we obtained from an exploratory factor analysis using an oblique quartimin rotation of the factor loading matrix. The number of factors retained was determined as outlined in Appendix C.1. The rows highlighted in gray and red represent the variables selected as measures of health and cognitive investments to be used in estimating the production and investment functions.

Table B3b: EFA of observable health and cognitive investment measures at each age (cont.)

	Factor 1	Factor 2	Factor 3	Uniqueness
Age 11				
Days per week child eats breakfast	0.177	0.212		0.908
Portions of fruit	0.267	0.108		0.905
How often drinks artificially sweetened drinks	0.066	0.112		0.980
How often drinks artificially sweetened drinks	0.036	0.022		0.998
How often child has regular bed times	0.071	0.225		0.938
How often plays active games with child	0.730	-0.030		0.474
Days per week child does non-club sport/exercise	0.169	0.110		0.952
How often plays active games with child	0.174	0.138		0.941
Hours per week doing homework	0.006	0.262		0.931
How often does someone check homework before other activities	-0.011	0.782		0.391
How often does someone help child with homework	0.007	0.366		0.865
How often talks to child about important topics	0.186	0.234		0.893
How often child visits library	0.142	0.059		0.973
How often plays games with child	0.622	0.028		0.605
N	10,791			
Age 15				
Days per week child hs breakfast	0.462	0.104		0.738
Portions of fruit per day	0.424	0.185		0.724
How often child has regular bed times	0.440	0.041		0.790
How often drinks sweetened drinks	0.026	0.677		0.527
How often drinks artificially sweetened drinks	-0.135	0.400		0.864
How often eats fast food	0.058	0.575		0.640
Hours per week child does homework	0.394	0.201		0.742
How often does someone help child with homework	0.525	-0.213		0.767
How often talks to child about things important to them	0.225	-0.045		0.955
How often does child visit museums,libraries,galleries etc.	0.342	0.121		0.836
School absences	0.146	0.183		0.924
N	10,973			

Note: The columns represent the observable measures of health and cognitive investment, their factor loadings on retained factors, and their unique variance respectively. All we obtained from an exploratory factor analysis using an oblique quartimin rotation of the factor loading matrix. The number of factors retained was determined as outlined in Appendix C.1. The rows highlighted in gray and red represent the variables selected as measures of health and cognitive investments to be used in estimating the production and investment functions.

D Additional figures and tables

D.1 Additional sample descriptive statistics

Table D1: Household characteristics in the MCS baseline survey and follow-ups

	(1) *Age 9 months*	(2) *Age 3*	(3) *Age 5*	(4) *Age 7*	(5) *Age 11*	(6) *Age 14*
Median equivalised household income	288.58	328.12	345.19	381.50	520.91	409.95
Mean	238.43	283.94	298.33	333.70	503.21	394.70
s.d	(196.38)	(218.64)	(217.07)	(227.47)	(219.00)	(178.10)
Equivalised household income quintiles						
Lower quintile	0.25	0.22	0.22	0.21	0.21	0.17
Second quintile	0.23	0.22	0.21	0.21	0.21	0.17
Third quintile	0.19	0.20	0.19	0.20	0.21	0.20
Fourth quintile	0.17	0.19	0.19	0.19	0.20	0.23
Highest quintile	0.16	0.18	0.18	0.19	0.18	0.23
Parent's age at birth						
12-19	0.06	0.05	0.05	0.05	0.05	0.04
20-29	0.44	0.42	0.43	0.42	0.43	0.42
30-39	0.46	0.49	0.48	0.49	0.49	0.50
40 +	0.03	0.04	0.04	0.04	0.04	0.04
UK country						
England	0.62	0.65	0.64	0.64	0.65	0.66
Wales	0.15	0.14	0.14	0.14	0.14	0.14
Scotland	0.13	0.12	0.12	0.12	0.11	0.11
Northern Ireland	0.10	0.09	0.10	0.10	0.10	0.09
Ethnicity						
White	0.84	0.85	0.85	0.85	0.83	0.84
Mixed	0.01	0.01	0.01	0.01	0.03	0.01
Indian	0.03	0.03	0.03	0.03	0.03	0.03
Pakistani and Bangladeshi	0.07	0.06	0.06	0.06	0.07	0.07
Black or Black British	0.04	0.03	0.03	0.03	0.03	0.03
Other Ethnic group (inc Chinese,Other)	0.02	0.02	0.02	0.02	0.01	0.02
Household Language						
English only	0.85	0.84	0.85	0.86	0.87	0.87
Mostly English	0.11	0.12	0.05	0.05	0.06	0.05
Half English, half other	0.04	0.03	0.05	0.04	0.04	0.04
Mostly other	0.00	0.00	0.04	0.03	0.03	0.04
Other only	0.00	0.00	0.01	0.01	0.01	0.00
N	18,296	15,381	15,042	13,681	13,112	11,558

Note: The table provides a statistical summary of the entire sample in each round of the MCS. Income is in 2010 prices. Conversion rates were accessed here: https://www.bankofengland.co.uk/monetary-policy/inflation/inflation-calculator. All numbers are proportions except for median, mean and the standard deviation (s.d) of income. Income quintiles are relative to the UK income distribution, not the sample distribution.

Table D2: Percent of families in each UK income quintile at age 14, by UK income quintile at age 9 months

		UK income quintile age 14					
		1	*2*	*3*	*4*	*5*	% Missing
UK Income quintile 9 months	*1*	46.90	28.75	15.50	6.34	2.52	49.72
	2	23.49	28.02	25.99	16.55	5.95	43.46
	3	5.13	14.17	28.67	34.27	17.75	38.43
	4	1.97	6.87	19.92	34.94	36.31	31.15
	5	0.97	3.52	11.63	26.21	57.67	28.77

Note: Each row/column indicates the income quintile a family was in when their child was aged 9 months/14 for those present at both ages. *% Missing* represents to percent in each income quintile at 9 months who were not present at age 14. Numbers represent the percent of each row that were in each column. Income quintiles are defined out of sample relative the the UK household income distribution.

Table D3: Health investment measures in period 1 (ages 9 months-3 years) across income quartiles

	(1) Quartile 1	(2) Quartile 2	(3) Quartile 3	(4) Quartile 4
Fresh fruit/veg once a day	0.94	0.96	0.98	0.99
Anyone help child with sport	0.74	0.76	0.81	0.83
Child has regular meals				
Never or almost never	0.04	0.03	0.01	0.01
Sometimes	0.12	0.10	0.06	0.04
Usually	0.38	0.41	0.45	0.46
Always	0.46	0.46	0.49	0.49
Child has regular bed times				
Never or almost never	0.13	0.10	0.06	0.03
Sometimes	0.20	0.16	0.12	0.08
Usually	0.31	0.35	0.41	0.42
Always	0.36	0.38	0.41	0.46
Observations	3,243	3,489	3,724	3,975

Note: The table provides a statistical description of the health investment measures used between 9 months and 3 years of age. Measures are in bold, and where appropriate answers are italicised. Where there are no answers, the measures are binary, with a value of one representing a positive response. All numbers are proportions. Income quartiles are relative to the sample income distribution.

Table D4: Cognitive investment measures in period 1 (ages 9 months-3 years) across income quartiles

	(1) Quartile 1	(2) Quartile 2	(3) Quartile 3	(4) Quartile 4
How often does maths with child				
Not at all	0.06	0.04	0.03	0.03
Occasionally or less than once a week	0.06	0.05	0.05	0.05
1 - 2 days per week	0.14	0.14	0.14	0.12
3 times a week	0.11	0.11	0.11	0.10
4 times a week	0.07	0.08	0.08	0.08
5 times a week	0.06	0.07	0.06	0.06
6 times a week	0.04	0.04	0.04	0.04
7 times a week constantly	0.44	0.47	0.50	0.51
How often reads to/with child				
Not at all	0.07	0.04	0.01	0.00
Less often	0.04	0.03	0.01	0.00
Once or twice a month	0.05	0.03	0.02	0.01
Once or twice a week	0.23	0.20	0.14	0.08
Several times a week	0.20	0.21	0.20	0.16
Every Day	0.41	0.49	0.62	0.74
How often practices the alphabet child				
Not at all	0.18	0.20	0.20	0.18
Occasionally or less than once a week	0.12	0.12	0.13	0.13
1-2 days per week	0.24	0.20	0.22	0.21
3 times a week	0.13	0.13	0.12	0.12
4 times a week	0.07	0.08	0.07	0.08
5 times a week	0.05	0.05	0.04	0.05
6 times a week	0.02	0.02	0.03	0.02
7 times a week/constantly	0.19	0.19	0.18	0.20
Observations	3,243	3,489	3,723	3,975

Note: The table provides a statistical description of the cognitive investment measures used between 9 months and 3 years of age. Measures are in bold, and where appropriate answers are italicised. All numbers are proportions. Income quartiles are relative to the sample income distribution.

D.2 Summaries of observable measures used in estimations

Table D5: Summary statistics of observable health measures used in estimating investment and production functions

	Mean	sd	Max.	Min.	Unique values
9 months					
Health conditions	-0.406	0.612	0	-5	6
Complications during labor	-0.423	0.704	0	-5	6
Complications during pregnancy	-0.541	0.858	0	-7	8
Non-regular hospital visits	-0.198	0.876	0	-84	14
Age 3					
Long-term illnesses	-0.183	0.466	0	-5	6
Health conditions	-0.976	1.038	0	-6	7
Non-regular hospital visits	-0.191	0.393	0	-1	2
Age 5					
Long-term illnesses	-0.252	0.577	0	-7	8
Subjective evaluation	4.285	0.884	5	1	5
Health conditions	-1.182	1.203	0	-7	8
Age 7					
Long-term illnesses	-0.241	0.568	0	-5	6
Subjective evaluation	4.425	0.813	5	1	5
Health conditions	-1.283	1.279	0	-8	9
Age 11					
Long-term illnesses	-0.207	0.673	0	-8	8
Subjective evaluation	4.420	0.822	5	1	5
Health conditions	-1.294	1.306	0	-6	7
Age 15					
Long-term illnesses	-0.246	0.743	0	-9	10
Subjective evaluation	3.470	0.917	5	1	5
Health conditions	-0.586	0.812	0	-5	6

Note: The measures in this table are those of health used to estimate the human capital production and investment functions. From left to right, the columns contain the aspect of health the measures capture, their sample mean and standard deviation (sd), and the maximum, minimum and number of unique values in the sample. A * indicates a the order of a measure was reversed from negative to positive so that a higher value indicates more skill.

Table D6: Summary statistics of observable cognitive skill measures used in estimating investment and production functions

	Mean	sd	Max.	Min.	Unique values
9 months					
Denver Developmental Screening Test	2.653	0.196	3	1	23
Communicative Development Inventory	2.115	0.349	3	1	16
Developmental concerns	-0.018	0.140	0	-3	4
Age 3					
BSR shapes	6.231	4.078	20	0	21
BAS naming vocabulary	73.198	17.983	141	10	31
BSR numbers	2.902	3.699	19	0	20
Age 5					
BAS pattern construction	87.271	19.582	152	10	47
BAS picture similarity	82.098	11.923	119	10	30
BAS naming vocabulary	107.349	16.425	170	10	35
Age 7					
NFER score	18.406	5.834	28	0	21
BAS reading	106.498	30.899	222	10	91
BAS pattern construction	116.154	17.238	211	10	79
Age 11					
CANTAB SWM: errors 8 boxes	-35.664	18.748	0	-173	108
CANTAB SWM: errors 4 boxes	-1.207	2.109	0	-23	23
CANTAB SWM: strategy	-34.307	5.962	0	-48	45
Age 15					
CANTAB gambling: Risk adjustment	1.203	0.834	5	0	423
CANTAB gambling: Risk taking	0.518	0.148	1	0	91
CANTAB gambling: Overall proportional bet	0.477	0.141	1	0	91

Note: The measures in this table are those of cognitive skill used to estimate the human capital production and investment functions. From left to right, the columns contain the aspect of cognitive skill the measures capture, their sample mean and standard deviation (sd), and the maximum, minimum and number of unique values in the sample. A * indicates a the order of a measure was reversed from negative to positive so that a higher value indicates more skill.

Table D7: Summary statistics of observable socio-emotional skill measures used in estimating investment and production functions

	Mean	sd	Max.	Min.	Unique values
9 months					
CIT: Mood	3.842	0.689	5	1	39
CIT: Emotional regulation	4.243	0.786	5	1	25
CIT: Adaptability/withdrawl	3.997	0.785	5	1	41
Age 3					
SDQ: Conduct problems	-2.834	2.077	0	-10	11
SDQ: Hyperactivity	-3.932	2.372	0	-10	11
SDQ: Emotional regulation	-1.384	1.522	0	-10	11
SDQ: Peer relationsips	-1.563	1.600	0	-10	11
SDQ: Pro-socialilty	7.356	1.889	10	0	11
CSR: Emotional regulation	-1.500	0.516	-1	-3	3
Age 5					
SDQ: Conduct problems	-1.522	1.519	0	-10	11
SDQ: Hyperactivity	-3.327	2.382	0	-10	11
SDQ: Emotional regulation	-1.396	1.604	0	-10	11
SDQ: Peer relationsips	-1.179	1.463	0	-10	11
SDQ: Pro-socialilty	8.372	1.681	10	0	11
CSR: Emotional regulation	-1.357	0.494	-1	-3	3
Age 7					
SDQ: Conduct problems	-1.396	1.551	0	-10	11
SDQ: Hyperactivity	-3.378	2.523	0	-10	11
SDQ: Emotional regulation	-1.538	1.774	0	-10	11
SDQ: Peer relationsips	-1.236	1.559	0	-10	11
SDQ: Pro-socialilty	8.578	1.648	10	0	11
CSBQ: Emotional regulation	-1.728	0.475	-1	-3	21
Age 11					
SDQ: Conduct problems	-1.390	1.577	0	-10	11
SDQ: Hyperactivity	-3.130	2.472	0	-10	11
SDQ: Emotional regulation	-1.873	1.993	0	-10	11
SDQ: Peer relationsips	-1.377	1.692	0	-10	11
SDQ: Pro-socialilty	8.781	1.571	10	0	11
Age 15					
SDQ: Conduct problems	-2.463	1.172	0	-10	11
SDQ: Hyperactivity	-4.021	1.454	0	-10	11
SDQ: Emotional regulation	-2.050	2.141	0	-10	11
SDQ: Peer relationsips	-1.377	1.692	0	-10	11
SDQ: Pro-socialilty	8.781	1.571	10	0	11

Note: The measures in this table are those of socio-emotional skill used to estimate the human capital production and investment functions. From left to right, the columns contain the aspect of socio-emotional skill the measures capture, their sample mean and standard deviation (sd), and the maximum, minimum and number of unique values in the sample. A * indicates a the order of a measure was reversed from negative to positive so that a higher value indicates more skill.

Table D8: Summary statistics of observable health investment measures used in estimating investment and production functions

	Mean	sd	Max.	Min.	Unique values
Age 3					
Regular bed times	3.109	0.922	4	1	4
Fruit or veg. once a day	0.968	0.176	1	0	2
How often child has regular meals	3.352	0.716	4	1	4
Age 5					
Days per week eats breakfast	6.697	1.128	7	0	8
Portions of fruit per day	2.228	0.891	3	0	4
How often child has regular meals	3.492	0.720	4	1	4
Regular bed times	3.109	0.922	4	1	4
Age 7					
How often plays active games with child	3.288	1.396	6	1	6
Portions of fruit per day	2.214	0.915	3	0	4
How often plays sports with child	4.169	1.369	6	1	6
How often child has regular bed times	3.459	0.773	4	1	4
Days per week child has breakfast	6.764	0.984	7	0	8
Age 11					
How often plays sports with child	2.683	1.347	6	1	6
Portions of fruit per day	2.028	0.970	3	0	4
Days per week child has breakfast	6.501	1.426	7	0	8
How often child plays non-club/class sports	5.343	1.935	7	1	7
Age 15					
How often drinks artificially sweetened drinks	3.818	1.751	7	1	7
How often eats fast food	4.939	1.012	7	1	7
How often drinks artificially sweetened drinks	4.247	1.899	7	1	7

Note: The measures in this table are those of health investment used to estimate the human capital production and investment functions. From left to right, the columns contain the aspect of health investment the measures capture, their sample mean and standard deviation (sd), and the maximum, minimum and number of unique values in the sample. A * indicates a the order of a measure was reversed from negative to positive so that a higher value indicates more skill.

Table D9: Summary statistics of observable cognitive investment measures used in estimating investment and production functions

	Mean	sd	Max.	Min.	Unique values
Age 3					
How often helps child with maths/counting	4.905	2.345	7	0	8
How often helps child with alphabet	2.989	2.461	7	0	8
How often sing songs/rhymes with child	5.119	2.323	7	0	8
Age 5					
How often helps child with reading	5.368	0.986	6	1	6
How often plays games with child	4.491	1.208	6	1	6
How often sings songs/plays music with child	4.773	1.302	6	1	6
How often paints/draws with child	3.869	1.222	6	1	6
How often reads/tells stories to child	3.609	1.563	6	1	6
Age 7					
How often helps child with writing	3.314	1.895	6	1	6
How often helps child with maths	2.867	1.829	6	1	6
How often helps child with reading	3.715	2.015	6	1	6
Age 11					
How often checks child's homework	3.405	0.894	4	1	4
How often helps child with homework	2.592	0.950	4	1	4
Hours per week doing homework	2.199	1.911	30	0	100
Age 15					
How often helps child with homework	3.031	1.013	7	1	7
How often talks to child about important topics	5.497	0.817	6	1	6
How often child visits museum/library/gallery	2.204	1.015	6	1	6
Hours per week doing homework	2.401	0.833	5	1	5

Note: The measures in this table are those of cognitive investment used to estimate the human capital production and investment functions. From left to right, the columns contain the aspect of cognitive investment the measures capture, their sample mean and standard deviation (sd), and the maximum, minimum and number of unique values in the sample. A * indicates a the order of a measure was reversed from negative to positive so that a higher value indicates more skill.

Table D10: Summary statistics of observable parental human capital measures used in estimating investment and production functions

	Mean	sd	Max.	Min.	Unique values
Health					
Health conditions	-1.192	1.263	0	-8	9
Has a long term illness	-0.211	0.408	0	-1	2
Subjective health	3.096	0.744	4	1	4
Socio-emotional skill					
Rosenberg self-esteem scale	4.963	1.450	6	0	7
Rutter Malaise psychological Inventory	7.290	1.801	9	0	10
Locus of control	2.429	0.880	3	0	4
Cognitive skill (measured without error)					
Main parent's highest NVQ	2.353	1.467	5	0	6

Note: The measures in this table are those of parental human capital used to estimate the human capital production and investment functions. From left to right, the columns contain the aspect of parental human capital the measures capture, their sample mean and standard deviation (sd), and the maximum, minimum and number of unique values in the sample. A * indicates a the order of a measure was reversed from negative to positive so that a higher value indicates more skill.

D.3 Measurement system estimates

Table D11: Measurement system estimates for observed health

	$\mu_{\theta,m,t}$	$\lambda_{\theta,m,t}$	$s_{\theta,m,t}$	$1 - s_{\theta,m,t}$
Initial (9 months)				
No. of long-term illnesses	0.418	1.000	0.052	0.948
Labor complications	0.427	1.704	0.117	0.883
Pregnancy complications	0.542	2.061	0.119	0.881
Age 3				
No. of long-term illnesses	0.418	1.000	0.280	0.720
Hospital admissions	0.367	2.606	0.368	0.632
No. of health conditions	0.408	0.574	0.125	0.875
Age 5				
No. of long-term illnesses	0.418	1.000	0.555	0.445
Hospital admissions	4.963	1.111	0.295	0.705
No. of health conditions	0.494	1.674	0.361	0.639
Age 7				
No. of long-term illnesses	0.418	1.000	0.571	0.429
Subjective health	5.092	1.027	0.289	0.711
No. of health conditions	0.605	1.695	0.324	0.676
Age 11				
No. of long-term illnesses	0.418	1.000	0.341	0.659
Subjective health	5.054	1.196	0.323	0.677
No. of health conditions	0.669	1.646	0.241	0.759
Age 15				
No. of long-term illnesses	0.418	1.000	0.354	0.646
Subjective health	4.133	0.303	0.021	0.979
No. of health conditions	0.077	0.622	0.114	0.886

Note: From left to right the columns represent the observable measure of health and its estimated mean, factor loading, signal and noise respectively. All parameters are estimated as outlined in Appendix A, and all measures are described in detail in Appendix B.

Table D12: Measurement system estimates for observed cognitive skill

	$\mu_{\theta,m,t}$	$\lambda_{\theta,m,t}$	$s_{\theta,m,t}$	$1 - s_{\theta,m,t}$
Initial (9 months)				
Communicative development invetories scale	2.109	1.000	0.254	0.746
Denver Developmental screening test	2.653	0.852	0.611	0.389
Parents' developmental worries	0.017	0.140	0.035	0.965
Age 3				
BAS: vocabulary	68.952	29.015	0.490	0.510
BSR: numbers	2.864	2.279	0.164	0.836
BSR: shapes	6.030	6.685	0.503	0.497
Age 5				
BAS: picture similarity	84.848	7.244	0.265	0.735
BAS: naming vocabulary	107.054	23.398	0.606	0.394
BAS: pattern construction	94.108	16.301	0.507	0.493
Age 7				
NFER score	115.769	26.686	0.476	0.524
BAS: word reading	121.478	13.748	0.406	0.594
BAS: pattern construction	20.107	5.551	0.577	0.423
Age 11				
CANTAB SWM: errors 4 boxes	1.109	0.634	0.286	0.714
CANTAB SWM: Strategy	34.015	2.201	0.431	0.569
CANTAB SWM: errors 8 boxes	34.225	10.643	1.009	-0.009
Age 15				
CANTAB gambling: proportional bet	0.425	0.017	0.056	0.944
CANTAB gambling: risk taking	0.475	0.009	0.027	0.973
CANTAB gambling: risk adjustment	1.527	0.562	1.830	-0.830

Note: From left to right the columns represent the observable measure of cognitive skill and its estimated mean, factor loading, signal and noise respectively. All parameters are estimated as outlined in Appendix A, and all measures are described in detail in Appendix B.

Table D13: Measurement system estimates for observed socio-emotional skill

	$\mu_{\theta,m,t}$	$\lambda_{\theta,m,t}$	$s_{\theta,m,t}$	$1 - s_{\theta,m,t}$
Initial (9 months)				
CIT mood	3.829	1.000	0.377	0.623
CIT: self-regulation	4.266	0.376	0.042	0.958
CIT: adaptation and withdrawl	4.013	0.485	0.071	0.929
Age 3				
CSR: emotional regulation	2.768	1.000	0.644	0.356
SDQ: hyperactivity	4.049	0.193	0.486	0.514
SDQ: emotional regulation	1.680	1.010	0.634	0.366
SDQ: peer relationships	4.185	0.458	0.325	0.675
SDQ: pro-sociality	4.014	0.545	0.406	0.594
SDQ: conduct problems	12.883	0.540	0.284	0.716
Age 5				
CSR: emotional regulation	2.768	1.000	0.609	0.391
SDQ: hyperactivity	2.891	0.287	0.618	0.382
SDQ: emotional regulation	1.002	1.428	0.655	0.345
SDQ: peer relationships	2.857	0.711	0.355	0.645
SDQ: pro-sociality	3.103	0.736	0.470	0.530
SDQ: conduct problems	12.620	0.683	0.300	0.700
Age 7				
CSR: emotional regulation	2.768	1.000	0.620	0.380
SDQ: hyperactivity	2.392	0.320	0.809	0.191
SDQ: emotional regulation	0.815	1.494	0.634	0.366
SDQ: peer relationships	2.580	0.796	0.363	0.637
SDQ: pro-sociality	2.909	0.771	0.447	0.553
SDQ: conduct problems	12.701	0.671	0.301	0.699
Age 11				
SDQ: hyp	2.768	1.000	0.575	0.425
SDQ: emotional regulation	1.033	1.514	0.583	0.417
SDQ: peer relationships	2.249	1.042	0.420	0.580
SDQ: pro-sociality	3.883	1.342	0.632	0.368
SDQ: conduct problems	12.914	0.662	0.280	0.720
Age 15				
SDQ: hyp	2.768	1.000	0.665	0.335
SDQ: emotional regulation	1.210	0.391	0.071	0.929
SDQ: peer relationships	3.182	2.156	0.997	0.003
SDQ: pro-sociality	3.883	1.342	0.632	0.368
SDQ: conduct problems	13.547	0.700	0.141	0.859

Note: From left to right the columns represent the observable measure of socio-emotional skill and its estimated mean, factor loading, signal and noise respectively. All parameters are estimated as outlined in Appendix A, and all measures are described in detail in Appendix B.

Table D14: Measurement system estimates for observed health investments

	$\mu_{\theta,m,t}$	$\lambda_{\theta,m,t}$	$s_{\theta,m,t}$	$1 - s_{\theta,m,t}$
Age 3				
Fruit or veg. once per pay	3.125	1.173	0.240	0.760
Has regular meals	0.972	0.039	0.016	0.984
Has regular bedtimes	3.354	0.898	0.447	0.553
Age 5				
Portions of fruit and veg. per day	6.711	1.000	0.120	0.880
Has regular meals	2.253	0.807	0.122	0.878
Has regular bed times	3.497	0.829	0.199	0.801
Days per week has breakfast	3.125	1.173	0.240	0.760
Age 7				
Portions of fruit and veg. per day	3.283	1.000	0.065	0.935
How often plays sport with child	2.239	0.930	0.133	0.867
Has regular bedtimes	4.163	0.922	0.058	0.942
Days per week has breakfast	3.462	0.562	0.067	0.933
How often plays physically active games	6.772	0.848	0.095	0.905
Age 11				
Portions of fruit and veg. per day	2.688	1.000	0.361	0.639
Days per week has breakfast	2.052	0.790	0.433	0.567
Days per weeldoes non-club physical activity	6.531	0.562	0.105	0.895
How often plays sport with child	5.342	0.409	0.029	0.971
Age 15				
How often has fast food	3.818	1.000	0.534	0.466
How often drinks artificially sweetened drinks	4.939	0.405	0.262	0.738
How often drinks sweetened drinks	4.247	0.481	0.105	0.895

Note: From left to right the columns represent the observable measure of health investment and its estimated mean, factor loading, signal and noise respectively. All parameters are estimated as outlined in Appendix A, and all measures are described in detail in Appendix B.

Table D15: Measurement system estimates for observed cognitive investments

	$\mu_{\theta,m,t}$	$\lambda_{\theta,m,t}$	$s_{\theta,m,t}$	$1 - s_{\theta,m,t}$
Age 3				
How often practices alphabet	4.929	1.000	0.684	0.316
How often plays music or sings	2.998	0.646	0.258	0.742
How often practices maths	5.144	0.620	0.271	0.729
Age 5				
Ho often plays games	5.370	1.000	0.075	0.925
How often sings	4.486	3.279	0.530	0.470
How often practices paints	4.750	2.957	0.365	0.635
How often tells stories	3.849	3.221	0.494	0.506
How often practices reading	3.590	3.252	0.314	0.686
Age 7				
How often practices maths	3.293	1.000	0.700	0.300
How ofen practices reading	2.860	0.814	0.499	0.501
How often practices writing	3.698	0.861	0.453	0.547
Age 11				
How often practices homework	3.410	1.000	0.605	0.395
Tie spent doing homework	2.591	0.481	0.123	0.877
How often checks homework	2.205	0.591	0.045	0.955
Age 15				
How often talks about important topics	3.031	1.000	0.192	0.808
How often visits museum/gallery/historical place	5.497	0.505	0.075	0.925
Tie spent doing homework	2.204	1.094	0.228	0.772
How often helps with homework	2.401	1.434	0.582	0.418

Note: From left to right the columns represent the observable measure of cognitive investment and its estimated mean, factor loading, signal and noise respectively. All parameters are estimated as outlined in Appendix A, and all measures are described in detail in Appendix B.

Table D16: Measurement system estimates for observed parental human capital

	$\mu_{\theta,m,t}$	$\lambda_{\theta,m,t}$	$s_{\theta,m,t}$	$1 - s_{\theta,m,t}$
Health				
Health conditions	1.205	1.000	0.231	0.769
Long term illness	0.214	0.482	0.511	0.489
Subjective health	3.114	0.630	0.269	0.731
Socio-emotional skill				
Rosenberg self-esteem	4.976	1.000	0.541	0.459
Rutter-Malaise psychological distress inventory	7.783	1.043	0.398	0.602
Locus of control	2.465	0.600	0.542	0.458

Note: From left to right the columns represent the observable measure of parental human capital and its estimated mean, factor loading, signal and noise respectively. All parameters are estimated as outlined in Appendix A, and all measures are described in detail in Appendix B.

D.4 Additional production estimates of initial conditions and production functions with intracted investments and human capital

Table D17: Variance covariance matrix of the initial conditions

	$\ln H_{h,0}$	$\ln H_{c,0}$	$\ln H_{c,0}$	$\ln P_h$	$\ln P_c$	$\ln P_s$	$\ln Y_0$
$\ln H_{h,0}$	0.020	0.006	0.005	0.078	-0.063	0.024	-0.024
$\ln H_{c,0}$	0.006	0.022	0.003	-0.002	0.018	0.012	0.001
$\ln H_{c,0}$	0.005	0.003	0.176	-0.006	-0.021	0.088	0.009
$\ln P_h$	0.078	-0.002	-0.006	0.371	0.007	0.255	0.036
$\ln P_c$	-0.063	0.018	-0.021	0.007	2.105	0.227	0.508
$\ln P_s$	0.024	0.012	0.088	0.255	0.227	1.132	0.153
$\ln Y_0$	-0.024	0.001	0.009	0.036	0.508	0.153	0.466

Table D18: Mean vector of the initial conditions

$\ln H_{h,0}$	$\ln H_{c,0}$	$\ln H_{c,0}$	$\ln P_h$	$\ln P_c$	$\ln P_s$	$\ln Y_0$
(0,	0,	0,	0,	2.522,	0,	9.473)

Table D19: Estimates of health production functions with interacted health and health investment

	Period 1 *Ages 9 months-3*	Period 2 *Ages 3-5*	Period 3 *Ages 5-7*	Period 4 *Ages 7-11*	Period 5 *Ages 11-15*
Lagged human capital					
$\ln H_{h,t-1}$	0.678***	1.222***	0.796***	0.527***	0.777***
	(0.148)	(0.081)	(0.037)	(0.043)	(0.062)
	[0.435,0.921]	[1.089,1.356]	[0.736,0.857]	[0.456,0.598]	[0.675,0.879]
$\ln H_{c,t-1}$	0.014	0.050	0.001	0.104***	0.009
	(0.122)	(0.036)	(0.019)	(0.017)	(0.009)
	[-0.187,0.215]	[-0.009,0.108]	[-0.031,0.033]	[0.076,0.131]	[-0.007,0.024]
$\ln H_{s,t-1}$	0.077	-0.003	0.003	0.060***	0.068***
	(0.067)	(0.008)	(0.008)	(0.010)	(0.017)
	[-0.033,0.188]	[-0.017,0.011]	[-0.010,0.017]	[0.042,0.077]	[0.040,0.095]
Parental human capital (fixed over time)					
$\ln P_h$	0.031*	0.057***	0.026	0.069***	0.034
	(0.017)	(0.022)	(0.017)	(0.020)	(0.023)
	[0.003,0.059]	[0.021,0.094]	[-0.001,0.053]	[0.035,0.103]	[-0.004,0.071]
$\ln P_c$	0.038*	-0.005	-0.008	-0.049***	-0.007
	(0.021)	(0.023)	(0.014)	(0.018)	(0.018)
	[0.004,0.072]	[-0.043,0.033]	[-0.030,0.014]	[-0.079,-0.020]	[-0.038,0.023]
$\ln P_s$	0.010	-0.007	-0.001	-0.021*	0.006
	(0.011)	(0.012)	(0.009)	(0.011)	(0.013)
	[-0.007,0.028]	[-0.026,0.013]	[-0.015,0.013]	[-0.039,-0.003]	[-0.014,0.027]
Investments					
$\ln I_{h,t-1}$	0.012	0.023	-0.015	-0.027	-0.025
	(0.024)	(0.054)	(0.013)	(0.035)	(0.017)
	[-0.027,0.052]	[-0.065,0.112]	[-0.036,0.005]	[-0.085,0.030]	[-0.053,0.004]
$\ln I_{h,t-1} \times \ln H_{h,t-1}$	-0.341	0.067	0.055	0.180	0.175**
	(0.330)	(0.243)	(0.048)	(0.125)	(0.076)
	[-0.883,0.202]	[-0.332,0.467]	[-0.024,0.134]	[-0.026,0.386]	[0.050,0.299]
$\ln A_t$	0.217***	0.148***	0.172***	0.206***	0.157***
	(0.022)	(0.026)	(0.016)	(0.019)	(0.020)
	[0.181,0.253]	[0.104,0.191]	[0.145,0.199]	[0.175,0.237]	[0.124,0.189]
RTS	0.520**	1.405***	0.857***	0.842***	1.036***
	(0.234)	(0.262)	(0.048)	(0.121)	(0.071)
	[0.135,0.904]	[0.974,1.837]	[0.778,0.935]	[0.643,1.041]	[0.919,1.153]
$\sigma^2_{\eta_h}$	0.015**	0.056***	0.032***	0.037***	0.031***
	(0.006)	(0.005)	(0.005)	(0.007)	(0.011)
	[0.005,0.026]	[0.047,0.065]	[0.024,0.039]	[0.027,0.048]	[0.013,0.049]
N	8,300	7,012	7,947	7,716	7,823

Notes: Standard errors in parentheses and 90% confidence intervals in square brackets are calculated using 100 bootstrap replications. The outcome in each equation column is children's health measured by the observables in Appendix Table D11. $t-1$ = ages 9 months and ages 3, 5, 7, and 11 years for the five columns respectively. The inputs in the left column are are lagged child health, cognitive skill and socio-emotional skill; parental health, cognitive skill and socio-emotional skill; health investment; and an interaction of health investment and health, respectively. All with the exception of parental cognitive skill are treated as unobservable. Section 2.5 describes the observables used as measures of each input, and their estimated measurement parameters are shown in Tables D11-D16.

Table D20: Estimates of cognitive production function parameters with interacted cognitive skill and health investment

	Period 1 *Ages 9 months-3*	Period 2 *Ages 3-5*	Period 3 *Ages 5-7*	Period 4 *Ages 7-11*	Period 5 *Ages 11-15*
Lagged human capital					
$\ln H_{h,t-1}$	0.191**	0.120	-0.033	-0.060	0.206*
	(0.082)	(0.093)	(0.055)	(0.076)	(0.114)
	[0.056,0.326]	[-0.033,0.273]	[-0.123,0.058]	[-0.184,0.064]	[0.019,0.394]
$\ln H_{c,t-1}$	0.083	0.700***	0.978***	0.825***	0.181***
	(0.120)	(0.202)	(0.067)	(0.124)	(0.033)
	[-0.114,0.280]	[0.367,1.032]	[0.868,1.087]	[0.621,1.030]	[0.127,0.235]
$\ln H_{s,t-1}$	0.122*	0.036**	0.026*	0.011	-0.034
	(0.069)	(0.016)	(0.015)	(0.022)	(0.034)
	[0.010,0.235]	[0.010,0.063]	[0.001,0.051]	[-0.026,0.047]	[-0.089,0.021]
Parental human capital (fixed over time)					
$\ln P_h$	-0.010	0.021	-0.008	-0.042	-0.024
	(0.018)	(0.031)	(0.028)	(0.042)	(0.050)
	[-0.040,0.019]	[-0.030,0.071]	[-0.054,0.038]	[-0.112,0.027]	[-0.106,0.057]
$\ln P_c$	0.206***	0.053*	0.136***	0.079*	0.288***
	(0.059)	(0.030)	(0.029)	(0.044)	(0.056)
	[0.109,0.303]	[0.005,0.102]	[0.089,0.184]	[0.007,0.151]	[0.196,0.381]
$\ln P_s$	0.011	-0.025	0.013	0.034	0.028
	(0.009)	(0.017)	(0.016)	(0.025)	(0.021)
	[-0.004,0.026]	[-0.053,0.002]	[-0.013,0.039]	[-0.008,0.076]	[-0.008,0.063]
Investments					
$\ln I_{h,t-1}$	0.056*	0.141	0.031	0.119	0.137***
	(0.029)	(0.102)	(0.027)	(0.106)	(0.035)
	[0.009,0.104]	[-0.027,0.309]	[-0.014,0.075]	[-0.055,0.293]	[0.079,0.196]
$\ln I_{c,t-1}$	0.049***	-0.074	-0.028***	-0.190**	0.143
	(0.014)	(0.084)	(0.010)	(0.080)	(0.094)
	[0.026,0.073]	[-0.212,0.065]	[-0.044,-0.012]	[-0.322,-0.057]	[-0.011,0.297]
$\ln I_{h,t-1} \times \ln H_{c,t-1}$	0.292	0.028	-0.115	0.224	0.075***
	(0.205)	(0.243)	(0.071)	(0.149)	(0.027)
	[-0.046,0.629]	[-0.373,0.428]	[-0.231,0.001]	[-0.021,0.470]	[0.030,0.120]
$\sigma^2_{\eta_c}$	0.228	0.102	0.052***	1.030**	0.105***
	(4.412)	(0.089)	(0.016)	(0.478)	(0.029)
	[-7.029,7.485]	[-0.045,0.249]	[0.025,0.078]	[0.243,1.817]	[0.058,0.152]
N	7,998	6,898	7,853	7,373	7404

Notes: Standard errors in parentheses and 90% confidence intervals in square brackets are calculated using 100 bootstrap replications. The outcome in each equation column is children's cognitive skill measured by the observables in Appendix Table D12. $t-1$ = ages 9 months and ages 3, 5, 7, and 11 years for the five columns respectively. The inputs in the left column are are lagged child health, cognitive skill and socio-emotional skill; parental health, cognitive skill and socio-emotional skill; health and cognitive investment; and an interaction of health investment and cognitive skill, respectively. All with the exception of parental cognitive skill are treated as unobservable. Section 2.5describes the observables used as measures of each input, and their estimated measurement parameters are shown in Tables D11-D16.

Table D21: Estimates of cognitive production function parameters with interacted cognitive skill and cognitive investment

	Period 1 *Ages 9 months-3*	Period 2 *Ages 3-5*	Period 3 *Ages 5-7*	Period 4 *Ages 7-11*	Period 5 *Ages 11-15*
Lagged human capital					
$\ln H_{h,t-1}$	0.258***	0.123	-0.046	-0.051	0.254**
	(0.099)	(0.108)	(0.055)	(0.090)	(0.129)
	[0.096,0.420]	[-0.054,0.300]	[-0.137,0.045]	[-0.199,0.097]	[0.042,0.466]
$\ln H_{c,t-1}$	0.139	0.558***	0.883***	0.973***	0.164***
	(0.144)	(0.151)	(0.050)	(0.155)	(0.033)
	[-0.098,0.375]	[0.310,0.807]	[0.801,0.966]	[0.717,1.228]	[0.110,0.218]
$\ln H_{s,t-1}$	0.175**	0.041**	0.026	0.012	-0.044
	(0.075)	(0.016)	(0.017)	(0.027)	(0.038)
	[0.052,0.298]	[0.014,0.068]	[-0.002,0.053]	[-0.033,0.057]	[-0.106,0.018]
Parental human capital (fixed over time)					
$\ln P_h$	-0.015	0.026	-0.004	-0.043	-0.044
	(0.025)	(0.033)	(0.027)	(0.049)	(0.051)
	[-0.056,0.026]	[-0.028,0.080]	[-0.049,0.040]	[-0.124,0.037]	[-0.129,0.040]
$\ln P_c$	0.287***	0.065*	0.129***	0.102**	0.317***
	(0.045)	(0.035)	(0.027)	(0.043)	(0.073)
	[0.212,0.362]	[0.008,0.123]	[0.085,0.173]	[0.032,0.173]	[0.197,0.437]
$\ln P_s$	0.013	-0.028	0.013	0.036	0.032
	(0.011)	(0.020)	(0.017)	(0.031)	(0.025)
	[-0.006,0.031]	[-0.060,0.005]	[-0.014,0.040]	[-0.016,0.088]	[-0.010,0.073]
Investments					
$\ln I_{h,t-1}$	0.083***	0.160*	0.011	0.240**	0.170***
	(0.025)	(0.089)	(0.023)	(0.112)	(0.042)
	[0.041,0.125]	[0.014,0.307]	[-0.026,0.049]	[0.056,0.424]	[0.102,0.239]
$\ln I_{c,t-1}$	0.069***	-0.119	-0.037**	-0.232**	0.152
	(0.014)	(0.113)	(0.014)	(0.098)	(0.114)
	[0.046,0.092]	[-0.305,0.066]	[-0.061,-0.013]	[-0.393,-0.070]	[-0.035,0.340]
$\ln I_{h,t-1} \times \ln H_{c,t-1}$	-0.008	0.172	0.026	-0.037	0.000
	(0.090)	(0.228)	(0.028)	(0.119)	(0.136)
	[-0.156,0.140]	[-0.203,0.547]	[-0.020,0.071]	[-0.232,0.158]	[-0.223,0.223]
$\sigma^2_{\eta_c}$	1.897	0.098***	0.065***	1.717**	0.118***
	(228.502)	(0.034)	(0.018)	(0.749)	(0.037)
	[-373.955,377.750]	[0.042,0.154]	[0.036,0.095]	[0.485,2.948]	[0.057,0.178]
N	7,998	6,898	7,853	7,373	7,404

Notes: Standard errors in parentheses and 90% confidence intervals in square brackets are calculated using 100 bootstrap replications. The outcome in each equation column is children's cognitive skill measured by the observables in Appendix Table D12. $t-1$ = ages 9 months and ages 3, 5, 7, and 11 years for the five columns respectively. The inputs in the left column are are lagged child health, cognitive skill and socio-emotional skill; parental health, cognitive skill and socio-emotional skill; health and cognitive investment; and an interaction of health investment and cognitive skill, respectively. All with the exception of parental cognitive skill are treated as unobservable. Section 2.5describes the observables used as measures of each input, and their estimated measurement parameters are shown in Tables D11-D16.

Table D22: Estimates of socio-emotional production function parameters with interacted socio-emotional skill and health investment

	Period 1 *Ages 9 months-3*	Period 2 *Ages 3-5*	Period 3 *Ages 5-7*	Period 4 *Ages 7-11*	Period 5 *Ages 11-15*
Lagged human capital					
$\ln H_{h,t-1}$	0.274	0.107	0.131*	0.020	0.114
	(0.292)	(0.143)	(0.071)	(0.081)	(0.073)
	[-0.207,0.755]	[-0.128,0.341]	[0.014,0.248]	[-0.112,0.153]	[-0.007,0.234]
$\ln H_{c,t-1}$	0.246	0.053	-0.002	0.078**	0.021
	(0.430)	(0.077)	(0.049)	(0.037)	(0.014)
	[-0.461,0.953]	[-0.074,0.180]	[-0.082,0.078]	[0.018,0.138]	[-0.002,0.044]
$\ln H_{s,t-1}$	0.437*	0.412***	0.793***	0.677***	0.307***
	(0.227)	(0.015)	(0.021)	(0.022)	(0.023)
	[0.063,0.811]	[0.387,0.436]	[0.758,0.828]	[0.642,0.713]	[0.269,0.346]
Parental human capital (fixed over time)					
$\ln P_h$	0.011	-0.018	-0.004	0.050	0.042
	(0.069)	(0.045)	(0.034)	(0.040)	(0.032)
	[-0.102,0.124]	[-0.092,0.057]	[-0.061,0.053]	[-0.017,0.116]	[-0.011,0.095]
$\ln P_c$	0.529***	0.041	0.142***	0.079*	0.084***
	(0.073)	(0.048)	(0.035)	(0.040)	(0.029)
	[0.409,0.649]	[-0.038,0.121]	[0.083,0.200]	[0.013,0.145]	[0.036,0.133]
$\ln P_s$	0.391***	0.097***	0.053**	0.044*	0.036*
	(0.041)	(0.026)	(0.024)	(0.026)	(0.020)
	[0.323,0.459]	[0.055,0.139]	[0.014,0.092]	[0.001,0.087]	[0.003,0.069]
Investments					
$\ln I_{h,t-1}$	0.712***	0.181	0.060*	0.303***	0.040*
	(0.085)	(0.112)	(0.032)	(0.083)	(0.023)
	[0.571,0.852]	[-0.002,0.365]	[0.007,0.112]	[0.166,0.440]	[0.003,0.078]
$\ln I_{c,t-1}$	0.063***	0.436***	-0.010	0.054	0.061
	(0.020)	(0.093)	(0.012)	(0.064)	(0.082)
	[0.030,0.096]	[0.283,0.589]	[-0.030,0.009]	[-0.052,0.160]	[-0.074,0.196]
$\ln I_{h,t-1} \times \ln H_{s,t-1}$	-0.078	-0.033	-0.048	0.013	-0.038
	(0.661)	(0.060)	(0.032)	(0.065)	(0.025)
	[-1.166,1.010]	[-0.132,0.066]	[-0.100,0.005]	[-0.094,0.119]	[-0.080,0.003]
$\ln A_t$	-0.473***	1.090***	1.130***	1.136***	0.166***
	(0.066)	(0.055)	(0.049)	(0.046)	(0.038)
	[-0.581,-0.364]	[1.000,1.180]	[1.050,1.211]	[1.061,1.211]	[0.104,0.228]
RTS	2.584***	1.277***	1.114***	1.319***	0.668***
	(0.749)	(0.158)	(0.078)	(0.121)	(0.097)
	[1.352,3.817]	[1.017,1.536]	[0.985,1.244]	[1.120,1.518]	[0.509,0.826]
$\sigma^2_{\eta_s}$	0.920***	0.343***	0.383***	0.384***	0.154***
	(0.085)	(0.031)	(0.034)	(0.029)	(0.011)
	[0.780,1.060]	[0.292,0.394]	[0.328,0.438]	[0.337,0.432]	[0.135,0.173]
N	8,195	6,908	7,892	7,578	7619

Notes: Standard errors in parentheses and 90% confidence intervals in square brackets are calculated using 100 bootstrap replications. The outcome in each equation column is children's socio-emotional skill measured by the observables in Appendix Table D13. $t-1$ = ages 9 months and ages 3, 5, 7, and 11 years for the five columns respectively. The inputs in the left column are are lagged child health, cognitive skill and socio-emotional skill; parental health, cognitive skill and socio-emotional skill; health and cognitive investment; and an interaction of health investment and socio-emotional skill, respectively. All with the exception of parental cognitive skill are treated as unobservable. Section 2.5 describes the observables used as measures of each input, and their estimated measurement parameters are shown in Tables D11-D16.

Table D23: Estimates of socio-emotional production function parameters with interacted socio-emotional skill and cognitive investment

	Period 1 *Ages 9 months-3*	Period 2 *Ages 3-5*	Period 3 *Ages 5-7*	Period 4 *Ages 7-11*	Period 5 *Ages 11-15*
Lagged human capital					
$\ln H_{h,t-1}$	0.360	0.129	0.126*	0.038	0.068
	(0.269)	(0.145)	(0.070)	(0.074)	(0.071)
	[-0.082,0.803]	[-0.109,0.367]	[0.012,0.241]	[-0.084,0.161]	[-0.049,0.186]
$\ln H_{c,t-1}$	0.215	0.038	0.009	0.077**	0.015
	(0.403)	(0.051)	(0.040)	(0.036)	(0.011)
	[-0.447,0.878]	[-0.046,0.123]	[-0.057,0.075]	[0.019,0.136]	[-0.003,0.034]
$\ln H_{s,t-1}$	0.425**	0.410***	0.788***	0.679***	0.300***
	(0.201)	(0.015)	(0.021)	(0.021)	(0.025)
	[0.095,0.756]	[0.385,0.435]	[0.753,0.823]	[0.643,0.714]	[0.259,0.342]
Parental human capital (fixed over time)					
$\ln P_h$	-0.000	-0.008	-0.008	0.042	0.056*
	(0.057)	(0.046)	(0.034)	(0.039)	(0.033)
	[-0.094,0.093]	[-0.083,0.068]	[-0.064,0.048]	[-0.022,0.107]	[0.003,0.110]
$\ln P_c$	0.534***	0.039	0.140***	0.080**	0.070**
	(0.071)	(0.048)	(0.034)	(0.040)	(0.031)
	[0.417,0.652]	[-0.040,0.119]	[0.084,0.197]	[0.015,0.145]	[0.020,0.120]
$\ln P_s$	0.397***	0.091***	0.058**	0.045*	0.034*
	(0.037)	(0.025)	(0.023)	(0.025)	(0.020)
	[0.336,0.457]	[0.050,0.132]	[0.020,0.096]	[0.003,0.087]	[0.001,0.067]
Investments					
$\ln I_{h,t-1}$	0.714***	0.146	0.047	0.288***	0.021
	(0.082)	(0.118)	(0.030)	(0.088)	(0.017)
	[0.579,0.848]	[-0.048,0.339]	[-0.001,0.096]	[0.143,0.434]	[-0.007,0.050]
$\ln I_{c,t-1}$	0.066***	0.475***	-0.007	0.039	0.091
	(0.019)	(0.128)	(0.016)	(0.067)	(0.079)
	[0.033,0.098]	[0.264,0.686]	[-0.033,0.019]	[-0.071,0.149]	[-0.039,0.221]
$\ln I_{c,t-1} \times \ln H_{s,t-1}$	0.098	-0.070	-0.008	-0.011	-0.131*
	(0.154)	(0.074)	(0.015)	(0.042)	(0.067)
	[-0.156,0.353]	[-0.192,0.052]	[-0.033,0.017]	[-0.081,0.059]	[-0.242,-0.021]
$\ln A_t$	-0.487***	1.095***	1.129***	1.137***	0.186***
	(0.070)	(0.057)	(0.049)	(0.046)	(0.042)
	[-0.602,-0.372]	[1.002,1.188]	[1.048,1.210]	[1.061,1.212]	[0.117,0.255]
RTS	2.810***	1.251***	1.146***	1.278***	0.525***
	(0.362)	(0.157)	(0.071)	(0.116)	(0.138)
	[2.214,3.406]	[0.993,1.509]	[1.029,1.262]	[1.087,1.470]	[0.298,0.752]
$\sigma^2_{\eta_s}$	0.915***	0.342***	0.385***	0.385***	0.154***
	(0.086)	(0.032)	(0.033)	(0.029)	(0.011)
	[0.774,1.057]	[0.289,0.395]	[0.330,0.440]	[0.338,0.432]	[0.136,0.173]
	[0.774,1.057]	[0.289,0.395]	[0.330,0.440]	[0.338,0.432]	[0.136,0.173]
N	8,195	6,908	7,892	7,578	7,619

Notes: Standard errors in parentheses and 90% confidence intervals in square brackets are calculated using 100 bootstrap replications. The outcome in each equation column is children's cognitive skill measured by the observables in Appendix Table D12. $t-1$ = ages 9 months and ages 3, 5, 7, and 11 years for the five columns respectively. The inputs in the left column are are lagged child health, cognitive skill and socio-emotional skill; parental health, cognitive skill and socio-emotional skill; health and cognitive investment; and an interaction of cognitive investment and socio-emotional skill, respectively. All with the exception of parental cognitive skill are treated as unobservable. Section 2.5describes the observables used as measures of each input, and their estimated measurement parameters are shown in Tables D11-D16.

D.5 Estimates of the investment and production functions of congitive and socio-emotional skill excluding health

Table D24: Estimates of cognitive investment function parameters, excluding health

	Period 1 *Ages 9 months-3*	Period 2 *Ages 3-5*	Period 3 *Ages 5-7*	Period 4 *Ages 7-11*	Period 5 *Ages 11-15*
Lagged human capital					
$\ln H_{c,t-1}$	1.505***	0.058***	-0.174***	-0.050***	-0.025***
	(0.459)	(0.022)	(0.027)	(0.012)	(0.005)
	[0.749,2.261]	[0.022,0.095]	[-0.219,-0.129]	[-0.069,-0.030]	[-0.033,-0.016]
$\ln H_{s,t-1}$	0.954***	0.037***	0.049*	0.060***	0.054***
	(0.218)	(0.010)	(0.026)	(0.011)	(0.016)
	[0.596,1.312]	[0.020,0.053]	[0.007,0.092]	[0.042,0.079]	[0.028,0.080]
Parental human capital (fixed over time)					
$\ln P_c$	0.137**	0.054	0.052	0.007	-0.018
	(0.068)	(0.033)	(0.053)	(0.032)	(0.030)
	[0.025,0.248]	[-0.001,0.108]	[-0.035,0.139]	[-0.045,0.059]	[-0.068,0.031]
$\ln P_s$	-0.059	0.060***	-0.054*	0.048***	0.032**
	(0.037)	(0.015)	(0.028)	(0.014)	(0.015)
	[-0.120,0.001]	[0.036,0.084]	[-0.100,-0.008]	[0.024,0.071]	[0.007,0.057]
Income					
$\ln Y_t$	0.146***	0.047**	0.013	0.066**	0.044
	(0.044)	(0.022)	(0.039)	(0.034)	(0.034)
	[0.074,0.219]	[0.011,0.082]	[-0.050,0.077]	[0.011,0.122]	[-0.012,0.100]
$\sigma^2_{\pi_c}$	3.347***	0.044***	1.965***	0.412***	0.066***
	(0.100)	(0.005)	(0.032)	(0.019)	(0.010)
	[3.183,3.511]	[0.035,0.053]	[1.914,2.017]	[0.381,0.444]	[0.049,0.083]
N	8239	6904	7821	7710	8098

Notes: Standard errors in parentheses and 90% confidence intervals in square brackets are calculated using 100 bootstrap replications. The outcome in each equation column is cognitive investment measured by the observables in Appendix Table D15. $t-1$ = ages 9 months and ages 3, 5, 7, and 11 years for the five columns respectively. The inputs in the left column are are lagged child cognitive and socio-emotional skill; parental cognitive and socio-emotional skill; and family income, respectively. All with the exception of parental cognitive skill and family income are treated as unobservable. Section 2.5 describes the observables used as measures of each input, and their estimated measurement parameters are shown in Tables D11-D16.

Table D25: Estimates of Cobb-Douglas cognitive skill production function, excluding health

	Period 1 *Ages 9 months-3*	Period 2 *Ages 3-5*	Period 3 *Ages 5-7*	Period 4 *Ages 7-11*	Period 5 *Ages 11-15*
Lagged human capital					
$\ln H_{c,t-1}$	0.180	0.962***	0.749***	0.993***	0.123***
	(0.132)	(0.185)	(0.045)	(0.145)	(0.019)
	[-0.037,0.396]	[0.658,1.267]	[0.675,0.823]	[0.754,1.231]	[0.092,0.154]
$\ln H_{s,t-1}$	0.312***	0.097***	0.043	0.029	0.013
	(0.090)	(0.035)	(0.027)	(0.043)	(0.036)
	[0.164,0.460]	[0.039,0.155]	[-0.001,0.087]	[-0.042,0.100]	[-0.046,0.073]
Parental human capital (fixed over time)					
$\ln P_c$	0.397***	0.168**	0.236***	0.239***	0.472***
	(0.065)	(0.073)	(0.045)	(0.074)	(0.080)
	[0.291,0.503]	[0.048,0.288]	[0.161,0.310]	[0.117,0.360]	[0.340,0.604]
$\ln P_s$	0.023	-0.004	0.019	0.081*	0.033
	(0.016)	(0.037)	(0.025)	(0.045)	(0.028)
	[-0.003,0.048]	[-0.065,0.057]	[-0.023,0.061]	[0.006,0.156]	[-0.013,0.079]
Investments					
$\ln I_{c,t-1}$	0.089***	-0.223	-0.047**	-0.341*	0.359***
	(0.018)	(0.246)	(0.019)	(0.178)	(0.105)
	[0.060,0.118]	[-0.627,0.182]	[-0.078,-0.017]	[-0.633,-0.049]	[0.186,0.531]
$\sigma^2_{\eta_c}$	1.226	0.284***	0.218***	5.415**	0.173***
	(43.914)	(0.064)	(0.067)	(2.491)	(0.041)
	[-71.006,73.458]	[0.178,0.390]	[0.107,0.328]	[1.317,9.512]	[0.106,0.240]
N	8002	6906	7866	7390	7468

Notes: Standard errors in parentheses and 90% confidence intervals in square brackets are calculated using 100 bootstrap replications. The outcome in each equation column is children's cognitive skill measured by the observables in Appendix Table D12. $t-1$ = ages 9 months and ages 3, 5, 7, and 11 years for the five columns respectively. The inputs in the left column are are lagged child cognitive and socio-emotional skill; parental cognitive and socio-emotional skill; and cognitive investment, respectively. All with the exception of parental cognitive skill are treated as unobservable. Section 2.5 describes the observables used as measures of each input, and their estimated measurement parameters are shown in Tables D11-D16.

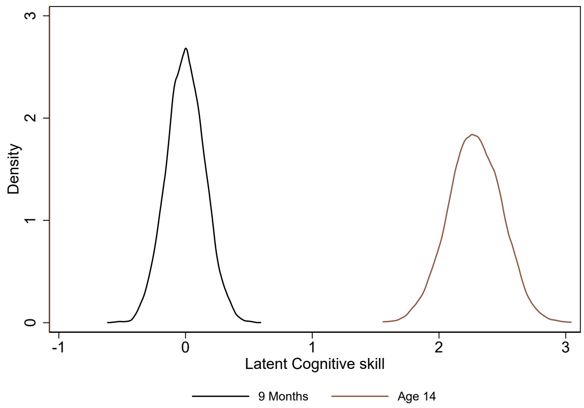
Table D26: Estimates of Cobb-Douglas socio-emotional skill production function, excluding health

	Period 1 *Ages 9 months-3*	Period 2 *Ages 3-5*	Period 3 *Ages 5-7*	Period 4 *Ages 7-11*	Period 5 *Ages 11-15*
Lagged human capital					
$\ln H_{c,t-1}$	-0.603*	0.036	0.007	0.036**	0.013**
	(0.351)	(0.038)	(0.017)	(0.015)	(0.006)
	[-1.180,-0.025]	[-0.027,0.098]	[-0.021,0.034]	[0.011,0.060]	[0.004,0.022]
$\ln H_{s,t-1}$	1.000***	0.411***	0.792***	0.695***	0.338***
	(0.176)	(0.017)	(0.021)	(0.019)	(0.021)
	[0.710,1.291]	[0.384,0.439]	[0.758,0.826]	[0.664,0.726]	[0.303,0.373]
Parental human capital (fixed over time)					
$\ln P_c$	0.740***	0.052	0.143***	0.110***	0.087***
	(0.057)	(0.041)	(0.032)	(0.039)	(0.027)
	[0.646,0.834]	[-0.016,0.119]	[0.091,0.196]	[0.045,0.174]	[0.043,0.132]
$\ln P_s$	0.423***	0.108***	0.073***	0.082***	0.052***
	(0.034)	(0.022)	(0.021)	(0.024)	(0.016)
	[0.368,0.479]	[0.072,0.145]	[0.039,0.108]	[0.043,0.122]	[0.025,0.078]
Investments					
$\ln I_{c,t-1}$	0.073***	0.529***	-0.003	0.073	0.097
	(0.021)	(0.109)	(0.011)	(0.055)	(0.089)
	[0.038,0.108]	[0.350,0.709]	[-0.021,0.014]	[-0.018,0.163]	[-0.050,0.244]
$\ln A_t$	-0.652***	1.009***	1.061***	1.062***	0.116***
	(0.058)	(0.052)	(0.044)	(0.051)	(0.036)
	[-0.747,-0.556]	[0.923,1.094]	[0.990,1.133]	[0.978,1.146]	[0.056,0.176]
RTS	1.634***	1.136***	1.012***	0.995***	0.587***
	(0.317)	(0.090)	(0.037)	(0.067)	(0.085)
	[1.113,2.156]	[0.987,1.285]	[0.950,1.073]	[0.885,1.106]	[0.447,0.727]
$\sigma^2_{\eta_n}$	0.973***	0.358***	0.389***	0.401***	0.161***
	(0.078)	(0.039)	(0.032)	(0.032)	(0.012)
	[0.845,1.101]	[0.294,0.421]	[0.336,0.443]	[0.347,0.454]	[0.141,0.181]
N	8199	6915	7905	7596	7690

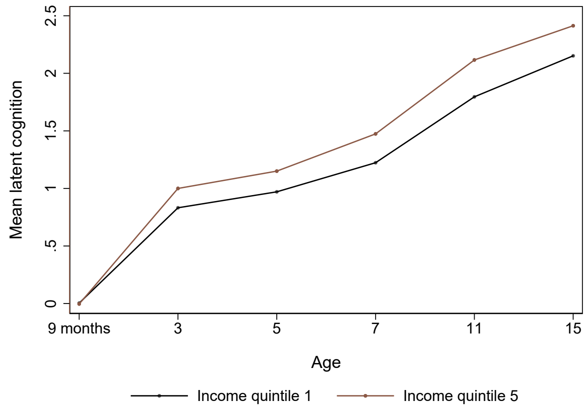
Notes: Standard errors in parentheses and 90% confidence intervals in square brackets are calculated using 100 bootstrap replications. The outcome in each equation column is children's socio-emotional skill measured by the observables in Appendix Table D12. $t-1$ = ages 9 months and ages 3, 5, 7, and 11 years for the five columns respectively. The inputs in the left column are are lagged child cognitive and socio-emotional skill; parental cognitive and socio-emotional skill; and cognitive investment, respectively. All with the exception of parental cognitive skill are treated as unobservable. Section 2.5 describes the observables used as measures of each input, and their estimated measurement parameters are shown in Tables D11-D16.

D.6 Additional simulation results

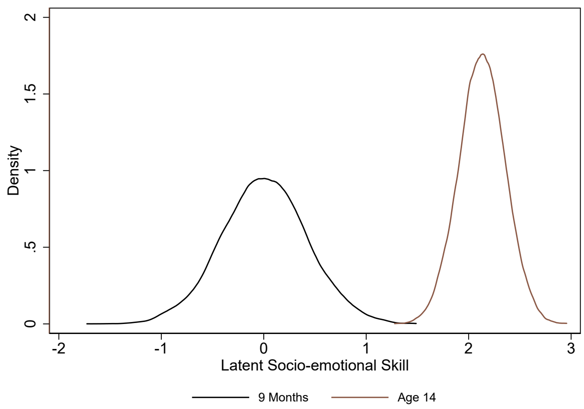
Figure D1: The estimated develomental path of cognitive and socio-emotional skill



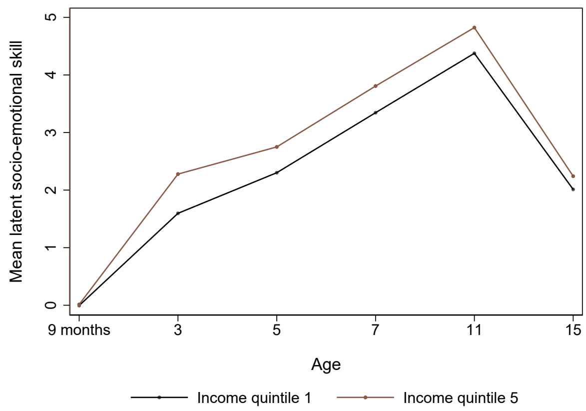
(a)



(b)



(c)



(d)

Note: Panel (a) and (c) show the simulated distribution of cognitive and socio-emotional skill at 9 months and age 14, and panels (b) and (d) shows the simulated evolution of mean latent cognitive and socio-emotional skill in the top and bottom quintiles of the income distribution. Both were estimated by simulating the developmental path of 10,000 observations randomly drawn from the estimated initial conditions.

D.6.1 The effects of income transfers

Table D27: Short- and long-term human capital impacts of a £5, 000 increase in income across childhood

Transfer period	**Health**		**Cognition**		**Socio-emotional**	
	Short-term	*Long-term*	*Short-term*	*Long-term*	Short-term	Long-term
Age 9 months-3	0.0298	0.1027	0.4082	0.0609	1.7316	0.1579
	(0.0109)	(0.0376)	(0.1495)	(0.0223)	(0.6344)	(0.0579)
Age 3-5	0.0120	0.0991	0.3625	0.0623	0.8946	0.1766
	(0.0028)	(0.0229)	(0.0839)	(0.0144)	(0.2071)	(0.0409)
Age 5-7	-0.0141	-0.0015	0.0048	0.0000	0.0476	0.0103
	(0.0020)	(0.0002)	(0.0007)	(0.0000)	(0.0069)	(0.0015)
Age 7-11	-0.1885	-0.0527	1.0232	0.1203	1.6638	0.5316
	(0.0172)	(0.0048)	(0.0932)	(0.0110)	(0.1515)	(0.0484)
Age 11-14	-0.1134	-0.1134	2.2019	2.2019	0.3748	0.3748
	(0.0065)	(0.0065)	(0.1255)	(0.1255)	(0.0214)	(0.0214)
N	10,000	10,000	10,000	10,000	10,000	10,000

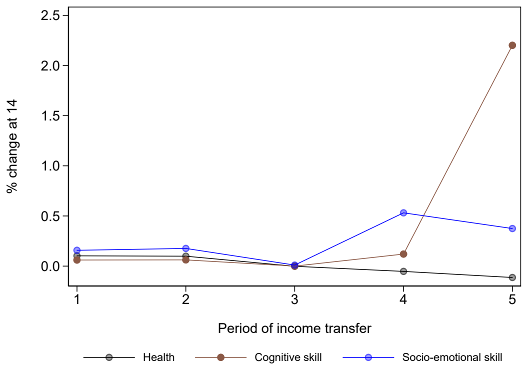
Note: Each cell shows $100 * E[\ln H^Y_{j,t} - \ln H_{j,t}]$ - the average change in human capital component j - indicated by the column - given an income transfer, Y, in the period indicated by the row. The differences are calculated by simulating the developmental path of 10,000 observations randomly drawn from the estimated initial conditions, with and without a one-time £5, 000 increase in income in the corresponding period. Standard errors of the difference are in parentheses.

Table D28: Short- and long-term human capital impacts of a £5,000 increase in income across childhood for these in the bottom quartile of the income distribution

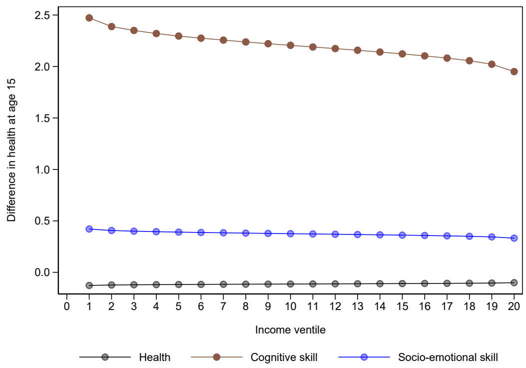
Transfer period	**Health**		**Cognition**		**Socio-emotional**	
	Short-term	*Long-term*	*Short-term*	*Long-term*	Short-term	Long-term
Age 9 months-3	0.0446	0.1538	0.6111	0.0912	2.5924	0.2364
	(0.0082)	(0.0281)	(0.1117)	(0.0167)	(0.4738)	(0.0432)
Age 3-5	0.0157	0.1297	0.4744	0.0815	1.1707	0.2311
	(0.0018)	(0.0151)	(0.0554)	(0.0095)	(0.1366)	(0.0270)
Age 5-7	-0.0168	-0.0018	0.0058	0.0000	0.0567	0.0122
	(0.0012)	(0.0001)	(0.0004)	(0.0000)	(0.0042)	(0.0009)
Age 7-11	-0.2108	-0.0589	1.1440	0.1345	1.8602	0.5944
	(0.0096)	(0.0027)	(0.0523)	(0.0061)	(0.0851)	(0.0272)
Age 11-14	-0.1217	-0.1217	2.3631	2.3631	0.4023	0.4023
	(0.0035)	(0.0035)	(0.0674)	(0.0674)	(0.0115)	(0.0115)
N	2,500	2,500	2,500	2,500	2,500	2,500

Note: Each cell shows $100 * E[\ln H^{Y}_{j,t} - \ln H_{j,t}]$ - the average change in human capital component j - indicated by the column - given an income transfer, Y, in the period indicated by the row. The differences are calculated by simulating the developmental path of 10,000 observations randomly drawn from the estimated initial conditions, with and without a one-time £5,000 increase in income in the corresponding period. Standard errors of the difference are in parentheses.

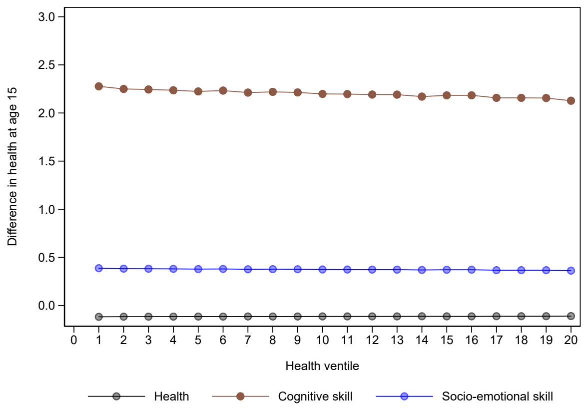
Figure D2: Long-term human capital impacts of a £5,000 increase in income across childhood



(a) Long-term effects by round of transfer



(b) Effects of an income transfer at age 11 by income ventile



(c) Effects of an income transfer at age 11 by health ventile

Note: Panel (a) shows the % increase in health and cognitive and socio-emotional skill at 14 given an income transfer of £5,000 at the age shown on the x-axis. panel (b) shows the % increase in each component of human capital at 14 given an income transfer at age 11 across ventiles of the income distribution. panel (c) shows the same change across ventiles of the health distribution. The effects were calculate by drawing 10,000 observations from the estimated initial conditions and forward simulating the child development path with and without income transfers in each period. It is assumed that the transfers are spent fully in the period they are given.

D.6.2 The effects of health improvements

Table D29: The short- and long-term impacts on human capital of health improvements across childhood

Transfer period	Health		Cognition		Socio-emotional	
	Short-term	*Long-term*	*Short-term*	*Long-term*	Short-term	Long-term
Age 9 months-3	6.6389	3.3289	2.2678	0.8966	2.2504	0.9729
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Age 3-5	11.7997	4.4938	1.6398	0.9354	0.3149	0.9821
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Age 5-7	12.2654	5.5817	-0.6797	0.8964	1.9143	1.1114
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Age 7-11	7.3225	6.0391	-0.7162	1.0929	0.1902	0.7726
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Age 11-14	9.9570	9.9570	1.9886	1.9886	1.1921	1.1921
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
N	10,000	10,000	10,000	10,000	10,000	10,000

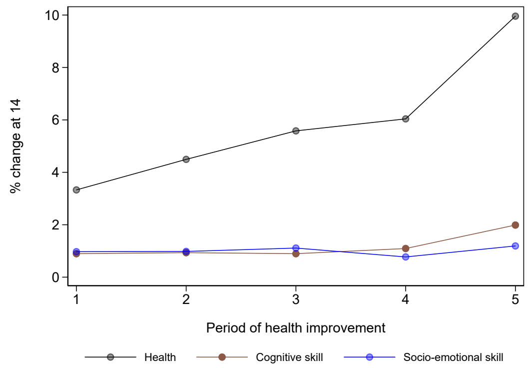
Note: Each cell shows $100 * E[\ln H_{j,t}^{H_h} - \ln H_{j,t}]$ - the average change in human capital component j - indicated by the column - given an improvement in health, H_h, in the period indicated by the row. The differences are calculated by simulating the developmental path of 10,000 observations randomly drawn from the estimated initial conditions, with and without a one-time 10% increase in health capital in each period. Standard errors of the difference are in parentheses.

Table D30: The short- and long-term impacts on human capital of health improvements across childhood for those in the bottom quartile of the health distribution

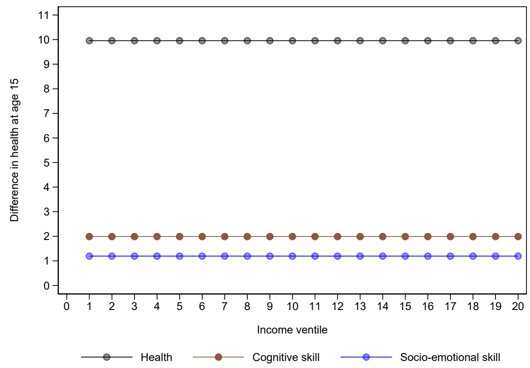
Transfer period	**Health**		**Cognition**		**Socio-emotional**	
	Short-term	*Long-term*	*Short-term*	*Long-term*	Short-term	Long-term
Age 9 months-3	5.4705	2.7430	1.8687	0.7388	1.8543	0.8017
	(2.5287)	(1.2680)	(0.8638)	(0.3415)	(0.8572)	(0.3706)
Age 3-5	11.2900	4.2997	1.5690	0.8950	0.3013	0.9396
	(2.3994)	(0.9138)	(0.3335)	(0.1902)	(0.0640)	(0.1997)
Age 5-7	12.0054	5.4633	-0.6653	0.8774	1.8738	1.0878
	(1.7672)	(0.8042)	(0.0979)	(0.1292)	(0.2758)	(0.1601)
Age 7-11	6.8597	5.6575	-0.6709	1.0239	0.1782	0.7238
	(1.7821)	(1.4698)	(0.1743)	(0.2660)	(0.0463)	(0.1880)
Age 11-14	9.0250	9.0250	1.8025	1.8025	1.0806	1.0806
	(2.9008)	(2.9008)	(0.5793)	(0.5793)	(0.3473)	(0.3473)
N	2,937	2,937	2,937	2,937	2,937	2,937

Note: Each cell shows $100 * E[\ln H_{j,t}^{H_h} - \ln H_{j,t}]$ - the average change in human capital component j - indicated by the column - given an improvement in health, H_h, in the period indicated by the row. The differences are calculated by simulating the developmental path of 10,000 observations randomly drawn from the estimated initial conditions, with and without a one-time 10% increase in health capital in each period. Standard errors of the difference are in parentheses.

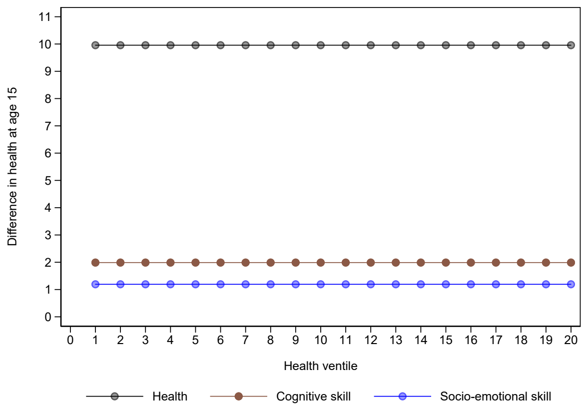
Figure D3: Long-term human capital impacts of a one standard deviation improvement in health across childhood



(a) Long-term effects by round of improvement



(b) Effects of an improvement at age 11 by income ventile

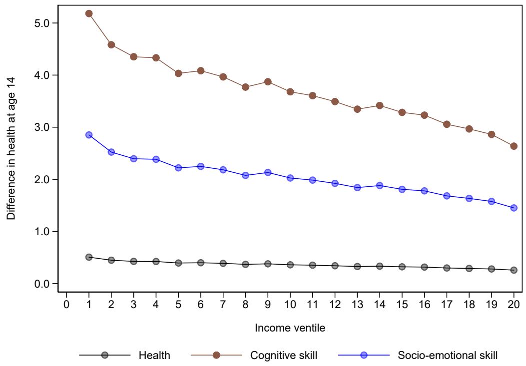


(c) Effects of an improvement at age 11 by health ventile

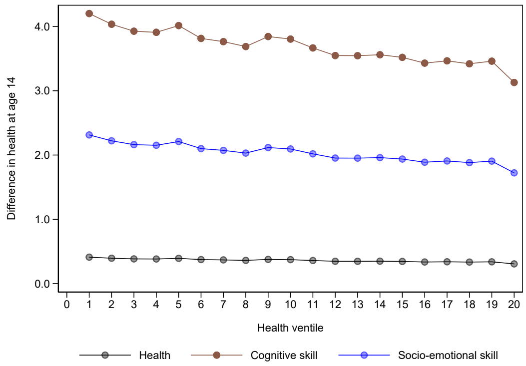
Note: panel (a) shows the % increase in health and cognitive and socio-emotional skill at 14 given a one standard deviation improvement in health at the age shown on the x-axis. panel (b) shows the % increase in each component of human capital at 14 given a health improvement at age 11 across ventiles of the income distribution. panel (c) shows the same change across ventiles of the health distribution. The effects were calculate by drawing 10,000 observations from the estimated initial conditions and forward simulating the child development path with and without health improvements in each period.

D.6.3 The effect of increases in parents' human capital

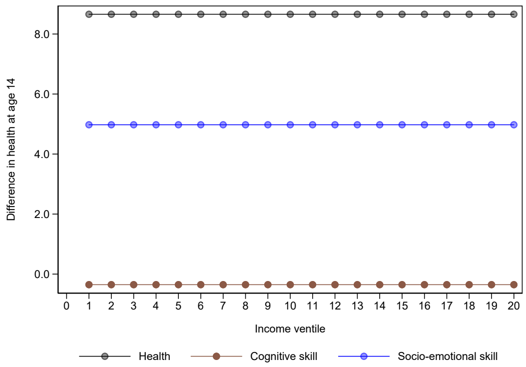
Figure D4: Long-term increases in health and cognitive and socio-emotional skills due to increases in parents' education and health, by position in the health and income distributions



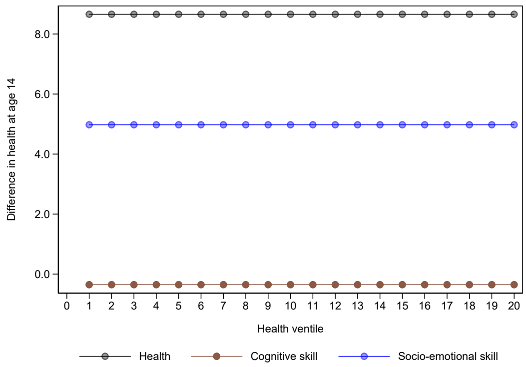
(a) % increase due to increased parental education by income ventile



(b) % increase due to increased parental education by health ventile



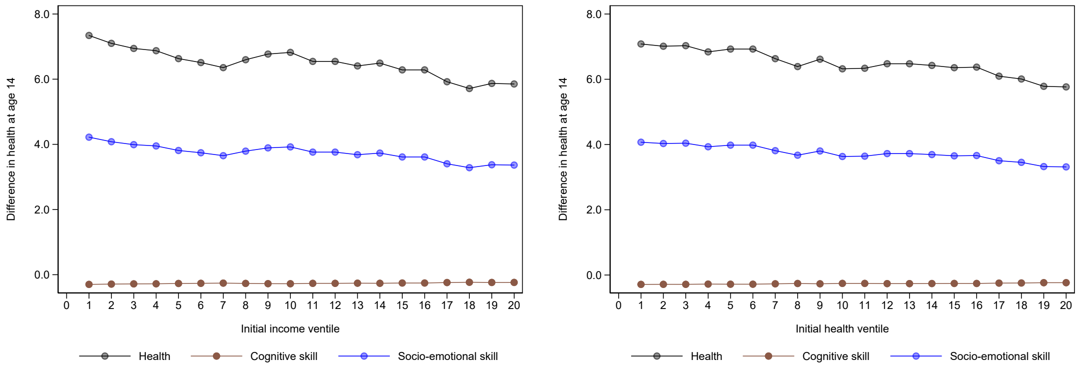
(c) % increase due to increased parental health by income ventile



(d) % increase due to increased parental health by health ventile

Note: Panels a and c show the % increase in health and cognitive and socio-emotional skill at 14 given an increases in parents' education and health respectively for all children at age 9 months by ventile of the income distribution. Panels b and d show the % increase in each component of human capital at 14 given an improvement in parents' education and health for all children at age 9 months across ventiles of the health distribution. The effects were calculate by drawing 10,000 observations from the estimated initial conditions and forward simulating the child development path with and without increases to parents' education and health at 9 months of age.

Figure D5: Long-term changes in the health and skill composition across the health and income distributions due to increases in parents' education and health for the 25% poorest and least healthy parents



(a) Increase in parents' health for the unhealthiest 25% of children

(b) Increase in parents' health for the poorest 25% of families

Note: Panels a and b show the % increase in health and cognitive and socio-emotional skill at 14 given an increases in parents' education for children in the poorest and unhealthiest 25% of families at age 9 months by ventiles of the health and income distributions respectively. The effects were calculated by drawing 10,000 observations from the estimated initial conditions and forward simulating the child development path with and without increases to parents' education and health at 9 months of age for children in the poorest and unhealthiest 25% of families.