University of Essex

Department of Economics

Discussion Paper Series

Early Maternal Time Investment and Early Child Outcomes

Emilia Del Bono, Marco Francesconi,
Yvonne Kelly and Amanda Sacker

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EMILIA DEL BONO

Institute for Social and Economic Research

University of Essex

MARCO FRANCESCONI

Department of Economics

University of Essex

and IFS

YVONNE KELLY

Department of Epidemiology and Public Health

University College London

AMANDA SACKER

Department of Epidemiology and Public Health

University College London

October 24, 2014

Abstract

Using large longitudinal survey data from the UK Millennium Cohort Study, this paper estimates the effect of maternal time inputs on early child development. We find that maternal time is a quantitatively important determinant of skill formation and that its effect declines with child age. There is evidence of a long shadow of the effect of early maternal time inputs on later outcomes, especially in the case of cognitive skill development. In the case of non-cognitive development, this effect disappears when we account for skill persistence.

JEL Classification: J24, J15, I20

Keywords: Education production functions; early interventions; cognitive and non-cognitive skill formation.

1. Introduction

The importance of parental time in determining child attainment has long been recognized by economists (Becker 1965; Leibowitz 1974, 1977; Hill and Stafford 1974). Despite this, there are surprisingly few empirical studies that analyze the effect of parental time inputs on child outcomes. Using a large representative data set on British children and their families, this paper's objective is to provide new evidence on how the time mothers devote to activities with their children affects early child outcomes.

Much recent research has found that skills measured in pre-school years are strong predictors of later life outcomes (e.g., Keane and Wolpin 1997; Cameron and Heckman 1998; Cunha et al. 2006) and that, by the time children enter primary school education, significant differences in verbal and mathematical competence exist among them (Feinstein, 2003; Cunha and Heckman 2007 and 2008; Cunha, Heckman, and Schennach 2010).[1]

Given this growing and compelling evidence, many studies have explored the potential determinants of such skills focusing on a wide variety of markers, such as childhood family income and family structure, parental education, mother's employment, child care, school quality, and neighbourhood characteristics (e.g., Haveman and Wolfe 1995; Brooks-Gunn, Han, and Waldfogel 2002; Ruhm 2004; Björklund and Salvanes 2011; Almond and Currie 2011a, 2011b; Ermisch, Jäntti and Smeeding 2012). But in comparison very little attention has been devoted to the role played by parental time.

There are only few recent studies that bring parental time right back into the research agenda on early child outcomes. Fiorini and Keane (2012) analyze time use diaries of about 1,000 children from the Longitudinal Study of Australian Children (LSAC) and describe how children aged between 1 and 9 years allocate their time into several different activities (not just time with parents). They find that time spent in educational activities, especially with parents, is the most productive input for cognitive skills, while non-cognitive skills are uncorrelated to different types of time allocations.

Using data on approximately 700 children from the Child Development Supplement of the Panel Study of Income Dynamics (PSID), Del Boca, Monfardini, and Nicoletti (2012) estimate adolescents' production functions of cognitive skills. They find that child's own time investment is more influential than mother's time investment during adolescence, but maternal time inputs are more important when children were 6–10 years old. Examining the same PSID data on about 1,500 children, Carneiro and Rodriguez (2009) confirm that

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[1]Interestingly this was already a key result of the Coleman Report (see Mosteller and Moynihan 1972; Leibowitz 1974.) Some studies raise a number of statistical concerns about the actual occurrence of this widening gap. See for example Jerrim and Vignoles (2012).

more time with mothers leads children (especially those aged 3 to 6 years) to perform better in cognitive tests.[2]

A closely related contribution is the work by Todd and Wolpin (2007). They do not have time use diaries but survey data on about 7,500 children from the National Longitudinal Survey of Youth (NLSY) to estimate the effect of home and school inputs on child cognitive abilities. Parental time here is proxied by a (scalar) home environment index, the Home Observation Measurement of the Environment (HOME). This is an age-specific composite measure, which includes information on learning materials, parental involvement, and a variety of stimulation and experience subscales, e.g., whether mothers of children aged less than 3 provide toys that challenge their child to develop new skills and the child has complex eye-hand coordination toys, or whether mothers of children between the ages of 3 and 5 help their child to learn the alphabet, numbers, shapes and sizes, or whether mothers of children under the age of 10 read stories to their child.[3] They find strong evidence that home inputs are important determinants of child cognitive development and differences in home inputs can account for 10–20 percent of the racial test score gaps.

In our paper we use data from the UK Millennium Cohort Study (MCS) and construct composite measures of maternal time investments to estimate production functions of child cognitive and non-cognitive skills.[4] Our time input measures are based on information collected from age 3 to age 7 of each child. Compared to the studies based on time use diaries, we have a much larger sample of more than 8,000 children and mothers, which allows us to explore whether cognitive and non-cognitive production functions are different for different subgroups. Compared to studies that use the HOME index, our time input measures are child specific and more directly related to time spent in activities with children and thus easier to interpret. Ours is also the first study to focus on Britain.

One of our key objectives is to understand whether the effect of maternal time investment on child development changes over early childhood (Cunha et al. 2006; Cunha and Heckman 2008). We begin our analysis with models in which both outcomes and inputs

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[2]Using a small sample of children and parents again from the Child Development Supplement of the PSID, Del Boca, Flinn, and Wiswall (2014) estimate a structural model of cognitive child development with both maternal and paternal time inputs. They find that mother's time is the most productive input for young children and that the productivity of all parental time inputs declines with child age.

[3]Several studies, especially in developmental pyschology and social demography, have used HOME scores and consistently found it has important effects on children's development (e.g., Brooks-Gunn, Klebanov, and Duncan, 1996; Guo and Harris 2000; Brooks-Gun, Han, and Waldfogel 2002; Linver, Brooks-Gunn, and Cabrera 2004). Although still limited, its use among economists is becoming more popular (Aughinbaugh and Gittleman 2003; Taylor, Dearing, and McCartney 2003).

[4]We have no ex-ante reason to believe that maternal time inputs influence the two production functions similarly. But since the work by Heckamn, Stixrud, and Urzua (2006) there is overwhelming evidence that the two functions are different and affected differently by different inputs.

are measured at the same age for each child. Although these specifications cannot tell us whether the effect of maternal time investments declines over child age, they provide us with a useful benchmark as they are often used by developmental psychologists, educationalists, and epidemiologists interested in early child development (e.g., Bus, van Ijzendoorn, and Pellegrini 1995; Sacker, Schoon, and Bartley 2002; Raikes et al. 2006; Kelly et al. 2009, 2011; McMunn et al. 2011).

To see directly if there are long shadows of early investments on later child outcomes we then estimate specifications in which lagged inputs and past test scores are controlled for, using similar techniques to those proposed by Todd and Wolpin (2003 and 2007) and also applied by Fiorini and Keane (2012) and Del Boca, Monfardini, and Nicoletti (2012). Our statistical analysis accounts for a number of important methodological issues, such as measurement error in the lagged inputs as well as outcomes (Ladd and Walsh 2002), and the presence of feedback effects (Andrabi et al. 2011).

The MCS does not collect time use diaries of children like the LSAC and PSID but contains detailed information on age-specific maternal activities with children on different domains of learning, cognitive stimulation, and emotional support. Rather than using one overall score, we use standard principal component analysis to extract two indexes that measure different domains of the mother's time involvement with the child. The first factor picks up age-specific activities that aim to stimulate the educational environment, such as reading to the child, helping the child with his/her homework, and engaging with the child's teachers and school initiatives. We refer to this as the *educational time* input. The second factor involves a wide range of other activities, including outdoor recreation, indoor games, drawing and singing at home. This is referred to as the *recreational time* input.

Although our focus is on maternal time investment, we also consider two other potential markers of child cognitive and non-cognitive development throughout our empirical work. The first is formal (paid) nonmaternal child care, which has received a lot of attention by social scientists.[5] The second is given by an index of parenting style that accounts for whether the child has regular bedtimes and mealtimes and rules on television and computer usage. Such measures are common in developmental psychology, public health, and sociology (e.g., McLoyd 1998; Guo and Harris 2000; Bornstein 2002; Brooks-Gunn and Markman 2005; Grantham-McGregor et al. 2007; Berger, Paxson and Waldfogel 2009; Kelly et al. 2011), but less so in economics (some exceptions are Dooley and Stewart

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[5]See, among others, the early contribution by Belsky and Eggebeen (1991) and the recent work by Bernal (2008), Bernal and Keane (2010), and Black et al. (2012). Blau and Currie (2006) provide an excellent overview.

2007; Ermisch 2008; Fiorini and Keane 2012).

We draw attention to five main results. First, there is a positive relationship between our two maternal time inputs (educational and recreational time) and child cognitive and emotional skill development between the ages of 3 and 7. The magnitude of these effects is large, corresponding to 20 to 40 percent of the impact of having a university educated mother rather than a mother without any qualification. Second, we find evidence that early time investments are more productive than later time investments. One explanation of this result is the presence of feedback effects, whereby parents respond to past outcomes by adjusting their current resource allocation decisions. Third, outcome persistence is generally high, with lagged scores being more predictive of non-cognitive skills. Fourth, we find input effect heterogeneity along mother's education and child birth order, with greater productivity of early investments in firstborn children and children of more educated mothers. Fifth, nonmaternal child care is correlated with none of our child outcomes, while a parenting style based on routine and discipline is associated with a strong positive effect on outcomes, especially verbal skill accumulation.

The remainder of the paper proceeds as follows. Section 2 describes our data, reports descriptive statistics on maternal time inputs and child outcomes, and provides a validation exercise for our time inputs against external time use diaries. Section 3 describes the basic specifications used in the econometric analysis. Section 4 presents our benchmark results on maternal time inputs, while Section 5 shows evidence on feedback effects, explores the role played by other inputs, and presents several robustness checks. Section 6 concludes.

2. Data

A. The Millennium Cohort Study

The Millennium Cohort Study (MCS) is a nationally representative longitudinal study of infants born in the UK. The sample was drawn from births occurred between September 2000 and January 2002. The survey design, recruitment process and fieldwork have been described in detail elsewhere (Dex and Joshi 2005). The first four sweeps of the survey involved home visits by interviewers and took place when cohort members were aged 9 months, 3, 5 and 7 years. During home visits questions were asked about socioeconomic circumstances, demographic characteristics, home learning, family routines and psychosocial environment. At age 3, 5 and 7 cognitive assessments were carried out by trained interviewers and questions were asked (typically to the mother) about the cohort

members' health development and socio-emotional behavior.

Our sample includes all singleton children interviewed at 9 months, for whom the main respondent is the natural mother (aged between 20 and 45 at the birth of the child) and with valid information on a set of family background variables. This implies a 20 percent reduction of the original sample and gives us 15,101 children. We further select our sample by constructing a balanced panel, including only cases where: (a) the child is present at all interviews up to age 7 (10,071 children), and (b) we have no missing information on the measures of cognitive and non-cognitive ability.[6] This leaves us with a sample of 8,652 children. We further retain only children attending school full time at age 5 and 7 (8,336 children). Finally, children whose information on parental activities is missing are excluded. Our final sample thus consists of 8,129 children, with 24,387 child-year observations.

B. Child Outcomes

Cognitive outcome — The cognitive outcome is assessed using widely validated, age-appropriate tests. These come from the British Ability Scales (BAS; see Elliott, Smith, and McCulloch [1996] and [1997]). Our measure of cognitive development is a test on verbal skills and is constructed using three assessments: the BAS Naming Vocabulary Test taken at ages 3 and 5 and the age 7 BAS Word Reading Test. In the Naming Vocabulary Test children are shown pictures of objects and are asked to identify them. In the Word Reading Test children read aloud a series of words presented on a card. For ease of interpretation all tests are transformed into z-scores, with mean 0 and standard deviation 1.

Non-cognitive outcome — When cohort members were approximately 3, 5 and 7 years old, parents were asked to complete the Strengths and Difficulties Questionnaire (SDQ). The SDQ is a behavioral screening questionnaire designed to measure psychological adjustment in children aged 3 to 16 (Goodman 1997 and 2001). The questionnaire identifies five different components: (i) hyperactivity/inattention, (ii) conduct problems, (iii) emotional symptoms, (iv) peer problems, and (v) pro-social behavior. Respondent indicate whether each item is "not true" (=1), "somewhat true" (=2), or "certainly true" (=3), and responses are scored so that higher scores indicate more problematic behaviors. Responses to the first four subscales (i.e., excluding pro-social behavior) are then summed up to obtain the Total Difficulty Score, which varies between 0 and 40. We take this is

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[6]Sampling weights which correct for attrition are used throughout our analysis.

as our measure of non-cognitive outcome. To facilitate the interpretation, the score is reverse-coded and expressed as a z-score with mean 0 and standard deviation 1.

Figures 1 and 2 show the age-specific distributions of the standardized cognitive and non-cognitive outcomes, respectively. Table 1 reports means and standard deviations of their non-standardized equivalents. The distributions of verbal skill scores are approximately normal and similar across ages, while the distributions of the (reverse-coded) Total Difficulty Score is skewed to the left and becomes more so as children grow older.

C. Maternal Time Inputs

At each interview, the MCS asks several questions about the type and frequency of activities that the main respondent (usually the mother) or other household members carry out with the survey child. The type of activities recorded are: (i) reading to the child, (ii) telling stories, (iii) playing music or teaching songs, (iv) drawing or painting, (v) playing sports/games outdoors or going to the park, and (vi) playing games indoors. For children aged 5 and 7, we also have: (vii) helping with homework, (viii) participating in school activities, and (ix) attending parents' evenings at school. In the case of activities (i)–(vi), mothers are asked to indicate how frequently they carry them out on a 6- or 8-point scale, ranging from "every day" to "never".

One drawback with the questions asked when children were 3 years old is that we cannot separate activities that were performed by the mother from those performed by other family members. We assume that all activities were carried out by the mother, however we will keep in mind that maternal pre-school time inputs may pick up not just maternal investments but also a broader measure of the home learning environment experienced by the child. When children were aged 5 and 7, instead, the questions were more explicitly related to the mother and the corresponding activities can thus be assigned to her directly.

Rather than using many different measures of maternal time investments (we count 24 types of activity and at least 6 degrees of intensity for most of them over the three age groups), we combine this information using principal component analysis. We find evidence of two common factors.[7] We notice that some activities — such as reading to the child, taking the child to the library and helping with homework — have higher loadings on the first factor, while other activities — such as drawing or painting and

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[7]These are found using standard procedures according to which only factors with eigenvalues greater than or equal to one should be retained (see Fiorini and Keane [2012] for a similar application). The two factors jointly explain 45.4, 42.0 and 37.4 percent of the total variance at ages 3, 5, and 7, respectively. Appendix Table A1 shows that the majority of the items load positively on the factors.

playing games indoors or outdoors — load predominantly on the second factor. We interpret the first factor as a measure of "educational" time and the second as an index of "recreational" time. This labeling does not mean that the recreational input excludes educational components and viceversa. Indeed, using an oblique rotation technique we explicitly allow the factors (from here onwards referred to as maternal time inputs) to be correlated.[8]

Figure 3 shows the distributions of the two inputs by child age. We notice that the recreational time input is normally distributed, except that at age 3 its distribution is right-truncated. This is likely to be due to the fact that a large fraction of mothers report that they (or others at home) perform some activities frequently when their children are 3 years old.[9] The distribution of the educational time input varies more by child age. This greater variability may in part reflect the fact that at age 5 the child starts school.[10]

D. Validating the MCS Time Input Measures with Time Use Diaries

We provide here a simple validation exercise of our derived maternal time input measures. To do this, we analyze the correlations of these derived measures with maternal education and employment status and compare such correlations with those obtained using direct measures of mother's time spent with children extracted from time use diaries.

The UK Time Use Survey (UK-TUS) was carried out in 2000-2001 and collects time diaries for a representative sample of 11,600 individuals aged 8 or above.[11] From this sample we select a sub-sample of women (6,223 observations) aged 20-55 (3,485 observations), whose youngest child is less than 9 years old (1,240 observations), and who have valid information on a set of maternal characteristics and complete time diaries. Our final sample consists of 720 individuals and 1,076 diaries, as each individual was asked to complete up to two diaries (one for a working day and one for a weekend day).[12]

The UK-TUS aggregates activities into 10-minute intervals and records a main and a secondary activity, the place where each activity was carried out and whether there were

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[8]The correlation coefficients between the two time inputs are 0.21, 0.12, and 0.14 at ages 3, 5, and 7, respectively.

[9]For instance, more than 50 percent of mothers report that their 3-year-old child is taught numbers and counting "every day" at home. At ages 5 and 7, the questions on parenting activities are more similar and there is greater dispersion in the answers. The resulting correlation of the indexes of recreational activities at ages 5 and 7 is 0.593, more than double the correlation between the indexes measured at ages 3 and 5 (0.288).

[10]As evidence, notice that the correlation of the educational time activity indexes is 0.232 at ages 3 and 5 and 0.266 at ages 5 and 7.

[11]See Office for National Statistics (2003) for a detailed description of the UK-TUS data.

[12]We will use weights specifically provided to combine information from more than 1 diary per individual.

other people involved. A detailed list of activities is recorded in the survey. We identify a subset of (main) activities that mothers do in relation to child care. These activities are further disaggregated into five categories: (a) physical care and supervision, (b) teaching, (c) reading, playing, and talking, (d) travel time, and (e) other activities (which is a residual category).

Before looking at the results, two remarks are in order. First, although there is a straightforward relationship between some of the activities recorded in the time use diaries and the factors derived with the MCS, this relationship is sometimes imperfect. For example, teaching time in the UK-TUS (activity (b)) corresponds quite directly to our measure of the educational time input. Similarly, our recreational time input and reading, playing and talking (activity (c)) do overlap considerably. However, there are relevant differences. For example physical care and supervision (activity (a)) includes activities such as taking the children to the playground, which contributes to our measures of recreational time inputs. Likewise, the UK-TUS sorts school meetings — which are part of the educational time input — into the travel time category (activity (d)). Second, the UK-TUS does not differentiate between activities performed with different children of different ages. Selecting mothers of children aged 0 to 9 years is an attempt to mitigate this problem.

Figure 4 illustrates the relationship of the two maternal time inputs constructed using the MCS data (educational and recreational) with maternal education and employment status. The educational time input has a strong positive relationship with mother's education, especially at age 3: the higher the mother's education, the higher the index value.[13] By contrast, this measure exhibits no clear association with maternal employment status. The recreational time input shows a positive, albeit modest, association with maternal education. As was the case for the educational input, recreational time has almost no detectable association with maternal employment and we find no differences in the strength of these associations by child age.

We repeat the same exercise on the five child care time measures derived from the UK-TUS data. Figure 5 shows the results.[14] We find no association of maternal education with mother's time devoted to physical care and supervision, travel time, and other activities. But more educated mothers tend to spend more time in activities related to teaching as

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[13]This is in line with the evidence shown by Guryan, Hurst, and Kearney (2008) for the United States. For Germany, instead, Lauber (2014) finds no relationship between maternal education and time spent by mothers in child care activities.

[14]For presentational purposes, the time use measures have been standardized to have a mean 0 and standard deviation 1. The unstandardized means are reported in Appendix Table A2. Moreover, since only have 87 women report having a university degree or higher qualification in the UK-TUS sample, we grouped them with women who have A level (or equivalent) qualification into one single category.

well as reading, playing and talking to their children than less educated mothers. This is consistent with the positive gradient found before for the two time input factors.

There is no association between mother's time spent in teaching, child-related travels and other activities and maternal employment status. This finding is again in line with our MCS time input measures. But working mothers (regardless of whether they are in part- or full-time jobs) are also observed to spend less time in physical care and supervision as well as in reading, playing and talking to their children. This negative relationship is not captured by the two MCS time factors, reflecting the fact that the overlap between our measures of maternal time inputs and the activities recorded in the time use diaries is imperfect.

A final piece of evidence is given by the pairwise correlations between the MCS time inputs and the time spent by mothers with children according to the UK-TUS data. To do this, we calculate 36 cell means for each set of measures (factors in the MCS and minutes in the UK-TUS), where the cells are defined over mother's education (3 groups), employment status (3 groups), and age (4 groups).[15] Since the time use diaries do not distinguish activities by child age, we consider an average of the two MCS time inputs over the three ages of the child (3, 5, and 7 years). Two correlations are of particular interest because their underlying measures are expected to be more concordant than others. These are the correlation between the MCS educational time input and the time devoted to teaching and the correlation between the MCS recreational time input and the time spent reading, playing, and talking to the child. With values of 0.504 and 0.608 respectively, our two MCS inputs appear to pick up a large fraction of the early actual time investments in children.[16]

E. Other Inputs

As mentioned in the Introduction, we analyze two additional inputs to the child development production function. One is nonmaternal child care, which can be broken down into informal and formal arrangements. Informal (unpaid) arrangements comprise the care provided by partners, grandparents, other relatives or friends. Formal (paid) arrangements include the care provided by nurseries, registered childminders, nannies, or

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[15]Due to sample size limitations of the UK-TUS sample, we cannot construct finer cells or other categories.

[16]In addition, there are other large and meaningful correlations. For instance, and in spite of our concern about modest overlap, the time devoted to physical care and supervision has a 0.534 correlation with the recreational time input, while the correlation between the time spent by mothers in reading, playing and talking and the educational time input is almost 0.2.

others.[17] Formal and informal arrangements are relevant only to working mothers, while nonworking mothers are assumed to be the main carers. Since in the UK all children aged 5 attend primary schools, the type of child care for those aged 5 and 7 refers to arrangements outside standard school hours, including school-based breakfast clubs and after-school clubs.[18] Table 1 shows that, as children grow older, more mothers rely on nonmaternal child care (from 30 percent at age 3 to 53 percent at 7). This pattern is mirrored by mothers' employment rates, which grow from 52 to 65 percent (including both part-time and full-time work).

The other additional input we focus on is parenting style. We identify four age appropriate questions about the types of rules and routines used by parents: (i) whether the child has regular bedtimes (with values ranging from 1 ("never") to 4 ("always")) , (ii) how many hours of TV time the child is allowed during the day (with values ranging from 1 to 4 corresponding to "more than 3 hours" and "not at all" respectively), (iii) whether the child has regular mealtimes (asked at age 3 only, with values ranging from 1 for "never" to 4 for "always"), and (iv) how many hours of computer time the child is allowed during the day (asked at ages 5 and 7, with values ranging from 1 for "more than 3 hours" to 4 for "not at all").

To derive a concise representation of the data we use principle component analysis and find evidence of a single common factor, which explains about 48, 41, and 42 percent of the variance at ages 3, 5, and 7, respectively. The age-specific factor loadings are reported in Appendix Table A3. As the underlying variables load positively on the factor, a higher value of the parenting index reflects greater parental discipline or stricter rules (Dooley and Stewart 2007; Ermisch 2008; Kelly et al. 2011; Fiorini and Keane 2012). By construction, the index is expressed as a z-score with mean 0 and standard deviation 1.

F. Other Conditioning Variables

Our analysis includes a set of standard child and family controls. Some are time invariant, such as child sex, birth weight, ethnicity, parity, an indicator of whether the child was born pre-term, region of birth (not reported in Table 1), mother's age at birth (and its square), and mother's education. Others are time varying and include: child age at interview (and its square), an indicator of whether the child lives in a single-parent household, and presence of siblings.

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[17]Separating out nurseries from other forms of paid child care arrangements does not change our results.

[18]About 11 percent of children in the sample do not have information on child care arrangements at age 3. This fraction goes down substantially to less than 2 percent when children are aged 5 and 7. To maximize the size of our estimating sample, in our analysis we include an indicator variable for children with missing information. Excluding them from the analysis, however, does not change our main findings.

Table 1 reports the summary statistics. The sample has an almost identical number of boys and girls. Nearly two-fifths of them are firstborn and more than 90 percent are white British. The average weight at birth across all children in the sample is 3.4 kilograms and about 5 percent of them were born pre-term. Mothers were on average 30 years old at the child's birth. 20 percent of them have a university degree and roughly an equal proportion do not have any qualification. As children age, family size (number of siblings) increases, and so does the percentage of children living in a single parent household. We have already mentioned the positive correlation between child age and maternal employment. Family income also increases, going from about £380 to £480 per week (in 2004 prices).

3. Methods

We estimate early child development production functions using the approach developed by Todd and Wolpin (2003 and 2007) and also applied by Fiorini and Keane (2012) and Del Boca, Monfardini, and Nicoletti (2012). As discussed in the Introduction, one of our main aims is to assess the importance of early child investments relative to late investments. To this end, we include lagged inputs and past test scores as determinants of current child achievements.

A standard identification problem is the endogeneity of the maternal time inputs (as well as of the other inputs) used in estimation. This is likely to be driven by unobserved child endowments, unobserved inputs, and measurement errors in test scores and input measures. We account for omitted past inputs and in part for unobserved ability by estimating models with past test scores. To address issues of measurement errors in lagged child outcomes we use instrumental variables methods and to attenuate the problem of measurement errors in inputs we use quantiles of our time input factors.[19]

We illustrate our approach by discussing the most general specification that nests other specifications. Let T_{ia} be a vector of time inputs and P_{ia} a vector of other parental inputs for child i at age a. In our analysis the latter comprises nonmaternal child care and parenting style, while the former consists of the mother's educational and recreational activities carried out with the child, labeled E_{ia} and R_{ia}, respectively. Assuming away the role of other conditioning variables for simplicity, the production function for skill (or

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[19]In addition to these methods, Del Boca, Monfardini, and Nicoletti (2012) use mother fixed effects on a subsample of siblings. Identification in Carneiro and Rodriguez (2009) relies on a selection-on-observables assumption through propensity score matching methods. Cunha and Heckman (2007 and 2008) and Cunha, Heckman and Schennach (2010) achieve identification of parental investment using cross-equation covariance restrictions, while Del Boca, Flinn and Wiswall (2014) identify their structural model with distributional and functional form assumptions on technology, preference, and wage processes.

test score) Y of child i observed at age a can be written as

$$Y_{ia} = \sum_{k=0}^{a} T_{i,a-k}\beta_{a-k} + \sum_{k=0}^{a} P_{i,a-k}\delta_{a-k} + \lambda Y_{i,a-1} + \epsilon_{ia}, \tag{1}$$

where ϵ is an error term that captures shocks to the child development path which are not under the parents' control as well as omitted variables (such as unobserved innate child endowments) and measurement error. This specification allows for the full history of observed inputs to affect child skills, that is, the inputs measured at the same time as the contemporaneous test score are observed as well as the inputs measured in earlier years. Furthermore, the inclusion of the one-period lagged outcome not only captures learning persistence but, as mentioned above, is also meant to control for unobserved ability (see Fiorini and Keane 2012). We refer to (1) as the *cumulative value-added* (CVA) model.

The CVA specification nests a number of models that have been widely used by economists and other social scientists as well as by developmental psychologists and epidemiologists. If $\lambda = 0$ and the effect of all past inputs are set to zero, then Y_{ia} is assumed to be affected only by current (age a) inputs. This is the *contemporaneous* model. If $\lambda = 0$ but all the observable lagged inputs in (1) are included, then we have a *cumulative* model. If instead in $\beta_{a-1} = \beta_{a-2} = \ldots = \beta_0 = 0$ and $\delta_{a-1} = \delta_{a-2} = \ldots = \delta_0 = 0$ but $\lambda \neq 0$, specification (1) boils down to what is known as the *value-added* model (VA). We shall estimate the CVA model and most of the alternative specifications that it nests.

Finally, in all value-added models, it is well known that measurement error attenuates the coefficient on lagged achievement, λ, and can bias the input coefficients, β and δ. A standard instrument in this context is the two-period lagged outcome, $Y_{i,a-2}$ (Arellano and Bond 1991; Andrabi et al. 2011). We label this specification *cumulative value-added instrumental variables* (CVA–IV) model.

4. Benchmark Estimates

Table 2 reports the estimated coefficients for maternal time inputs in the cognitive and non-cognitive production functions, respectively, by child age. Separating children by age means that we essentially estimate contemporaneous specifications at each age of the child. We present estimates only on the two inputs of interest, recreational time and educational time of the mother. The results refer to all children in the sample and do not distinguish boys from girls. The discussions about the effect of other inputs and estimates by gender are deferred to the next section.

For both outcomes, each time input has generally a greater influence at earlier ages

than at later ages. For instance, one unit increase (which corresponds to an increase of one standard deviation) in the educational time factor, E_a, at age 3 increases cognitive achievement significantly at that age by 0.13 of a standard deviation. By age 7 the increase in verbal skills is less than 0.01 of a standard deviation and it is not statistically significant. In the case of the recreational time factor, R_a, we find that a unit increase in this measure increases verbal skills by 0.07 of a standard deviation at age 3 but significantly *decreases* them by almost 0.05 of a standard deviation when the child is 7 years old. As for the non-cognitive outcome, the effect of E_a goes from 0.08 at age 3 to 0.05 at age 7, and that of R_a from 0.07 to 0.05 of a standard deviation. These coefficients are all statistically significant and statistically different from each other between age 3 and 7.

To get a sense of how important these estimates are, we compare them to the effect of maternal education. For instance, at age 3, having a mother with a university (or higher) degree is associated with 0.33 standard deviation increase in verbal skills as opposed to having a mother with no formal qualification. Having a mother with at least A level (or equivalent) qualifications but short of a university degree comes with an effect of 0.22 standard deviations. The 0.07 effect of maternal recreational time on verbal skill development is therefore about one-fifth of the impact of having a university-educated mother rather than a mother without any qualification. The educational time effect is nearly twice as large. If instead we compare children whose mothers have a university degree to those whose mothers have below-university qualifications, the effect of recreational time is about 60 percent of this 'marginal' effect of maternal education and that of educational time is 13 percent *larger*.

Does the reduction in the effect of maternal time inputs reflect a genuine decrease in the importance of maternal time in the production of child skills over the early life cycle? Or does it pick up some other aspects of the technological relationship between inputs and outcomes or parental responses to the human and health capital accumulation of the child?

To address these important questions we consider the estimates reported in Table 3. In this table we show the coefficients from a contemporaneous specification where all ages are pooled together and each outcome is regressed on the inputs and other regressors at the same age in column (i). This specification helps us link these new results to the estimates shown in Table 2. In columns (ii) and (iii) we report the results from two cumulative specifications that include either one or two lags of data on inputs respectively. The former considers the effects of inputs measured at age 3 on outcomes observed at age 5 and of inputs at age 5 on outcomes at age 7, while the latter specification allows for

the time inputs at ages 3 and 5 to affect outcomes at age 7. In column (iv) we present the estimates from the cumulative value-added (CVA) specification that, besides lagged inputs, includes also a one-period lagged dependent variable, Y_{a-1}. Finally column (v) shows a CVA–IV model in which the potential measurement error in the lagged dependent variable is addressed by instrumenting Y_{a-1} with Y_{a-2}.[20]

The estimates from the contemporaneous specification in column (i) are an average of the age-specific coefficients reported in Table 2. A unit increase in the factor of maternal time devoted to educational activities, E_a, significantly increases verbal skills by 0.06 and emotional development by 0.07 of their respective standard deviations. The corresponding effects of an increase in time devoted to recreational activities, R_a, are 0.02 and 0.07.

When the information on past inputs is included in column (ii), the estimated effects of current inputs decline considerably suggesting that omitting historical measures leads to an overstatement of the immediate impact of a unit increase in time inputs. In the case of the non-cognitive outcome (panel B) the contemporaneous impact is about 0.04 of a standard deviation for both inputs and it is statistically significant. Past inputs are important too, with an effect of 0.04 and 0.05 of a standard deviation for time in recreational and educational activities, respectively.

The evidence is slightly different for the cognitive outcome (panel A). The impact of contemporaneous inputs either becomes very small and loses significance (as in the case of educational time) or becomes negative (recreational time). These zero or negative coefficients might reflect feedback effects, whereby mothers invest less time in some activities when they see that their child does well cognitively. We shall explore this possibility in subsection 5.B. Past inputs in contrast play a more important role. This is especially true in the case of the lagged measures of time spent by the mother in educational activities, which increase the child's verbal skills by 0.10 of a standard deviation. These last results indicate that earlier maternal time investment in children has a *long shadow* on later child outcomes.

The same patterns for both cognitive and non-cognitive skills emerge when we consider the two-period lagged cumulative specification in column (iii). A unit increase in the (lagged) recreational time input at ages 3 and 5 increases verbal skills at age 7 by 0.053 ($=-0.000+0.053$) of a standard deviation and emotional skills by 0.059 ($=0.047+0.012$), while a similar unit increase in the educational time factor leads to increases of 0.17 and

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[20]We also estimated other models in which we used alternative instruments, e.g., the cognitive outcome at age $a-1$ was instrumented by the non-cognitive outcome at $a-2$, and viceversa. All the results, which are similar to those shown in Table 3, are not reported for convenience.

0.09 in the cognitive and non-cognitive outcomes, respectively.[21] When we add the impact of the time investments at age 7, the effects on emotional development increase slightly, but the effects on verbal skills become smaller, with the net effect of the recreational time input being negative. These results confirm what we saw in column (ii) and emphasize that the earliest inputs, i.e., those measured at age $a-2$ rather than those at $a-1$, have the strongest effects on current outcomes.

To see whether part of this long shadow is due to a problem of omitted lagged inputs we turn to the CVA models. In the case of verbal skills, the past outcome Y_{a-1} does play a substantial role, but past inputs continue to be by and large highly positively significant and their quantitative impact does not differ much from what we found in column (iii). Correcting for measurement error doubles the impact of the lagged outcome persistence coefficient from 0.25 to 0.53, consistent with attenuation bias due to measurement error, and reduces slightly the effect of all inputs (column (v)). These results therefore confirm the notion of a long shadow of early maternal time investments on the subsequent cognitive development of the child.

The evidence is different in the case of emotional development. Both CVA and CVA–IV specifications in columns (iv) and (v) reveal both a substantial persistence in non-cognitive outcomes and a general lack of impact of current and past time inputs. In this case, outcome persistence is particularly strong with a coefficient on Y_{a-1} going from 0.67 of a standard deviation in column (iv) to 0.89 in column (v) where we account for the potential of measurement error in the outcome variable.

To summarize, we emphasize three aspects of our findings. First, the greater the time mothers spend with their children the higher their cognitive and non-cognitive outcomes. The magnitude of these effects is comparable to some of the existing estimates found in other studies on time inputs. For instance, Fiorini and Keane (2012) find that one extra hour a week spent in educational activities with parents rather than in general care or in social activities increases verbal ability by 0.034 standard deviations.

Second, there is evidence of a long shadow of the effect of early maternal time inputs on later child outcomes. This is particularly strong in the case of educational inputs and verbal skill development, for which we find a cumulative effect that ranges between 0.14 and 0.07 standard deviations, depending on whether we rely on the two-period lagged cumulative specification or the CVA–IV model respectively. This result echoes the finding by Del Boca, Flinn, and Wiswall (2014), according to which the productivity of parental time inputs on child cognitive development declines with child age. In the case of emotional

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[21]Computing the effects only on the estimates that are statistically significant lead to similar results.

skills however there is no long shadow effect once we account for outcome persistence.

Third, outcome persistence is generally high, with lagged scores being more predictive of non-cognitive skills. In particular, between a quarter to a half of verbal skill achievement persists over time, while between two-thirds and 90% of emotional development persist across ages. This result, which is also emphasized by Fiorini and Keane (2012), is consistent with the idea that skill malleability differs at different ages and that it is likely to be greater for cognitive ability early in life, while non-cognitive abilities may be more malleable at later ages (Cunha et al. 2006). This in turn suggests that the production functions for cognitive and non-cognitive skills are very different.

5. Further Evidence

We present our additional findings in four subsections. First we examine the robustness of the benchmark estimates and consider the role played by missing inputs and measurement error in the maternal time inputs. Subsection B explores whether maternal time allocation decisions respond to realizations of past outcomes (feedback effects). In subsection C we analyze effect heterogeneity, while in the last subsection we discuss the results on the inputs included in the vector P in (1) — that is, formal child care and parenting style — which are included in all our specifications.

A. Robustness

We focus on two checks. First, our results may be sensitive to the inclusion of other variables that are important in the child human capital production function and that we have not included in our previous analysis. Some of these variables could be missing (unobserved) inputs and purchased goods and services, such as food, clothes, books, travels, medical services, tutors, and school quality.[22] As mentioned by Todd and Wolpin (2007) one way to account for missing data on such inputs is to substitute input demand equations — which represent the missing inputs as functions of current and past family income, prices, and preference shocks — in place of the unobserved inputs. This means that variables such as family income and mother's employment status will be included in the estimation. But their inclusion, which gives rise to a hybrid specification of the production function (Rosenzweig and Schultz 1983; Ermisch and Francesconi 2013), is problematic because they will pick up not just technological aspects of child development but also preference parameters. This would imply a nonzero correlation between observed

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[22]The discussion on the role of other two (observed) inputs, child care and parenting style, is deferred to a later subsection.

included inputs and the unobservables that govern child skill development.

In addition to the variables used in the benchmark specifications, our hybrid specification includes family income, maternal employment status, an indicator variable for whether the child is enrolled in a private school, an area deprivation index (in deciles), and primary school fixed effects. The first three variables are time varying, whereas the area deprivation score is measured at birth and kept fixed over time. The results of this analysis are reported in Table 4, where we only show the estimates on the two time inputs of interest and, for convenience, we only focus on the CVA–IV specification.[23]

Regardless of the outcome, the estimates from the hybrid specification are remarkably similar to those reported in column (v) of Table 3. This provides strong evidence that the estimated effects are robust to the inclusion of other predictors of child outcomes, even if these are correlated with the unobserved stochastic component of the child production functions.

A second problem we face is the presence of measurement error in the time inputs. The CVA–IV specification addresses the problem of potential measurement error in the lagged dependent variable, but clearly there can be measurement error in other variables, including the two maternal time inputs. If this measurement error were nonrandom and if it systematically increased as children aged (because, for instance, mothers find it more difficult to define joint activities with older children in the survey questionnaire), then the fading out of the effect of contemporaneous maternal time inputs seen in Tables 2 and 3 would reflect the presence of measurement error rather than a genuine decline in the importance of time inputs as children become older.

To account for this possibility we stratified children in the sample by quartiles defined on the 6 maternal time input distributions (i.e., 2 inputs $\times$ 3 age points). Movements across quartiles are arguably less sensitive to measurement error than arbitrarily small changes within a continuous index If measurement error were a major source of bias for any specific input at a given age, we then expect to detect large effects across quartiles on the one hand *and* no mean effect (shown in column (v) of Table 3) on the other. If instead measurement error were modest we expect to see very few inconsistencies. The results for both outcomes from the CVA–IV specification are presented in Table 5, in which the first (lowest) quartile is used as the base category.

For verbal skills, out of the 18 quartile input coefficients we find only one estimate that is inconsistent with its corresponding mean effect. This is the coefficient on the third

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[23]The number of observations is lower than in Table 3 mainly because school identifiers are available only for schools in England. The results are robust to the inclusion or exclusion of the school fixed effects however.

quartile of the contemporaneous educational time input, E_a measured at age 7, whose effect of –0.066 standard deviations is statistically significant while the overall mean effect is statistically indistinguishable from zero. Such effect however is not statistically different from those estimated at the two adjacent quartiles. A similar picture emerges for the non-cognitive outcome, for which we again detect one inconsistency (at the third quartile of E_{a-1} measured at age 5). We conclude that, although measurement error is present in our measures of maternal time inputs, it is not what is driving our main results.

Looking at quartiles allows us also to detect possible nonlinearities in the way in which time inputs influence child outcomes. The results in Table 5 demonstrate that most of the effect on verbal skills comes from the top half of the time input distributions. This suggests that only mothers who invest more intensively will reap the benefit of their investment. We instead cannot find any substantial nonlinearity in the effect on non-cognitive outcomes.

B. Feedback Effects

In Section 4 we document a fading out of the effect of maternal time inputs over the early life cycle. We also document the presence of long shadows in the effect of early maternal time inputs on later child outcomes.

One mechanism through which this can occur is that parents may use past outcomes as new information about their children's endowments and adjust their subsequent resource allocation decisions. This is what we refer to as *feedback effects*. Such decisions will be influenced by parental preferences and resource constraints as well as by the technology governing human capital production.[24]

To detect the possible presence of feedback effects, we follow an approach based on the "levels and differences" generalized method of moments (GMM) framework introduced by Arellano and Bover (1995) and extended by Blundell and Bond (1998).[25] A similar approach has been used in a different context by Andrabi et al. (2011) to analyze learning persistence in Pakistani public and private primary schools.

This GMM framework estimates a system of simultaneous equations in which the first is given by the standard (level) VA model

$$Y_{ia} = T_{ia}\beta + P_{ia}\delta + \lambda Y_{i,a-1} + \epsilon_{ia}, \tag{2}$$

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[24]Examining intrahousehold resource allocations, Rosenzweig and Wolpin (1995) and Del Bono, Ermisch, and Francesconi (2012) assume that parents learn about the endowment of a child at birth, and estimate parental responses to the feedback parents receive from older children in terms of the prenatal investment in children who are not born yet.

[25]See Arellano (2003) for an excellent review of this and other related models.

where β and δ are input effects that are constant across ages, $\epsilon_{ia} = v_{ia} + \mu_i$, v_{ia} is a transitory error term, and μ_i represents unobserved fixed child endowments (or innate ability). The second component of the system is a (differenced) equation of the form

$$Y_{ia} - Y_{i,a-1} = \beta(T_{ia} - T_{i,a-1}) + \delta(P_{ia} - P_{i,a-1}) + \lambda(Y_{i,a-1} - Y_{i,a-2}) + (v_{ia} - v_{i,a-1}). \quad (3)$$

Our instruments are past inputs for equation (2) and twice lagged outcomes as well as past inputs for equation (3). This allows for current inputs to be correlated with past disturbances, and therefore captures potential correlations between earlier child outcome shocks and parental decisions over current inputs. In the presence of feedback effects we expect to observe both a reduction in the persistence parameter, λ, and an increase in the time input coefficients.[26]

Table 6 reports the GMM estimates obtained from three alternative sets of instruments for Y_{a-1} for each of the two outcomes. Specifically, the instrument used in column (ii) is the two-period lagged test score, Y_{a-2} (age 3), a two-period lagged test score on an alternative outcome is used in column (iii),[27] while in column (iv) we use all the scores available in the MCS at $a - 3$ (when the child was aged 9 months), i.e., the Denver Developmental Screening Test and the Carey Infant Temperament Scale. The VA–IV estimates reported in column (i), which are computed using the two-period lagged outcome as instrument for Y_{a-1}, are reported for comparison.[28]

Consider first the results on the cognitive outcome. We find evidence that suggests the presence of strong feedback effects. The persistence coefficient goes down slightly from 0.56 in the VA–IV specification in column (i) to between 0.44 and 0.54. In all specifications the time input coefficients increase considerably, suggesting that mothers are likely to respond to earlier outcome shocks by adjusting the time they devote to recreational and educational activities with their children. The effect of the educational time input is around 0.03–0.04 standard deviations, and the coefficient on the recreational time input becomes positive, albeit statistically insignificant.

The same, perhaps ever clearer, findings emerge when we look at emotional skills. In this case, the educational time input estimates range from 0.03 to 0.06 standard deviations and the recreational time input effects go from 0.01 to 0.06 standard deviations. Both sets of estimates represent a substantial increase with respect to the VA–IV results

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[26]More details are in Andrabi et al. (2011).

[27]More specifically, we use the Braken test score for school readiness at age 3 and mother's reported measures of child self regulation at age 3 (emotional dysregulation, independence and self regulation) to instrument the one-period lagged cognitive and non-cognitive outcomes, respectively.

[28]Using the other instruments for the lagged outcome to estimate the VA–IV model in column (i) does not affect the results on maternal time inputs.

reported in column (i). At the same time, the effect of outcome persistence is reduced substantially. These results provide evidence that non-cognitive skill malleability is likely to be important also in the early stages of the child's life cycle, and not only when the child is older as previous research has emphasized and as we documented in Section 4.

C. Heterogeneity

In this subsection we explore whether our benchmark estimates are heterogenous across subgroups, i.e. whether there is evidence that the production functions for cognitive and non-cognitive skills are different for different subgroups of the population. For the sake of brevity we only focus on the results from CVA–IV specifications, the benchmark estimates of which are shown in column (v) of Table 3. The results from the other specifications are qualitatively similar. We also concentrate on the effects on verbal skills because we cannot find any relevant difference in the case of emotional skills. The estimates are reported in Table 7.

Child gender — The negative impact of the mother's contemporaneous recreational time on cognitive development at age 7, R_a, is stronger for girls than for boys. In fact, boys (but not so much girls) seem to benefit from earlier maternal investment in recreational activities. Long shadow effects of earlier educational investments instead appear to benefit girls and boys quite similarly.

Mother's education — We distinguished two groups of children based on their mother's education, those whose mother attained a qualification above the minimum school leaving age qualification and all the other children. Early educational time investments (at ages 3 and 5) by educated mothers lead to an increase in verbal skills at age 7 that is significantly greater than that achieved by children whose mothers are less educated (0.12 versus 0.075). But the penalty associated with current (age 7) recreational investments is also greater for children of more educated mothers (–0.11 versus –0.05).

Furthermore, less than half of cognitive learning persists by age 7 among children whose mothers have higher educational qualifications, while learning persistence is almost 10 percentage point greater among children whose mothers have lower-level qualifications. Although lower persistence might indicate a greater rate at which learning is lost over time, it might also reflect higher skill malleability, with verbal skills being more responsive to inputs.

Birth order — The joint positive effect of early educational time at ages 3 and 5 is similar for firstborn and higher birth order children at about 0.08 standard deviations.

So is the negative impact of contemporaneous recreational time. But firstborn children seem to benefit more from early (age 3) maternal time investment in recreational and educational activities, while the same investment has no consequences on higher parity children. Almost three-fifths of verbal skills persist among higher parity children, while learning persistence is much lower at about 43 percent among firstborn.

Taken together, we find therefore evidence of heterogeneous functions for the production of verbal skills, especially across children of mothers with different educational qualifications and between firstborn and higher birth order children.

D. Other Parental Inputs

In this section we examine the impact of two other (observed) inputs included in our basic specifications. These are nonmaternal child care – formal (paid) and informal (unpaid) — and an index of parenting style, which assumes higher values when stricter family rules about bed and meal times, and exposure to TV and computer are enforced.

Table 8 reports the estimates from the cumulative specification with two lags of data on inputs and the CVA–IV model. The corresponding coefficients on maternal time inputs and persistence are shown in columns (iii) and (v) of Table 3, respectively. Notice that the exclusion of these two inputs (nonmaternal child care and parenting style) from our benchmark specifications does not affect any of our previous results.

Paid child care is correlated with neither of the two outcomes, except for the case of child care arrangements at age 7 on verbal skills at age 7, where the evidence points to a negative effect of 0.07 standard deviations. The same no-correlation result emerges in the case of informal child care arrangements. Here however, according to the cumulative specification, informal child care at age 3 has a positive effect of 0.07 and 0.09 standard deviations on age 7 verbal and emotional skills, respectively. But accounting for outcome persistence as in the CVA–IV model eliminates these effects. These findings are in line with much of the evidence discussed in Blau and Currie (2006) indicating that the effect of non-parental child care is generally insignificant, and sometimes wrong-signed (see also the more recent studies by Bernal [2008] and Bernal and Keane [2010]).

In the case of parenting style, we find that our index of family routine and discipline is associated with a positive effect on verbal skill accumulation. For example, taking the CVA–IV estimates, a unit increase in the index at ages 3 and 5 leads to a 0.03 (=−0.003+0.033) standard deviation increase in verbal abilities by age 7. The same increase has a small negative (and statistically insignificant) impact on emotional skills. It is worth noting that in the cumulative model where lagged outcomes are excluded, the

contemporaneous and cumulative effects of parenting style on the cognitive outcome are twice as large (around 0.06 standard deviations), and those on the non-cognitive outcome are positive, substantially larger (about 0.12 standard deviations), and significant. This reiterates the importance of persistence in the early formation of emotional skills.

Overall, these results confirm the evidence presented in other studies that use data from the MCS (e.g., Ermisch 2008; Kelly et al. 2011). But differently from the evidence on Australian children found by Fiorini and Keane (2012), they also indicate that parenting style can affect cognitive outcomes quite substantially.

Finally, it is useful to report on the impacts of family income and maternal employment, which have received most of the attention in prior work. We comment on results obtained from the CVA–IV model discussed in subsection 5.A (hybrid specification), but do not report the estimates because of space concerns. In the case of income, we find that a 10 percent increase in equivalized weekly family income (corresponding approximately to £45 in 2004 prices) is associated with a statistically significant increase in verbal skills at age 7 of about 0.01 standard deviations, which is arguably a quantitatively small impact. The same increase in income does not have any effect on emotional skills. These results are consistent with those found, among others, by Mayer (1997), Blau (1999), Dooley and Stewart (2007), and Fiorini and Keane (2012). Maternal employment instead has no impact on the cognitive outcome and a positive impact of about 0.03–0.04 standard deviations on the non-cognitive outcome, although this effect is not statistically significant.

These results document that maternal time inputs can be just as important for child development as inputs that have generally received more attention in previous studies. They also confirm our previous observation that the production functions for cognitive and non-cognitive skills are very different.

6. Conclusions

Many studies stress the importance of maternal time in shaping early child outcomes. But very few analyze the direct effect of time inputs on human capital production. The main contribution of the paper is to provide this analysis, focusing for the first time on Britain and examining a large representative sample of children and their families.

Unlike some recent studies that look at time use data, we derive age- and child-specific measures of the time mothers spend with their children using information on the type and frequency of parental activities. We perform a validation exercise, showing that our measures of educational and recreational time correlate with observed maternal

characteristics, such as education and employment status, in the same way as direct measures derived from time diaries.

We draw attention to five findings. First, the more time mothers spend with their children the higher cognitive and non-cognitive outcomes over ages 3 to 7. This effect is quantitatively large and corresponds to 20–40 percent of the magnitude of the effect of having a mother with a university degree as opposed to having a mother with no qualification.

Second, there is evidence that early time investments are more productive than later time investments. This effect is particularly strong in the case of verbal skills, but disappears in the case of emotional skills when we account for outcome persistence. One explanation of this result is the presence of feedback effects, whereby parents respond to past outcomes by adjusting their current resource allocation decisions. Such effects are present in the production of both cognitive and non-cognitive skills, suggesting that non-cognitive skill malleability is likely to be important also in the early stages of the child life cycle, and not just when the child is older as previous research has emphasized.

Third, outcome persistence is generally high, with lagged scores being more predictive of non-cognitive skills. Indeed, two-thirds to 90% of emotional skill differences persist between age 3 and age 7. Fourth, we find a fair amount of heterogeneity along mother's education and child birth order. For instance, early educational time investments (at ages 3 and 5) by educated mothers lead to an increase in verbal skills at age 7 that is significantly greater than that achieved by children whose mothers are less educated. Similarly, early investments in firstborn children are more productive than early investments in subsequent children. Fifth, the effect of nonmaternal child care is generally small and insignificant, while a parenting style based on family routines and discipline leads to greater verbal skill accumulation but does not influence emotional development.

Our estimates emphasize that maternal time inputs have a noticeable influence on early child development and mothers are likely to change time investments over the early years of life of their children in response to earlier outcomes. When this is the case, the socioeconomic gradient in outcomes observed at later points of children's life may be driven by variation between *and* within families. This limits the scope for later interventions that aim to affect mother's time availability or inform them about the effectiveness of their time investments.

Although this study represents one of the first attempts to estimate early production functions for Britain, there are a few desirable extensions that rely on data improvements. First, the MCS does not collect information on maternal time investments between birth

and age 3. Given that early investment casts a long shadow on later outcomes, future data collection exercises, such as the new UK birth cohort (Life Study), might want to pay more attention to this critical developmental period. Second, examining the impact of parental time inputs on child outcomes beyond age 7 would provide us with a useful picture of the dynamic evolution of skill formation. Unfortunately, the latest sweep of the MCS (when children are 11 years old) collects little information on the time spent by parents on activities with children. Third, our study disregards the role played by fathers. This is due to data unavailability, as fathers nonresponse rates are extremely high. Knowing the time contribution of fathers and whether this complements or substitutes mother's time inputs would improve our understanding of early child development.

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Figure 1: Distribution of the Cognitive Outcome by Child Age
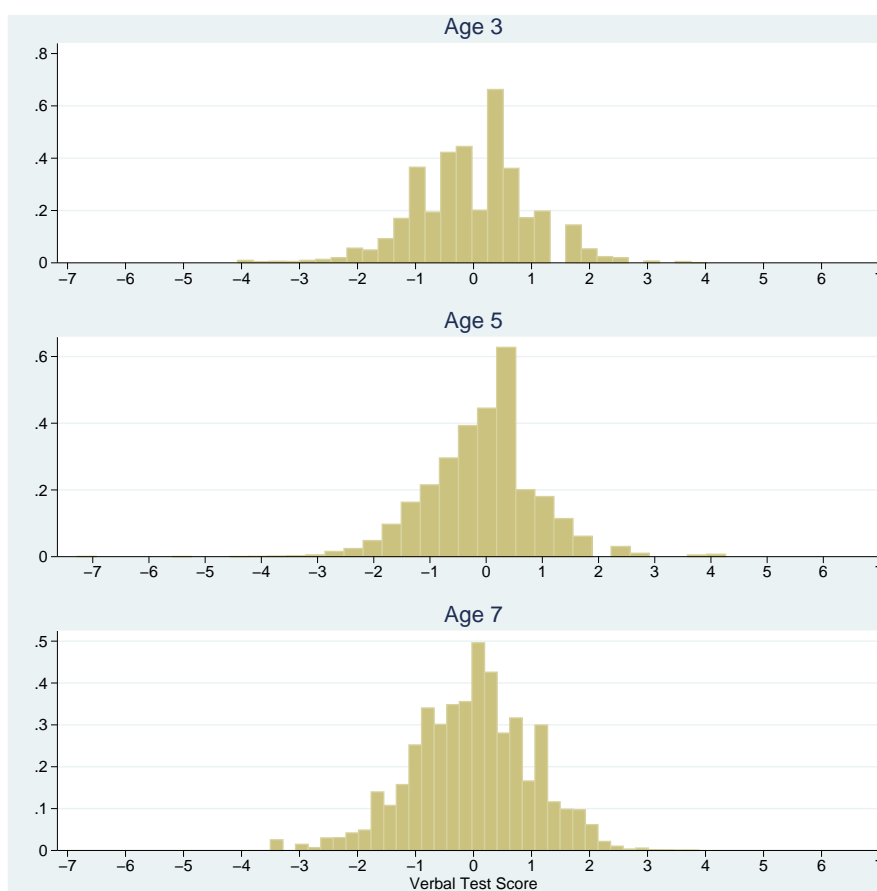
Source: UK Millennium Cohort Study.
Notes: The cognitive outcome is measured by verbal test scores from the British Ability Scales (BAS) in Naming Vocabulary at ages 3 and 5 and the BAS in Word Reading at age 7. See subsection 2.B for an explanation of how these measures have been constructed using MCS data.

Figure 2: Distribution of the Non-Cognitive Outcome by Child Age
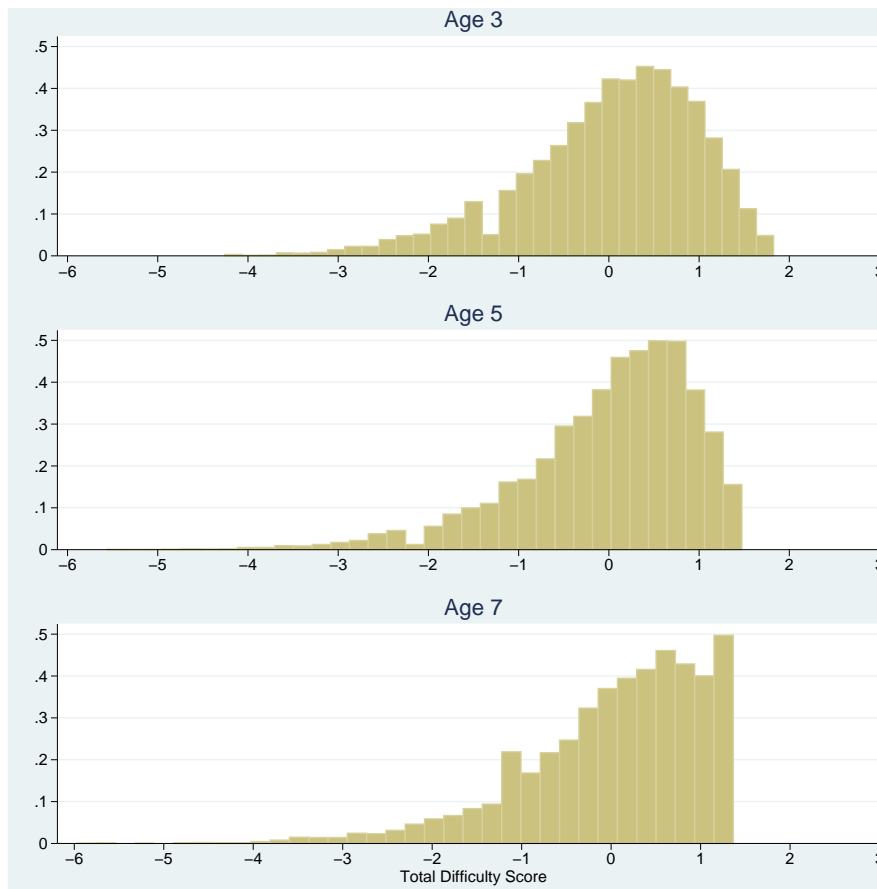
Source: UK Millennium Cohort Study.

Notes: The non-cognitive (emotional skill) outcome is measured by the Total Difficulty Score obtained from the Strengths and Difficulties Questionnaires. See subsection 2.B for an explanation of how these measures have been constructed using MCS data.

Figure 3: Distribution of the Educational and Recreational Time Inputs by Child Age
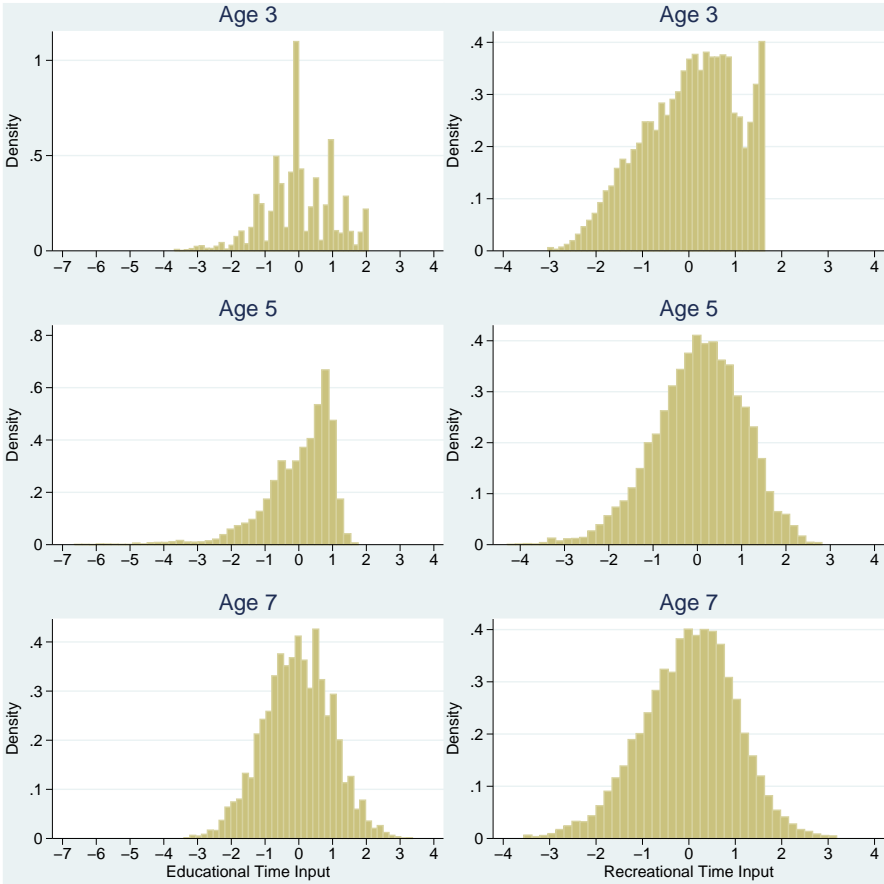
Figure 4: Relationship between Maternal Time Inputs and Maternal Education and Employment Status
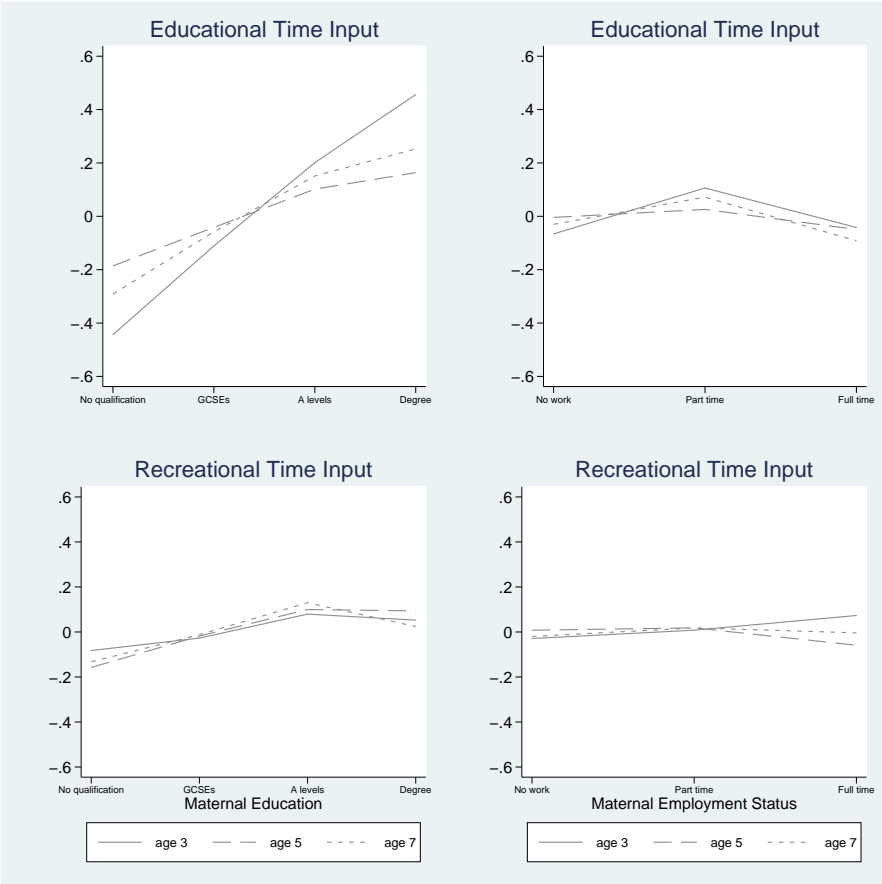
Figure 5: Relationship between Child Care Time and Maternal Education and Employment Status
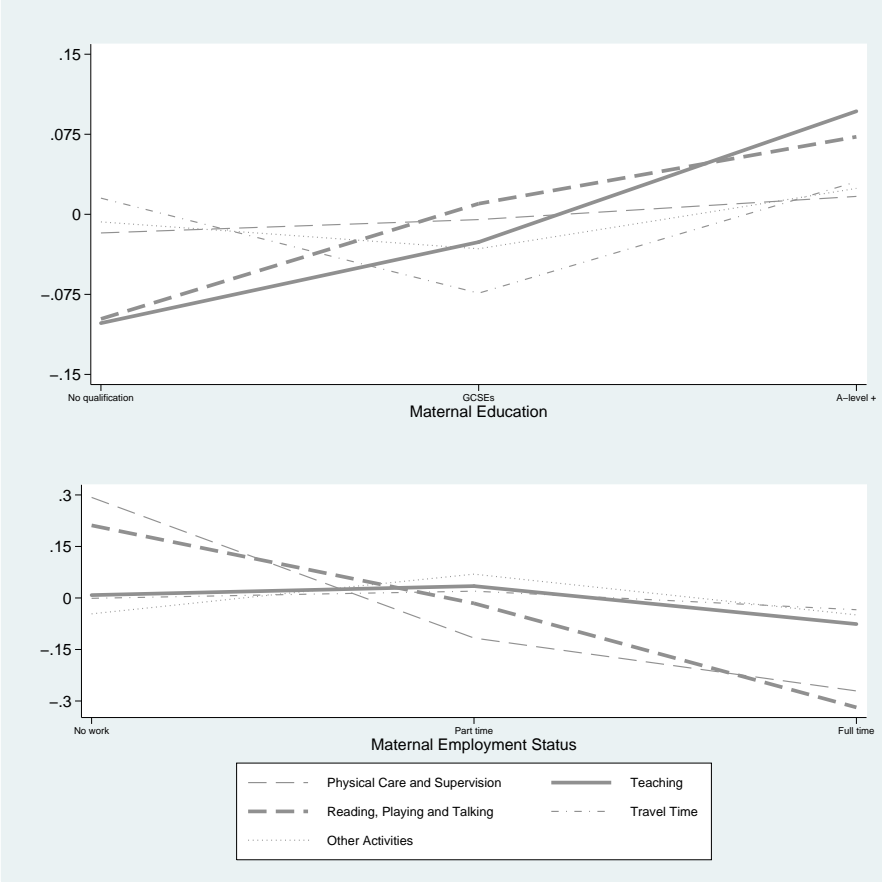
Notes: Each measure of maternal time use is standardized to have mean 0 and standard deviation 1. Unstandardized measures are reported in Appendix Table A3.

Table 1. Summary Statistics by Child Age

	Age 3	Age 5	Age 7
Outcomes			
Cognitive (verbal skill score)[a]	75.937	110.936	110.546
	(16.205)	(13.866)	(28.705)
Non-cognitive (Total Difficulty Score)[a]	30.994	33.297	33.112
	(4.933)	(4.545)	(5.046)
Inputs			
Educational time[b]	0.000	0.000	0.000
	(1.000)	(1.000)	(1.000)
Recreational time[b]	0.000	0.000	0.000
	(1.000)	(1.000)	(1.000)
Nonmaternal child care arrangement			
None	0.584	0.530	0.452
Informal (unpaid)	0.116	0.281	0.266
Formal (paid)	0.187	0.171	0.265
Missing	0.113	0.018	0.017
Parenting style[b]	0.000	0.000	0.000
	(1.000)	(1.000)	(1.000)
Time-invariant controls			
Male	0.498	0.498	0.498
Firstborn	0.394	0.394	0.394
White British	0.907	0.907	0.907
Birth weight (in grams)	3405.9	3405.9	3405.9
	(559.4)	(559.4)	(559.4)
Child born before 37 weeks	0.051	0.051	0.051
Mother's education			
No qualification	0.214	0.214	0.214
GCSE/O-level (or equivalent)	0.369	0.369	0.369
A level or more but below university degree	0.214	0.214	0.214
University degree or higher qualification	0.203	0.203	0.203
Mother's age at birth	30.2	30.2	30.2
	(5.0)	(5.0)	(5.0)
Time-varying controls			
Child's age at interview (in days)	1138.7	1900.6	2637.6
	(67.4)	(86.2)	(87.8)
Presence of siblings	0.772	0.856	0.890
Single parent family	0.127	0.151	0.171
Child attends private school	0.000	0.044	0.044
Mother's employment status			
No work	0.485	0.408	0.351
Part time	0.361	0.410	0.428
Full time	0.154	0.182	0.221
Equivalized weekly family income[c]	381.9	418.9	482.2
	(231.2)	(237.4)	(260.4)
Observations (unweighted)	8,129	8,129	8,129

Source: UK Millennium Cohort Study.

Notes: Figures are means (standard deviations for the continuous variables are in parentheses). All figures are weighted using MCS sampling weights.

[a] Non-standardised.

[b] Obtained through principal component analysis.

[c] Deflated using the Consumer Price Index (base=2004)

Table 2. Coefficients on Maternal Time Inputs for Cognitive and Non-Cognitive Outcomes by Child Age

	Verbal Skills			Emotional Skills		
	Age 3	Age 5	Age 7	Age 3	Age 5	Age 7
E_a	0.127**	0.044**	0.004	0.079**	0.076**	0.045**
	(0.011)	(0.010)	(0.011)	(0.012)	(0.012)	(0.011)
R_a	0.067**	0.034**	−0.049**	0.074**	0.097**	0.048**
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
R^2	0.214	0.174	0.164	0.163	0.127	0.110
Observations[a]	8,129	8,129	8,129	8,129	8,129	8,129

Source: UK Millennium Cohort Study.

Notes: Standard errors are in parentheses. *E*=educational time input; *R*=recreational time input. The figures are obtained from a contemporaneous specification estimated at each child age using MCS sampling weights. Each regression includes indicator variables for nonmaternal child care and parenting style. Additional controls are child sex, birth weight, ethnicity, birth order, whether the child was born pre-term or not, region of birth, mother's age at birth (and its square), mother's education, child age at interview (and its square), whether the child lives in a single-parent household, and presence of siblings.

[a] Number of children.

* significant at 5% level; ** significant at 1% level.

Table 3. Coefficients on Maternal Time Inputs for Cognitive and Non-Cognitive Outcomes by Model Specification

	(i) Contemporaneous	(ii) Cumulative (1-period lag)	(iii) Cumulative (2-period lag)	(iv) CVA	(v) CVA–IV
A. Verbal Skills					
E_a (age 7)	0.056**	0.002	−0.027*	−0.023*	−0.019
	(0.007)	(0.008)	(0.011)	(0.011)	(0.012)
R_a (age 7)	0.020**	−0.032**	−0.090**	−0.083**	−0.075**
	(0.007)	(0.009)	(0.013)	(0.013)	(0.013)
E_{a-1} (age 5)		0.100**	0.060**	0.054**	0.048**
		(0.008)	(0.011)	(0.011)	(0.011)
R_{a-1} (age 5)		0.019*	−0.000	−0.004	−0.008
		(0.008)	(0.014)	(0.013)	(0.014)
E_{a-2} (age 3)			0.106**	0.075**	0.042**
			(0.012)	(0.012)	(0.013)
R_{a-2} (age 3)			0.053**	0.043**	0.032**
			(0.011)	(0.011)	(0.011)
λ (age 5)				0.254**	0.527**
				(0.011)	(0.029)
R^2	0.147	0.150	0.187	0.238	0.178
Observations[a]	24,387	16,258	8,129	8,129	8,129
B. Emotional Skills					
E_a (age 7)	0.068**	0.042**	0.022*	0.008	0.003
	(0.007)	(0.008)	(0.011)	(0.009)	(0.009)
R_a (age 7)	0.070**	0.044**	−0.000	0.006	0.009
	(0.007)	(0.009)	(0.014)	(0.011)	(0.011)
E_{a-1} (age 5)		0.054**	0.034**	−0.001	−0.013
		(0.008)	(0.012)	(0.009)	(0.009)
R_{a-1} (age 5)		0.038**	0.047**	−0.001	−0.017
		(0.008)	(0.014)	(0.011)	(0.011)
E_{a-2} (age 3)			0.056**	0.019*	0.007
			(0.013)	(0.009)	(0.010)
R_{a-2} (age 3)			0.012	−0.006	−0.011
			(0.012)	(0.009)	(0.009)
λ (age 5)				0.669**	0.894**
				(0.010)	(0.018)
R^2	0.127	0.126	0.128	0.513	0.470
Observations[a]	24,387	16,258	8,129	8,129	8,129

Source: UK Millennium Cohort Study.
Notes: Standard errors are in parentheses. See equation (1) for notation and Section 3 for an explanation of the different models. See the notes to Table 2 for further details.
[a] Number of child-wave observations. In the last three columns, this corresponds to the number of children.
* significant at 5% level; ** significant at 1% level.

Table 4. Coefficients on Maternal Time Inputs from a CVA–IV Hybrid Specification

	Verbal Skills	Emotional Skills
E_a (age 7)	−0.027*	0.004
	(0.013)	(0.010)
R_a (age 7)	−0.079**	0.014
	(0.015)	(0.013)
E_{a-1} (age 5)	0.048**	−0.015
	(0.013)	(0.011)
R_{a-1} (age 5)	−0.005	−0.022
	(0.015)	(0.013)
E_{a-2} (age 3)	0.041**	0.006
	(0.014)	(0.011)
R_{a-2} (age 3)	0.033*	−0.009
	(0.013)	(0.010)
λ (age 5)	0.492**	0.904**
	(0.032)	(0.021)
R^2	0.227	0.483
Observations[a]	6,490	6,490

Source: UK Millennium Cohort Study.

Notes: Standard errors are in parentheses. The figures are obtained from a hybrid specification which adds to the CVA–IV model of Table 3 column (v) the following variables: family income, maternal employment status, and index of area deprivation, whether the child attends a private (fee-paying) school, and school fixed effects. See the notes to Table 2 for additional details.

[a] Number of children.

* significant at 5% level; ** significant at 1% level.

Table 5. Coefficients on Maternal Time Inputs for Cognitive and Non-Cognitive Outcomes by Input Quartile

		Verbal Skills by Input Quartile			Emotional Skills by Input Quartile		
		Second	Third	Fourth	Second	Third	Fourth
E_a	(age 7)	−0.015	−0.066*	−0.025	0.010	0.014	0.010
		(0.031)	(0.031)	(0.031)	(0.024)	(0.024)	(0.025)
R_a	(age 7)	−0.026	−0.112**	−0.162**	0.020	0.012	0.034
		(0.031)	(0.033)	(0.035)	(0.024)	(0.026)	(0.028)
E_{a-1}	(age 5)	0.078*	0.090**	0.115**	−0.015	−0.050*	−0.041
		(0.031)	(0.032)	(0.031)	(0.024)	(0.024)	(0.025)
R_{a-1}	(age 5)	−0.005	−0.021	0.029	−0.030	−0.027	−0.055
		(0.031)	(0.033)	(0.036)	(0.024)	(0.026)	(0.029)
E_{a-2}	(age 3)	−0.005	0.111**	0.075*	0.014	0.026	0.005
		(0.032)	(0.034)	(0.035)	(0.025)	(0.026)	(0.026)
R_{a-2}	(age 3)	0.017	0.051	0.080*	−0.016	−0.017	−0.035
		(0.030)	(0.031)	(0.033)	(0.024)	(0.024)	(0.025)
λ	(age 5)		0.532**			0.895**	
			(0.029)			(0.018)	
R^2			0.176			0.470	
Observations			8,129			8,129	

Source: UK Millennium Cohort Study.

Notes: Standard errors are in parentheses. The figures are obtained using a CVA–IV model as in Table 3 column (v). See notes to Table 2 for additional details.

* significant at 5% level; ** significant at 1% level.

Table 6. Feedback Effects — GMM Estimates

		Verbal Skills				Emotional Skills			
		VA–IV	GMM			VA–IV	GMM		
		(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
E_a	(age 7)	−0.000	0.041**	0.037**	0.034**	0.000	0.061**	0.041**	0.028**
		(0.011)	(0.009)	(0.009)	(0.009)	(0.009)	(0.010)	(0.010)	(0.010)
R_a	(age 7)	−0.058**	0.010	0.007	0.006	−0.002	0.059**	0.030**	0.011
		(0.011)	(0.009)	(0.008)	(0.008)	(0.009)	(0.010)	(0.009)	(0.009)
λ	(age 5)	0.560**	0.439**	0.530**	0.535**	0.886**	0.381**	0.641**	0.786**
		(0.028)	(0.027)	(0.043)	(0.045)	(0.017)	(0.026)	(0.035)	(0.039)
Observations[a]		8,129	8,129	8,129	7,928	8,129	8,129	8,129	7,928

Source: UK Millennium Cohort Study.

Notes: Standard errors are in parentheses. The estimates in column (i) are from a VA–IV specification which is computed using the two-period lagged outcome as instrument for Y_{a-1}. The next columns show GMM estimates where the lagged outcome is instrumented using the two-period lagged test score in column (ii), a two-period lagged test score on an alternative outcome in column (iii), and all the scores available at 9 months in column (iv). See Sections 3 and 5.B for more details. See also the notes to Table 2 for the list of additional inputs and time-varying controls.

[a] Number of children.

* significant at 5% level; ** significant at 1% level.

Table 7. Heterogenous Effects of Maternal Time Inputs on the Cognitive Outcome

		Child gender		Maternal education		Birth order	
		Girls	Boys	Low	High	Firstborn	Second+
E_a	(age 7)	−0.030*	−0.010	−0.008	−0.053**	−0.035	−0.008
		(0.015)	(0.018)	(0.016)	(0.017)	(0.018)	(0.015)
R_a	(age 7)	−0.104**	−0.051*	−0.054**	−0.114**	−0.066**	−0.077**
		(0.018)	(0.020)	(0.017)	(0.023)	(0.022)	(0.017)
E_{a-1}	(age 5)	0.052**	0.044**	0.031*	0.069**	0.020	0.059**
		(0.015)	(0.017)	(0.014)	(0.018)	(0.019)	(0.014)
R_{a-1}	(age 5)	0.026	−0.036	−0.011	0.009	−0.020	0.003
		(0.019)	(0.021)	(0.018)	(0.023)	(0.023)	(0.018)
E_{a-2}	(age 3)	0.035*	0.053**	0.044**	0.050*	0.060**	0.026
		(0.017)	(0.019)	(0.017)	(0.020)	(0.020)	(0.016)
R_{a-2}	(age 3)	0.022	0.042*	0.023	0.043*	0.069**	0.011
		(0.015)	(0.017)	(0.016)	(0.017)	(0.018)	(0.015)
λ	(age 5)	0.509**	0.540**	0.574**	0.480**	0.425**	0.594**
		(0.042)	(0.042)	(0.039)	(0.045)	(0.044)	(0.040)
R^2		0.203	0.170	0.132	0.123	0.174	0.170
Observations		4,096	4,033	4,571	3,558	3,230	4,899

Source: UK Millennium Cohort Study.

Notes: Standard errors are in parentheses. The figures are obtained from a CVA–IV model (as in Table 3 column (v)). 'Low' maternal education corresponds to GCSE/O level qualifications and below, while 'high' maternal education corresponds to A level or higher qualifications. See notes to Table 2 for further details.

* significant at 5% level; ** significant at 1% level.

Table 8. Coefficients on Nonmaternal Child Care and Parenting Style

	Verbal Skills		Emotional Skills	
	Cumulative (2-period lag)	CVA–IV	Cumulative (2-period lag)	CVA–IV
Formal (paid) child care				
Age 7	−0.075**	−0.071*	−0.035	0.009
	(0.028)	(0.028)	(0.029)	(0.023)
Age 5	−0.010	−0.015	0.015	−0.022
	(0.033)	(0.033)	(0.033)	(0.025)
Age 3	0.052	0.007	0.043	−0.030
	(0.029)	(0.030)	(0.028)	(0.022)
Informal (unpaid) child care				
Age 7	0.003	−0.001	0.016	0.023
	(0.029)	(0.029)	(0.029)	(0.022)
Age 5	−0.027	−0.029	−0.017	−0.008
	(0.027)	(0.027)	(0.028)	(0.021)
Age 3	0.072*	0.036	0.094**	−0.005
	(0.034)	(0.034)	(0.033)	(0.026)
Parenting style				
Age 7	0.012	0.022*	0.025*	0.003
	(0.012)	(0.011)	(0.012)	(0.009)
Age 5	−0.002	−0.003	0.010	0.001
	(0.012)	(0.012)	(0.012)	(0.009)
Age 3	0.049**	0.033**	0.091**	−0.009
	(0.012)	(0.012)	(0.012)	(0.009)

Source: UK Millennium Cohort Study.

Notes: Standard errors are in parentheses. The figures are obtained from the cumulative specification with one- and two-period lagged inputs and from the CVA–IV model presented in Table 3, columns (iii) and (v), respectively. 'Age 7' indicates the effects of contemporaneous inputs, while 'Age 5' and 'Age 3' indicate the effects of one- and two-period lagged inputs, respectively. See the notes to Table 2 for further details.

* significant at 5% level; ** significant at 1% level.

Appendix Table A1. Maternal Time Inputs: Factor Loadings

	Educational	Recreational
Age 3		
Mother reads to child	**0.713**	0.086
Anyone at home takes child to the library	**0.826**	-0.202
Anyone at home takes child to play sport outdoors	0.231	0.162
Anyone at home teaches the child to paint or draw	-0.069	**0.527**
Anyone at home teaches songs and nursery rhymes	0.110	**0.707**
Anyone at home teaches numbers or counting	-0.010	**0.784**
Anyone at home helps with letters of alphabet	-0.008	**0.681**
% total variance explained by each factor	16.3	29.0
% total variance explained by both factors		45.4
Age 5		
Mother reads to the child	**0.701**	**0.297**
Mother tells stories (not from a book)	-0.053	**0.606**
Mother goes to the park or playground	-0.016	**0.682**
Mother plays games indoors	0.116	**0.665**
Mother paints or draws with the child	0.057	**0.677**
Mother plays music or sings songs with the child	-0.082	**0.609**
Mother goes to the park	0.016	**0.499**
Anyone at home helps the child with reading[a]	**0.841**	0.057
Mother attended meeting at school[b]	0.192	-0.059
% total variance explained by each individual factor	12.4	29.5
% total variance explained by both factors		41.9
Age 7		
Mother reads to the child	**0.492**	**0.361**
Mother tells stories (not from a book)	-0.024	**0.566**
Mother goes to the park or playground	0.010	**0.686**
Mother plays games indoors	0.028	**0.715**
Mother paints or draws with the child	-0.008	**0.703**
Mother plays music or sings songs with the child	-0.012	**0.534**
Mother goes to the park	-0.024	**0.523**
Anyone at home helps the child with homework[c]	**0.683**	-0.018
Mother participates in school activities[d]	**0.535**	0.060
Mother attended meeting at school[b]	**0.444**	-0.123
% total variance explained by each individual factor	11.1	26.3
% total variance explained by both factors		37.4

Source: UK Millennium Cohort Study.

Notes: Loadings larger than 0.25 in absolute value are in bold. Unless otherwise indicated, respondents were asked to indicate how frequently they carried out these activities on a 6- or 8-point scale, ranging from "every day" to "none at all". See subsection 2.C for details.

[a] Includes homework.

[b] 0/1 variable.

[c] Homework (measured in hours) is divided into 4 categories: less than 1/2 an hour; up to 1 hour; up to 2 hours; more than 2 hours.

[d] Refers to the total number of activities.

Appendix Table A2: Maternal Time Spent in Child Care Activities (Minutes per Day)

	All activities	Physical care and supervision	Teaching	Reading, playing, and talking	Travel time	Other activities
Maternal education						
No qualification	104.3	70.5	3.2	25.7	4.5	0.3
GCSE/O level qualifications[a]	110.2	71.5	4.9	30.5	2.9	0.3
A level or higher qualification	119.6	73.3	7.7	33.3	4.8	0.4
Maternal employment status						
No work	145.3	95.6	5.7	39.6	4.2	0.2
Part time	103.4	62.5	6.3	29.4	4.6	0.6
Full time	73.5	50.1	3.8	15.8	3.6	0.2

Source: 2000-01 UK Time Use Survey.
Note: Mean values of time (minutes per day) spent by mothers in child care activities.
[a] Includes all equivalent qualifications short of A level attainment.

Appendix Table A3. Parenting Style: Factor Loadings

Family rules	Age 3	Age 5	Age 7
Bedtimes	0.809	0.371	0.263
Mealtimes	0.788		
TV times	0.410	0.736	0.772
Computer times		0.751	0.766
% total variance explained	48.1	41.4	41.7

Source: UK Millennium Cohort Study.
Notes: Factor loadings of parenting styles. The respondents were asked to indicate how frequently their child went to bed at a regular time, ate at a regular time and how many hours of TV or computer time he/she was allowed during a normal weekday. All variables are categorical and assume values from 1 to 4, with higher values indicating stricter rules.