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EARLY MATERNAL TIME INVESTMENT AND EARLY CHILD OUTCOMES*

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Using large longitudinal survey data from the UK Millennium Cohort Study, this article estimates the relationship between maternal time inputs and 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 long-term effects of early maternal time inputs on later outcomes, especially in the case of cognitive skill development. In the case of non-cognitive development, the evidence of this long-term impact disappears when we account for skill persistence.

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

Much recent research has found that skills measured in pre-school years are strong predictors of later life outcomes (Keane and Wolpin, 1997; Cameron and Heckman, 1998; Cunha *et al.*, 2006; Conti *et al.*, 2016) 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, 2008; Cunha *et al.*, 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, parental leave entitlements and neighbourhood characteristics (Haveman and Wolfe, 1995; Ermisch and Francesconi, 2001, 2013; Brooks-Gunn *et al.*, 2002; Ruhm, 2004; Berger *et al.*, 2005; Baker and Milligan, 2010; Liu and Skans, 2010; Almond and Currie, 2011*a,b*; Björklund and Salvanes, 2011; Havnes and Mogstad, 2011; Dustmann and Schönberg, 2012; Ermisch *et al.*, 2012; Dahl

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[1] Interestingly this was already a key result of the 1966 Coleman Report (Mosteller and Moynihan, 1972; Leibowitz, 1974). Some studies raise a number of statistical concerns about the actual occurrence of this widening gap (Jerrim and Vignoles, 2013).

et al., 2013; Carneiro *et al.*, 2015; Dickson *et al.*, 2016). By comparison, however, very little attention has been devoted to the direct 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. Using data from the Children of the National Longitudinal Survey of Youth, Carneiro and Ginja (2016) use parental time and other inputs to measure the reaction of parental investments in children in time and goods to permanent and transitory income shocks. Fiorini and Keane (2014) analyse time use diaries of about 1,000 children from the Longitudinal Study of Australian Children (LSAC) and describe how children aged between one and nine 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 *et al.* (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 are 6–10 years old. Examining the same data on about 1,500 children, Carneiro and Rodriguez (2009) confirm that more time with mothers leads children (especially those aged three to six years) to perform better in cognitive tests.[2] The same time diaries and PSID data are also used by Hsin and Felfe (2014) on a sample of approximately 1,600 children. They analyse the effect on child outcomes of three types of parental time spent with children: time in educationally oriented activities (e.g. studying, reading and doing homework), time in structured activities that offer children high levels of active engagement and verbal exchange (e.g. doing arts and crafts, performing music and playing sport) and time in other unstructured activities (e.g. watching television and doing nothing). They find that the time children spend with mothers in educational and structured activities correlate positively with child outcomes.[3]

A closely related contribution is the work by Todd and Wolpin (2007). They do not have time to 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

[2] Using a small sample of children and parents from the Child Development Supplement of the PSID, Del Boca *et al.* (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. These results are broadly confirmed in Del Boca *et al.* (2016), which also explores the impact of various transfer policies on the distribution of child outcomes.

[3] Hsin (2009) provides an interesting overview of the small, but growing, literature on parental time and child cognitive outcomes using time use data (Monfardini and See, 2012; Villena-Roldán and Ríos-Aguilar, 2012).

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.[4] They find strong evidence that home inputs are important determinants of child cognitive development and differences in home inputs can account for 10–20% of the racial test score gaps.

In our article, 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.[5] 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 their mothers, which allows us to have greater statistical power and, from a substantive viewpoint, break new ground in exploring 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 on the effect of maternal time investment to focus on Britain.

One of our primary objectives is to understand whether the relationship between maternal time investment and child outcomes changes over early childhood (Cunha *et al.*, 2006; Cunha and Heckman, 2008). As pointed out by Rosenzweig and Schultz (1983), Todd and Wolpin (2003, 2007) and Fiorini and Keane (2014), this analysis must overcome two major issues, i.e. the difficulty of measuring all the relevant inputs to child development and the problem of distinguishing a simple correlation between inputs and outcomes from a true causal impact. We tackle the first issue by estimating child skill production functions with an exceptionally rich set of parental inputs and other socio-demographic controls, although we clearly do not claim we include all the inputs relevant to child development. The second issue is harder to address. The recent literature has proposed a number of strategies, each of which comes with its own limitation (Todd and Wolpin, 2003, 2007). We follow this literature estimating a wide variety of models and, for each of them, we spell out the assumptions under which our estimates identify the key parameters of the child skill production functions.

We begin our analysis with models in which both outcomes and 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 (Bus *et al.*, 1995; Sacker *et al.*, 2002; Raikes *et al.*, 2006; Kelly *et al.*, 2009, 2011; McMunn *et al.*, 2012).

To see directly if there are longer term effects of early investments on later child outcomes, we then estimate specifications in which lagged inputs and past test scores

[4] Several studies, especially in developmental psychology and social demography, have used HOME scores and consistently found it is an important predictor of child development (Brooks-Gunn *et al.*, 1996; Guo and Harris, 2000; Brooks-Gunn *et al.*, 2002; Linver *et al.*, 2004). Although still limited, its use among economists is becoming more popular (Aughinbaugh and Gittleman, 2003; Taylor *et al.*, 2004).

[5] We have no *ex ante* reason to believe that maternal time inputs influence the two production functions similarly. Since the work by Heckman *et al.* (2006), there is overwhelming evidence that the two functions are different and are affected differently by parental inputs.

are controlled for, using similar techniques to those proposed by Todd and Wolpin (2003, 2007) and also applied by Fiorini and Keane (2014) to account for input endogeneity. We also discuss other methodological issues, such as measurement error in lagged outcomes, which is shown to be important to estimate outcome persistence correctly and affects input effect estimates, and the presence of feedback effects (Ladd and Walsh, 2002; 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 each activity separately or one overall score (such as the HOME index), 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, which shares features with some of the structured activities used by Hsin and Felfe (2014), while our former input includes activities that are closer to their educational activities.

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 non-maternal child care, which we distinguish into formal (paid) and informal.[6] 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 (McLoyd, 1998; Guo and Harris, 2000; Bornstein, 2002; Brooks-Gunn and Markman, 2005; Grantham-McGregor *et al.*, 2007; Berger *et al.*, 2009; Kelly *et al.*, 2011) but less so in economics (some exceptions are Dooley and Stewart, 2007; Ermisch, 2008; Fiorini and Keane, 2014). Like maternal time, child care and parenting style decisions are also likely to be endogenous inputs in the production of child outcomes. Our statistical methodology is intended to account for this possibility in the same way as it does for maternal time investment.

We draw attention to five main results. First, there is an overall 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 correlations is large, corresponding to 20–40% 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

[6] This has received a lot of attention by social scientists. We have already mentioned some of the relevant research in this literature. See also the early contribution by Belsky and Eggebeen (1991) and the recent work by Bernal (2008), Bernal and Keane (2010), Havnes and Mogstad (2011), and Black *et al.* (2014). Blau and Currie (2006) provide an excellent overview.

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, non-maternal 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 article proceeds as follows. Section 1 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 2 describes the basic specifications used in the econometric analysis and discusses the issue of how we identify the effect of parental inputs on child outcomes. Section 3 presents our benchmark results on maternal time inputs, while Section 4 shows evidence on feedback effects, explores the role played by other inputs, and presents several robustness checks. Section 5 concludes.

1. Data

1.1. *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 nine months, three, five and seven years. During home visits, questions were asked about socio-economic circumstances, demographic characteristics, home learning, family routines and psychosocial environment. At ages 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 behaviour.

Our sample includes all singleton children interviewed at age 3, for whom the main respondent is the natural mother. This implies a 20% reduction in relation to the original sample in the first sweep of data (18,552 children interviewed at nine months) and gives us 15,077 children. We also restrict the sample to cases in which the mother is the main respondent in at least two consecutive waves and is aged 20–45 years at the child's birth, a restriction that leaves us with 12,460 children. We then construct a balanced panel, including only cases where:

(*i*) we have information on the family background measures (12,298 children);
(*ii*) the child is present at all interviews up to age 7 (10,071 children); and
(*iii*) we have no missing information on the measures of cognitive and non-cognitive ability (8,652 children).

In addition, we 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. Each of these selections and the corresponding reductions in sample size are documented in Appendix Table A1, where we break the information down by child age (or MCS wave).

1.2. *Child Outcomes*

1.2.1. *Cognitive outcome*

The cognitive outcome is assessed, using widely validated, age-appropriate tests. These come from the British Ability Scales (BAS; Elliott *et al.*, 1996 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.

1.2.2. *Non-cognitive outcome*

When cohort members were approximately three, five and seven years old, parents were asked to complete the Strengths and Difficulties Questionnaire (SDQ). The SDQ is a behavioural screening questionnaire designed to measure psychological adjustment in children aged 3–16 (Goodman, 1997, 2001). The questionnaire identifies five different components:

(*i*) hyperactivity/inattention;
(*ii*) conduct problems;
(*iii*) emotional symptoms;
(*iv*) peer problems; and
(*v*) pro-social behaviour.

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 behaviours. Responses to the first four subscales (i.e. excluding pro-social behaviour) are then summed up to obtain the Total Difficulty Score, which varies between 0 and 40. We take this is as our measure of non-cognitive outcome.[7] 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 standardised cognitive and non-cognitive outcomes respectively. Table 1 reports means and standard deviations of their non-standardised equivalents. The distributions of verbal skill scores are approximately normal and similar across ages, while the distributions of the

[7] It is well known that there are problems in relation to the measurement of a child's state of mental health. Parental assessments are influenced by the feedback received from children themselves, besides those received from doctors, nurses, child care workers, family and friends. Parents are found to be most accurate when child performance falls at an extreme, either very high or very low, because of the clarity of the feedback. But parents whose children fall between such extremes are likely to be more inaccurate (Frankenburg *et al.*, 1976; Knobloch *et al.*, 1979). A recent study by Johnston *et al.* (2014) examines the extent of survey measurement error using data that contain assessments of child mental state from three observers (parent, teacher and child) and expert quasi-diagnoses. The identification in that study relies on the assumption that the experts are able to make the best possible use of all available information but with random variations in the threshold of seriousness they use for generating diagnoses. This assumption may or may not be legitimate, depending on the aspects of child mental health under analysis. In any case, information on expert assessments is not available in the MCS. The MCS instead collects SDQ information for each child at age 7 also from the teacher. The correlation between mother's and teacher's assessments is fairly high and around 0.41.

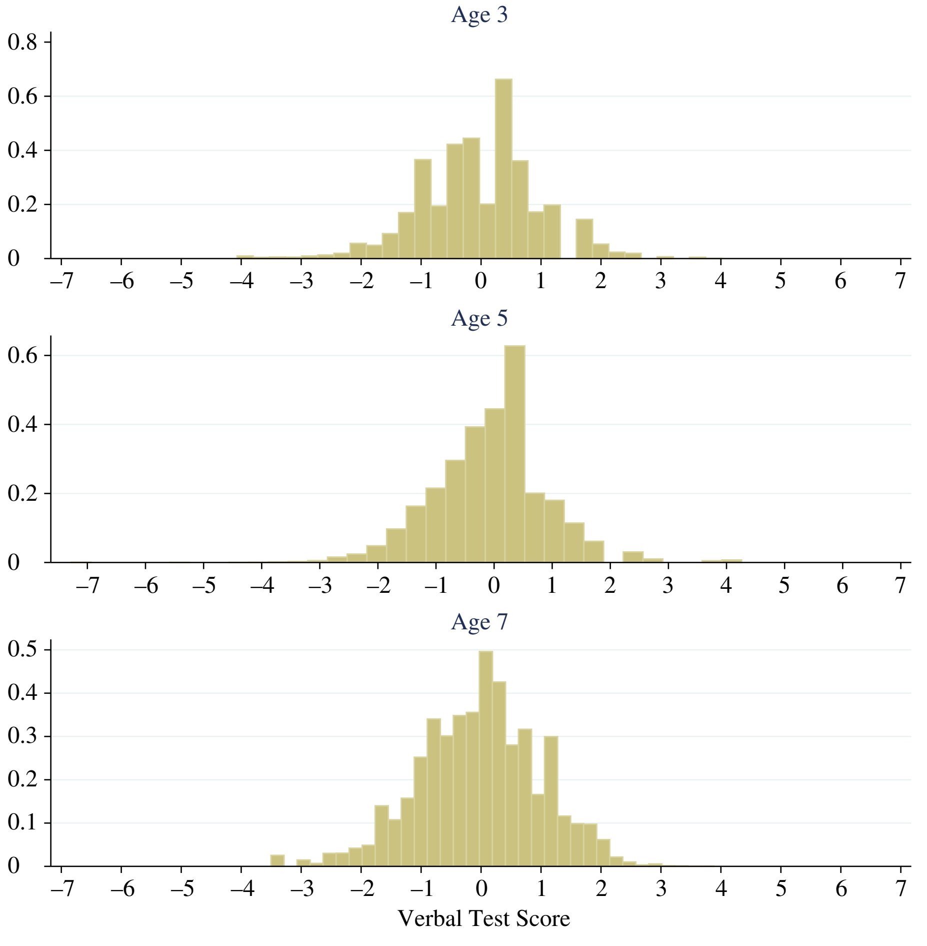

Fig. 1. *Distribution of the Cognitive Outcome by Child Age*

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 1.2 for an explanation of how these measures have been constructed using MCS data.
Source. UK Millennium Cohort Study.

(reverse-coded) Total Difficulty Score is skewed to the left and becomes more so as children grow older.

1.3. *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 as follows:

(*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 three years old is that we cannot separate activities that were performed by the mother from those performed by

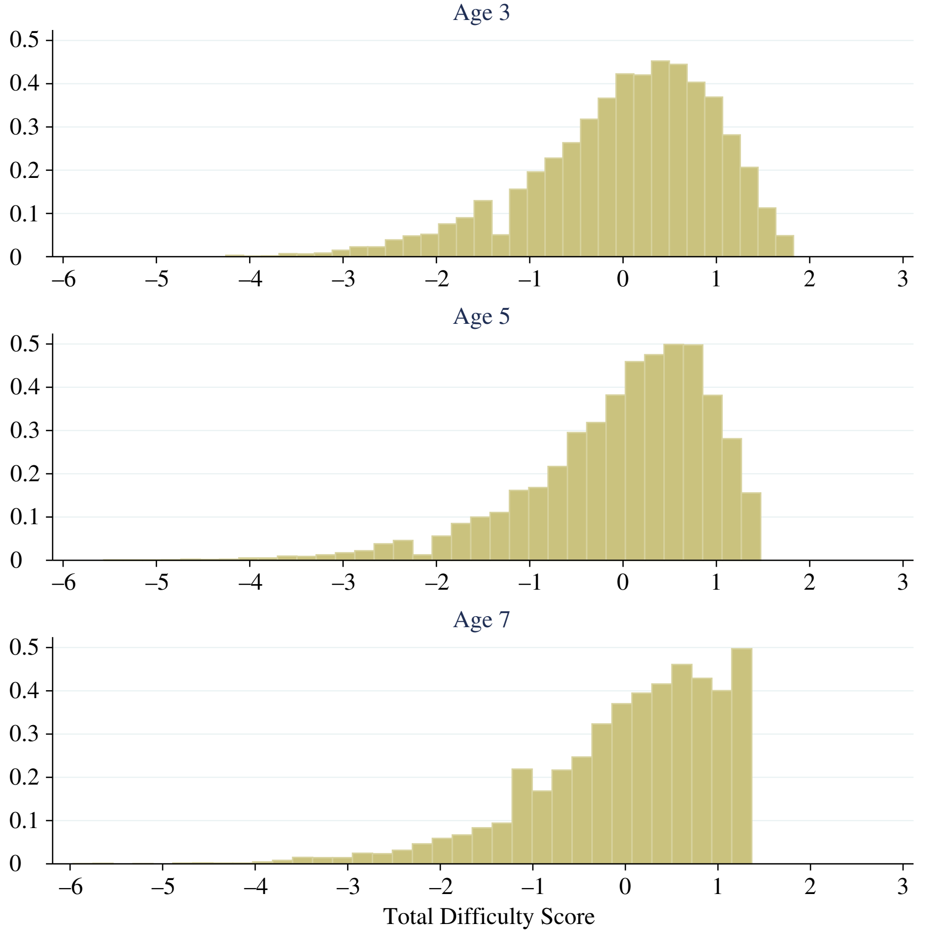

Fig. 2. *Distribution of the Non-cognitive Outcome by Child Age*
Notes. The non-cognitive (emotional skill) outcome is measured by the Total Difficulty Score obtained from the Strengths and Difficulties Questionnaires. See subsection 1.2 for an explanation of how these measures have been constructed using MCS data.
Source. UK Millennium Cohort Study.

Table 1

Summary Statistics by Child Age

	Age 3	Age 5	Age 7
Outcomes			
Cognitive (verbal skill score)*	75.937	110.936	110.546
	(16.205)	(13.866)	(28.705)
Non-cognitive (Total Difficulty Score)†	30.994	33.297	33.112
	(4.933)	(4.545)	(5.046)
Inputs			
Educational time†	0.000	0.000	0.000
	(1.000)	(1.000)	(1.000)
Recreational time†	0.000	0.000	0.000
	(1.000)	(1.000)	(1.000)
Non-maternal 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†	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)	3,405.9	3,405.9	3,405.9
	(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)	1,138.7	1,900.6	2,637.6
	(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
Equivalised weekly family income‡	381.9	384.4	393.5
	(231.2)	(217.9)	(212.5)
Observations (unweighted)	8,129	8,129	8,129

Notes. Figures are means (standard deviations for the continuous variables are in parentheses). All figures are weighted using MCS sampling weights. *Non-standardised. †Obtained through principal component analysis. ‡Deflated using the Consumer Price Index (base = 2004).
Source. UK Millennium Cohort Study.

other family members. We assume that all activities were carried out by the mother, however we 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.[8]

Rather than using many different measures of maternal time investments (we count 24 types of activity and at least six 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.[9] 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 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 labelling does not mean that the recreational input excludes educational components and *vice versa*. Indeed, using an oblique rotation technique we explicitly allow the factors (from here onwards referred to as maternal time inputs) to be correlated.[10] It is worthwhile noting that this latter factor includes some of the activities that make up Hsin and Felfe's (2014) structured and unstructured activities, while our former factor shares some of the same features as their educational and structured time activities.[11]

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 three years old.[12] 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.[13]

1.4. *Validating the MCS Time Input Measures with Time Use Diaries*

Because no other study has used our derived maternal time input measures, we provide here a validation exercise. The purpose of this exercise is to check whether our new measures are meaningfully associated with actual maternal time use. To do this, we analyse the correlations of the derived measures with maternal education and

[8] The inclusion of measures of time spent by fathers with their children at ages 5 and 7 is possible. But this can be done only at the cost of having a severe sample selection problem due to missing observations. For instance, around 15% of two-parent households in our sample have missing values for the variables related to father's time with children. We therefore decided not to include such variables.

[9] 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 (2014) for a similar application. The two factors jointly explain 45.4%, 42.0% and 37.4% of the total variance at ages 3, 5, and 7 respectively. Appendix Table A2 shows that the majority of the items load positively on the factors.

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

[11] Differently from Hsin and Felfe (2014), however, we cannot construct a measure of total maternal time devoted to the child, because our data do not come from time use diaries.

[12] For instance, more than 50% of mothers report that their three-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).

[13] 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.

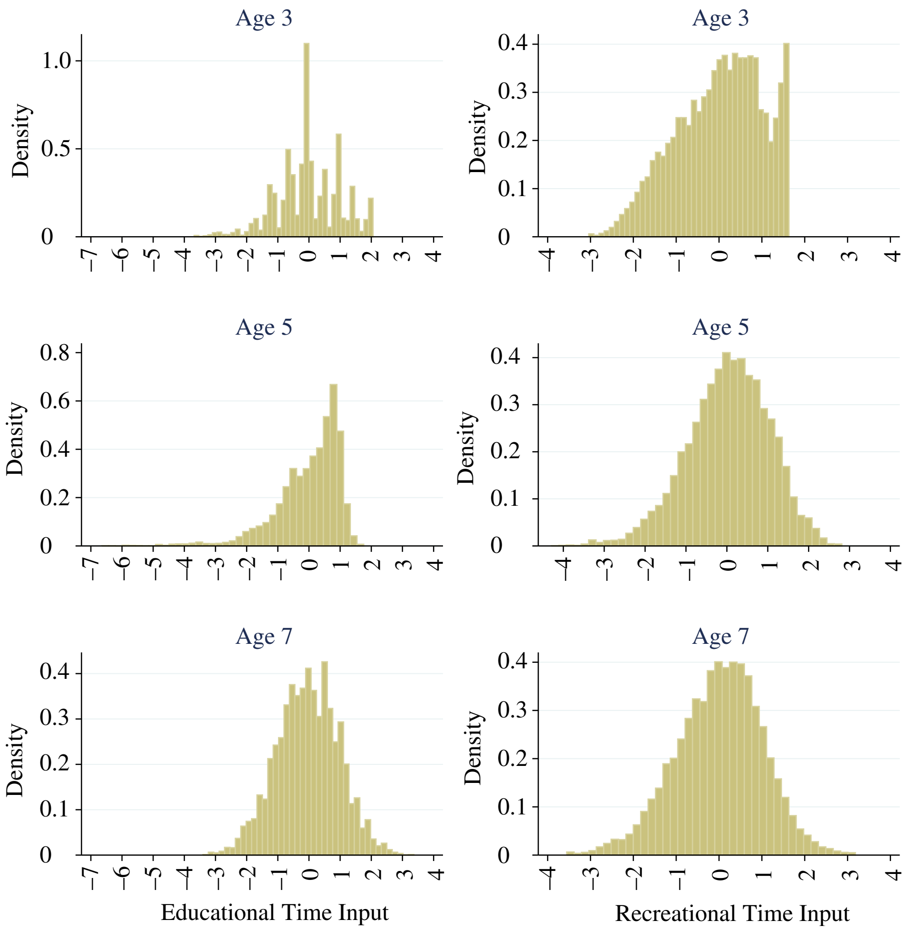

Fig. 3. *Distribution of the Educational and Recreational Time Inputs by Child Age*
Notes. See subsection 1.3 for an explanation of how these measures have been constructed using the MCS data.
Source. UK Millennium Cohort Study.

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 2000–1 and collects time diaries for a representative sample of 11,600 individuals aged 8 or above.[14] 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 nine 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).[15]

[14] See Office for National Statistics (2003) for a detailed description of the UK-TUS data.
[15] We use weights specifically provided to combine information from more than one diary per individual.

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 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:

(*i*) physical care and supervision;
(*ii*) teaching;
(*iii*) reading, playing and talking;
(*iv*) travel time; and
(*v*) 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 (*ii*)) corresponds quite directly to our measure of the educational time input. Similarly, our recreational time input and reading, playing and talking (activity (*iii*)) do overlap considerably. However, there are relevant differences. For example, physical care and supervision (activity (*i*)) 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 (*iv*)). Second, the UK-TUS does not differentiate between activities performed with different children of different ages. Selecting mothers of children aged zero to nine 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.[16] 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.[17] 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.[18] 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

[16] It is worth stressing that these are only correlations and not causal relationships. We shall come back to this point in subsection 4.3 where we analyse child skill production functions by mother's education.

[17] This is in line with the evidence shown by Guryan *et al.* (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.

[18] For presentational purposes, the time use measures have been standardised to have a mean 0 and standard deviation 1. The unstandardised means are reported in Appendix Table A3. Moreover, since only 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.

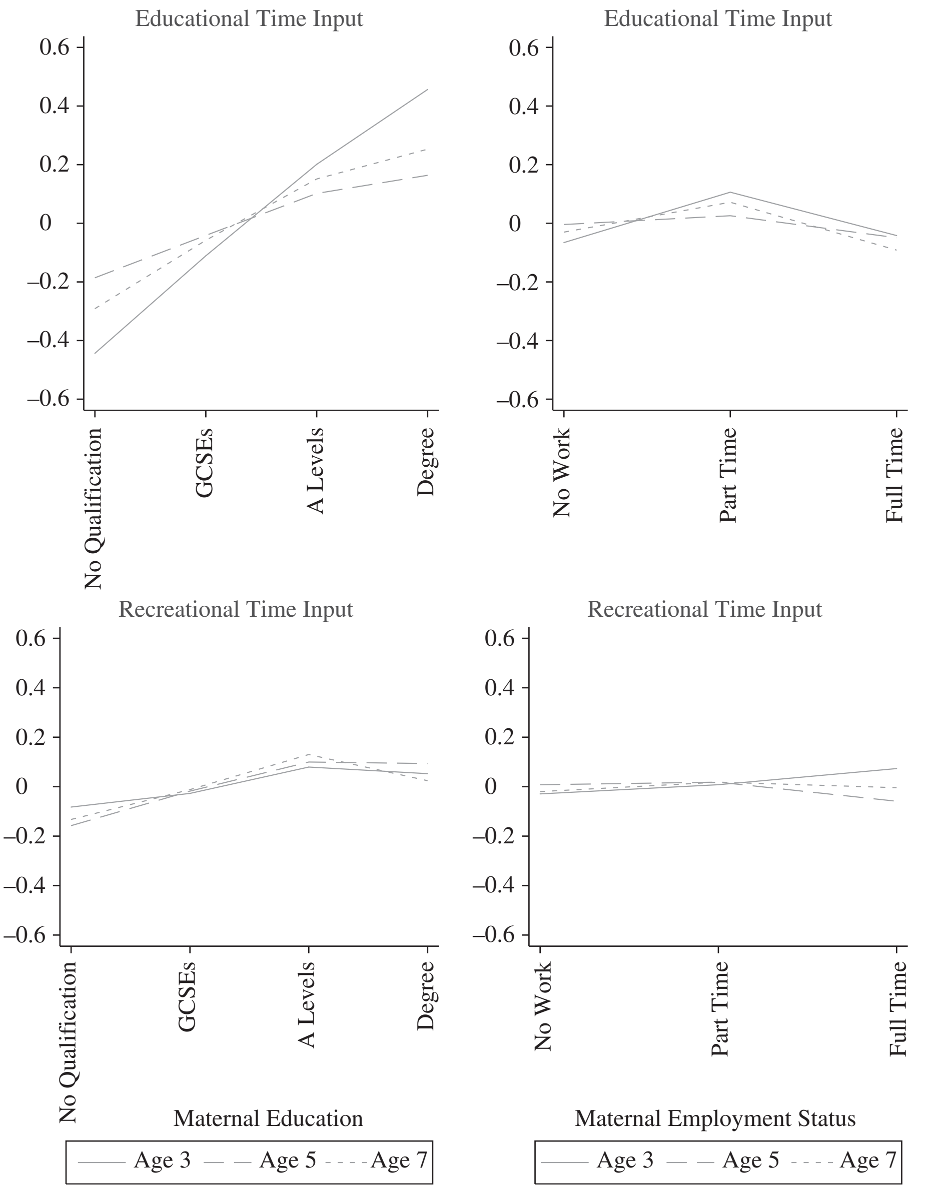

Fig. 4. *Relationship between Maternal Time Inputs and Maternal Education and Employment Status*
Notes. See subsection 1.3 for an explanation of how these measures have been constructed.
Source. UK Millennium Cohort Study.

related to teaching as 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

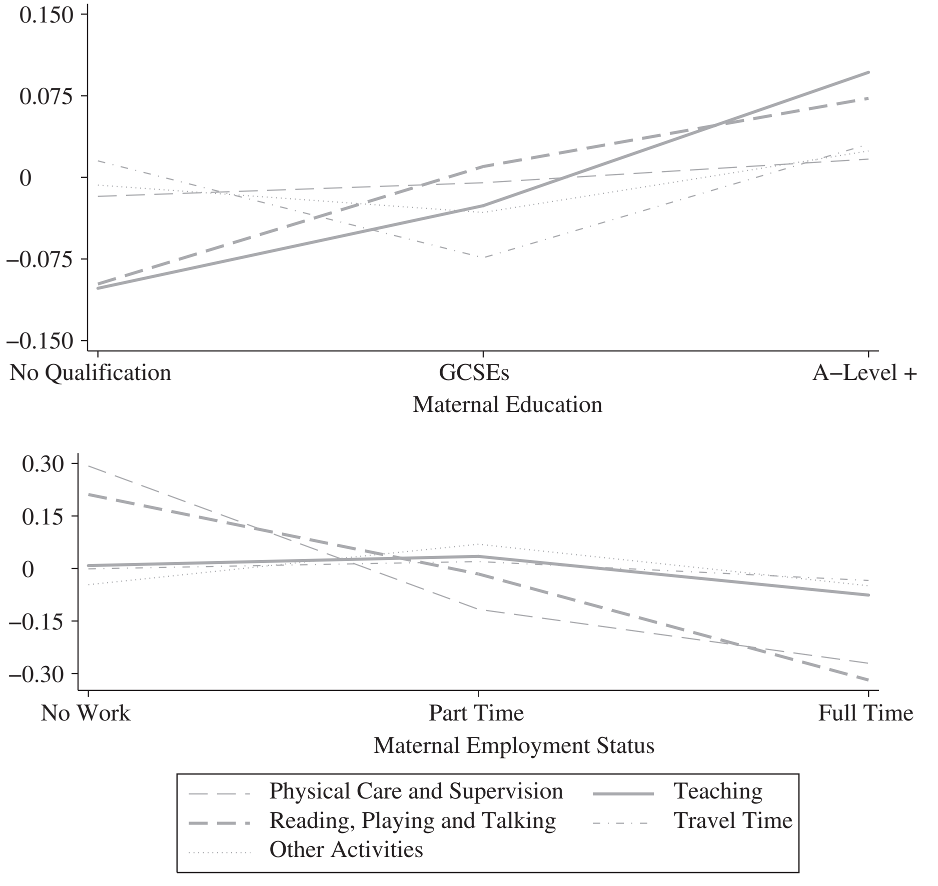

Fig. 5. *Relationship between Child Care Time and Maternal Education and Employment Status*
Notes. Each measure of maternal time use is standardised to have mean 0 and standard deviation 1. Unstandardised measures are reported in Appendix Table A3.
Source. 2000–1 UK Time Use Survey.

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).[19] Since the time use

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

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 (three, five and seven 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.[20]

1.5. *Other Inputs*

As mentioned in the Introduction, we analyse two additional inputs to the child development production function. One is non-maternal child care, which can be broken down into formal and informal arrangements. Formal (paid) arrangements include the care provided by nurseries, registered childminders, nannies or others.[21] Informal (unpaid) arrangements comprise the care provided by grandparents, other relatives, or friends.[22] Formal and informal arrangements are relevant only to working mothers, while non-working 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.[23] Table 1 shows that, as children grow older, more mothers rely on non-maternal child care (from 30% at age 3 to 53% at 7). This pattern is mirrored by mothers' employment rates, which grow from 52% to 65% (including both part-time and full-time work).

The other additional input we focus on is the 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 three hours' and 'not at all' respectively);

[20] 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.

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

[22] The MCS allows us also to identify the informal child care provided by fathers. About 9% of the children at age 3 receive paternal child care services and about 21% at ages 5 and 7. Our key results however are robust, whether we include paternal child care as an additional input or not. Furthermore, paternal care does not have any significant impact on child outcomes across virtually all the models described in the next Section, with the exception of the contemporaneous effect on verbal skills at age 3 and the one-period lag effect on each outcome from the cumulative specification. For simplicity therefore we do not distinguish this input in the analysis below.

[23] About 11% 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% when children are aged 5 and 7. To maximise the size of our estimating sample, in our analysis, we include an indicator variable for children with missing child care information. Excluding them from the analysis, however, does not change our main findings.

(*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 three 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% of the variance at ages 3, 5 and 7 respectively. The age-specific factor loadings are reported in Appendix Table A4. 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, 2014). By construction, the index is expressed as a z-score with mean 0 and standard deviation 1.

1.6. *Other Conditioning Variables*

Our analysis includes a set of standard child and family controls. Some are time invariant, such as child sex, birthweight, ethnicity and 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.

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% are white British. The average weight at birth across all children in the sample is 3.4 kilograms and about 5% of them were born pre-term. Mothers were on average 30 years old at the child's birth. About 20% 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 £394 per week (in 2004 prices).[24]

In subsection 1.1, we mention the various selections imposed to construct our final estimating sample. Appendix Table A1 shows the sample selection process, suggesting that most of the selection takes place because of attrition. A direct way of assessing whether attrition is affecting the composition of the sample is to compare the summary statistics in Table 1 with those for a larger unbalanced sample, which includes singleton children whose natural mothers are aged 20–45 and with no missing information in the main family background variables. These are reported in Appendix Table A5. In this less restricted sample, the number of children is 12,298, 12,386 and 10,847 at ages 3, 5

[24] All summary statistics take into account sampling weights, which are meant to correct for the fact that the MCS had a stratified sampling design in order to obtain sufficient numbers of children from deprived areas and from ethnic minorities. Our estimates do not use weights but control for the sampling design by including a set of dummies for the strata (for each country, we can distinguish deprived areas or areas with a high percentage of ethnic minorities). For more details see Plewis (2004).

and 7 respectively, or about 79%, 81%, and 78% of their corresponding original samples. The differences between our final sample and the less restricted sample are very small along almost all domains. There are some slightly larger differences in the socio-economic dimension. In the less restricted sample, for instance, we have a slightly larger fraction of children whose mothers have no educational qualification (25–26% *versus* 21%) and are less active in the labour market (39% of them are not in a paid job when their child is aged 7 *versus* 35% in our sample). This is reflected in a marginally lower family income at all ages. Nevertheless, these differences are quantitatively negligible and never statistically significant. The role played by attrition therefore is likely to be limited.

2. Methods

We estimate early child development production functions using the approach developed by Todd and Wolpin (2003, 2007) and also applied by Fiorini and Keane (2014) and Del Boca *et al.* (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, in the sense that it is hard to distinguish a simple correlation between inputs and child outcomes from a true causal effect. There are three likely sources of this endogeneity issue (Fiorini and Keane, 2014). A first source is omitted variables, such as unobserved child endowments or unobserved inputs. Another is simultaneity or reverse causality: for instance, a mother who reads more to her children can make them smarter, but it is equally possible that smart children enjoy reading more with their mother. A final source is measurement errors in the input measures and test scores. An example of the former occurs if parents do not know exactly how much time they spend with their child on a specific activity. An example of the latter is that parents may not know precisely (or may not truthfully report) their child's behavioural problems and this, in turn, may generate problems when we include past outcomes in our estimation.

We account for omitted past inputs, and in part for unobserved ability endowments, by estimating models with past test scores. These models, however, have to face the potential problem induced by measurement error in earlier outcomes and, therefore, their estimates are likely to be downward biased. Simultaneity is an issue with models in which both outcomes and inputs are measured at the same age for each child. But it is likely to be less problematic in the models that are most relevant to our study, where we assess the dynamic effect of early inputs affecting later outcomes. Such models instead may pick up feedback effects, whereby current parental decisions (in terms of time investment or parenting style) respond to realisations of past outcomes. We shall estimate models that try to account for such effects. Finally, 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.[25]

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 non-maternal child care and parenting style, while the former consists of the mother's educational and recreational activities carried out with the child, labelled E_{ia} and R_{ia}, respectively. Assuming away the role of other conditioning variables for simplicity, the production function for skill (or test score) Y of child i observed at age a can be written as:

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

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 (or self-productivity in the terminology of Cunha and Heckman (2007)) but, as mentioned above, is also meant to control for unobserved ability (Todd and Wolpin, 2003; Fiorini and Keane, 2014). 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 $\delta_{a-1} = \delta_{a-2} = \cdots = \delta_0 = 0$ 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. As explained in Section 4, this model allows us to address issues in relation to feedback effects.

[25] In addition to these methods, Del Boca *et al.* (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, 2008) and Cunha *et al.* (2010) achieve identification of parental investment using cross-equation covariance restrictions, while Del Boca *et al.* (2014) identify their structural model with distributional and functional form assumptions on technology, preference and wage processes.

3. 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 other inputs and the 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 seven 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.[26]

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

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†	8,129	8,129	8,129	8,129	8,129	8,129

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. Each regression includes indicator variables for non-maternal child care and parenting style. Additional controls are child sex, birthweight, ethnicity and 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, presence of siblings and a full set of dummy variables to indicate the sampling strata. *Significant at 5% level; **Significant at 1% level. †Number of children.
Source. UK Millennium Cohort Study.

[26] Given the longitudinal aspect of the MCS data, we can estimate within-child fixed effects models. These models however do not allow us to identify our key responses of interest, i.e. whether the effects of observed inputs change over the child's life cycle and whether past idiosyncratic individual shocks affect current input decisions.

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 impact 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 qualifications. The educational time effect is nearly twice as large. If instead we compare children whose mothers have a university degree with those whose mothers have below-university qualifications, the effect of recreational time is about 60% of this 'marginal' effect of maternal education and that of educational time is 13% larger.

Does the reduction in the impact 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}.[27]

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

[27] 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 *vice versa*. All the results, which are similar to those shown in Table 3, are not reported for convenience. To account for the possible complementarity between E and R, we also performed the whole analysis including contemporaneous and lagged (where suitable) interaction terms between these two inputs E and R. These terms are never statistically significant and their inclusion does not alter any the results in Table 3. They are therefore not shown.

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
Panel (*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†	24,387	16,258	8,129	8,129	8,129
Panel (*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†	24,387	16,258	8,129	8,129	8,129

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

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 explore this possibility in subsection 4.2. 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 early maternal time investment in children has a long-term impact on 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 0.09 in the cognitive and non-cognitive outcomes respectively.[28] 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 emphasise 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-term effect 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 existence of long-term impact 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 summarise, we emphasise 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 (2014) 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 relationship between early maternal time inputs and 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

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

the finding by Del Boca *et al.* (2014), according to which the productivity of parental time inputs on child cognitive development declines with child age. In the case of emotional skills however, there is no evidence of a long-term impact of early inputs on later outcomes 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 emphasised by Fiorini and Keane (2014), 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.

4. 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 4.2 explores whether maternal time allocation decisions respond to realisations of past outcomes (feedback effects). In subsection 4.3 we analyse 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.

4.1. *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, travel, medical services, tutors and school quality. 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 non-zero correlation between observed 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

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[†]	6,490	6,490

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. *Significant at 5% level; **significant at 1% level. [†]Number of children.
Source. UK Millennium Cohort Study.

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	

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.
Source. UK Millennium Cohort Study.

two time inputs of interest and, for convenience, we only focus on the CVA-IV specification.[29]

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 non-random 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 impact 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 six 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 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 an 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 non-linearity in the effect on non-cognitive outcomes.

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

4.2. *Feedback Effects*

In Section 3, we documented a fading out of the effect of maternal time inputs over the early life cycle. We also documented the presence of a large long-term impact 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.[30]

To detect the possible presence of feedback effects, we follow an approach based on the 'levels and differences' generalised method of moments (GMM) framework introduced by Arellano and Bover (1995) and extended by Blundell and Bond (1998).[31] A similar approach has been used in a different context by Andrabi *et al.* (2011) to analyse 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:

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

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:

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

Our instruments are past inputs for (2) and twice lagged outcomes as well as past inputs for (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.[32]

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*),[33] while in column (*iv*) we use all the scores available in the MCS at $a - 3$ (when the child was aged nine months), i.e. the Denver Developmental Screening Test and the Carey Infant Temperament Scale.

[30] Examining intrahousehold resource allocations, Rosenzweig and Wolpin (1995) and Del Bono *et al.* (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 antenatal investment in children who are not born yet.

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

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

[33] 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.

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†	8,129	8,129	8,129	7,928	8,129	8,129	8,129	7,928

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 nine months in column (*iv*). See Section 2 and subsection 4.3 for more details. See also the notes to Table 2 for the list of additional inputs and time-varying controls. *Significant at 5% level; ** significant at 1% level. †Number of children.
Source. UK Millennium Cohort Study.

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.[34]

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 even 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 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 emphasised and as we documented in Section 3.

4.3. *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 as we cannot find any relevant difference in the case of emotional skills. The estimates are reported in Table 7.

4.3.1. *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-term effects of earlier educational investments instead appear to benefit girls and boys quite similarly.

4.3.2. *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

[34] 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.

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

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.
Source. UK Millennium Cohort Study.

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.

The greater positive effect of educated mothers' educational time on cognitive skills, which is also observed in the data as shown in Figure 4, may be driven either by a causal relationship (i.e. a greater education makes women more productive mothers) or by selection (i.e. more educated mothers have more educated children), or both. Although the recent literature suggests that intergenerational schooling associations are primarily due to selection and not causation (Black *et al.*, 2005; Holmlund *et al.*, 2011), we cannot distinguish between these explanations, since our data do not allow us to pin down the causal link between mother's education and child's cognitive ability.

4.3.3. *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% among firstborn.

These results may be driven by a variety of mechanisms other than those related to the positive impact of lagged inputs over the child's life cycle or to the feedback effects illustrated above. For instance, parents might respond to the needs of older or younger siblings who are not interviewed by the MCS. That is, our estimates might reflect the presence of intrafamily endowment responses that that could be associated with inequity aversion considerations (Rosenzweig, 1986; Rosenzweig and Wolpin, 1995; Del Bono *et al.*, 2012). Since our data do not collect information on the other siblings who live in the household, we cannot test for this explanation. More research is needed in this area.

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.

4.4. *Other Parental Inputs*

In this subsection, we examine the impact of two other observed inputs included in our basic specifications. These are non-maternal 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. Like maternal time allocation decisions, such inputs are endogenous and the models we estimate attempt to account for their endogeneity exactly as we do for maternal time investments. The inclusion of such inputs is not only motivated by the fact that they are of interest because they have already received much attention in earlier research and are of potential policy relevance. It is also because, as explained in the Introduction and in Section 2, we seek to overcome the difficulty of measuring as many inputs as possible by estimating child skill production functions with an exceptionally rich set of parental inputs and other socio-demographic controls (Rosenzweig and Schultz, 1983; Todd and Wolpin, 2007; Fiorini and Keane, 2014). Despite this, we do not claim we include all the inputs relevant to child development.

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 (non-maternal child care and parenting style) from our benchmark specifications does not affect any of our previous results.[35]

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

[35] As mentioned in subsection 1.5, we performed the whole analysis distinguishing paternal child care as an additional input. This inclusion does not change any of our previous results nor those shown in Table 8. The input itself is never statistically (and quantitatively) significant and this is true also for fixed effects models.

Table 8

Coefficients on Non-maternal 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)

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.
Source. UK Millennium Cohort Study.

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) and with the more recent results by Bernal (2008) and Bernal and Keane (2010), according to which the effect of non-parental child care is generally insignificant, and sometimes wrong-signed, in the sense that it is negatively correlated to child outcomes.

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 on parenting style confirm the evidence presented in other studies that use data from the MCS (Ermisch, 2008; Kelly *et al.*, 2011). Different from the evidence on Australian children found by Fiorini and Keane (2014), 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 4.1 (hybrid specification) but do not report the estimates because of space concerns. In the case of income, we find that a 10% increase in equivalised 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 (2014). 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 suggest that maternal time inputs might 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.

5. Conclusions

Many studies stress the importance of maternal time in shaping early child outcomes. But very few analyse the direct effect of time inputs on human capital production. The main contribution of the article is to provide this analysis, focusing on Britain for the first time, considering the interplay of maternal time with parenting style and child care decisions, 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 use 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 3–7. This effect is quantitatively large and corresponds to 20–40% 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 emphasised.

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 non-maternal 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 emphasise 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 socio-economic gradient in outcomes observed at later points of children's life may be driven by variation between and within families. This suggests there might be only small scope for later interventions that aim to affect mother's time availability or inform them about the effectiveness of their time investments. But more work is needed to corroborate this conclusion.

Although this study represents one of the first attempts to estimate early production functions for Britain, there are a few desirable extensions that crucially rely on data improvements. First, the MCS does not collect information on maternal time investments between birth and age 3. Given that early parental time investments have long-term effects on child 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 limitations, as fathers' non-response rates are extremely high and information on absent fathers is not at hand in the MCS. Knowing the time contribution of all fathers and whether this complements or substitutes mother's time inputs would improve our understanding of early child development.

Appendix A. Additional Tables

Table A1

Sample Selection by Child Age

	Wave 1 (birth and nine months)	Wave 2 (Age 3)	Wave 3 (Age 5)	Wave 4 (Age 7)
Original sample	18,552	15,590	15,246	13,857
Singleton birth only	18,150	15,382	15,043	13,681
Natural mother is in the family	18,143	15,077	14,596	13,222
Mother is main respondent in two consecutive waves	16,752	13,457	13,624	11,846
Mother's age at birth of child is 20-45	15,337	12,460	12,560	10,997
Excluding missing in family background variables	15,101	12,298	12,386	10,847
Present at all waves up to age 7	10,071	10,071	10,071	10,071
Excluding cases for which outcome variables are missing	8,652	8,652	8,652	8,652
Child is in full time school at ages 5 and 7	8,336	8,336	8,336	8,336
Excluding cases in which parental activity and parenting style variables and information on mother's work are missing	8,129	8,129	8,129	8,129

Note. Each figure refers to the (unweighted) number of children in each sweep of MCS data.
Source. UK Millennium Cohort Study (MCS).

Table A2

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*	*0.841*	0.057
Mother attended meeting at school†	0.192	−0.059
% total variance explained by each individual factor	12.4	29.5
% total variance explained by both factors	41.9	

Table A2

(*Continued*)

	Educational	Recreational
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‡	*0.683*	−0.018
Mother participates in school activities§	*0.535*	0.060
Mother attended meeting at school†	*0.444*	−0.123
% total variance explained by each individual factor	11.1	26.3
% total variance explained by both factors	37.4	

Notes. Loadings larger than 0.25 in absolute value are in italic. 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 1.3 for details. *Includes homework. †0/1 variable. ‡Homework (measured in hours) is divided into 4 categories: less than half an hour; up to one hour; up to two hours; more than two hours. §Refers to the total number of activities.
Source. UK Millennium Cohort Study.

Table A3

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*	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

Notes. Mean values of time (minutes per day) spent by mothers in child care activities. *Includes all equivalent qualifications short of A level attainment.
Source. 2000–1 UK Time Use Survey.

Table A4

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

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.
Source. UK Millennium Cohort Study.

Table A5

Summary Statistics on Unbalalanced Sample by Child Age

	Age 3	Age 5	Age 7
Outcomes			
Cognitive (verbal skill score)†	75.004	109.470	108.731
	(17.003)	(15.307)	(29.781)
Non-cognitive (Total Difficulty Score)*	30.821	33.003	32.713
	(5.073)	(4.818)	(5.346)
Inputs			
Educational time†	–	–	–
Recreational time†	–	–	–
Non-maternal child care arrangement			
None	0.602	0.540	0.467
Informal (unpaid)	0.108	0.280	0.266
Formal (paid)	0.175	0.161	0.247
Missing	0.115	0.019	0.020
Parenting style†	–	–	–
Time-invariant controls			
Male	0.507	0.509	0.509
Firstborn	0.383	0.386	0.382
White British	0.882	0.880	0.875
Birth weight (in grams)	3,392.7	3,390.9	3,388.8
	(569.8)	(573.1)	(571.7)
Child born before 37 weeks	0.056	0.056	0.055
Mother's education			
No qualification	0.248	0.247	0.257
GCSE/O-level (or equivalent)	0.352	0.355	0.357
A level or more but below university degree	0.206	0.204	0.199
University degree or higher qualification	0.193	0.193	0.186
Mother's age at birth	30.2	30.1	30.0
	(5.1)	(5.1)	(5.1)
Time-varying controls			
Child's age at interview (in days)	1,142.2	1,900.9	2,637.9
	(72.0)	(88.1)	(89.0)
Presence of siblings	0.777	0.855	0.890
Single parent family	0.138	0.168	0.189
Child attends private school	0.000	0.043	0.037

Table A5

(*Continued*)

	Age 3	Age 5	Age 7
Mother's employment status			
No work	0.507	0.436	0.389
Part time	0.344	0.391	0.403
Full time	0.149	0.173	0.208
Equivalised weekly family income‡	368.9	367.9	373.6
	(230.0)	(216.7)	(211.3)
Observations (unweighted)	12,298	12,386	10,847

Notes. See the notes to Table 1. *Calculated on the sub-sample that has non-missing values for these variables. †These statistics are not reported because a direct comparison with the corresponding statistics in Table 1 cannot be made. ‡Deflated using the Consumer Price Index (base = 2004). *Source*. UK Millennium Cohort Study.

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Additional Supporting Information may be found in the online version of this article:

Data S1.

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