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The Effect of Breastfeeding on Children's Cognitive Development

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Non-Technical Summary

This paper examines the effect of breastfeeding on children's cognitive outcomes, as measured by test scores in reading, writing and mathematics measured at ages 5, 7, 11, and 14.

Breastfeeding is an issue of considerable importance for policy in the UK. Breastfeeding rates are relatively low in the UK compared to elsewhere in the developed world: the World Health Organization recommends breastfeeding exclusively for six months and alongside solid foods for two years, but in the UK, barely one in three infants is exclusively breastfed during the first four months of life.

The links between breastfeeding and positive health outcomes in children are well known. There is also a well-documented relationship between breastfeeding and better cognitive outcomes. However, a difficulty arises in studying this relationship. Because breastfeeding is more likely to be practiced by mothers whose characteristics (higher social class, higher IQ, higher levels of human capital, etc.) favour more positive outcomes for their children, it is not clear whether the relationship between breastfeeding and better cognitive outcomes is causal (breastfeeding *causes* children to do better) or whether it arises merely because mothers who breastfeed are likely to have more successful children anyway.

Several statistical approaches exist which are able to deal with this issue of causality. However, it is not always easy to implement these approaches in the study of breastfeeding (for example, there would be obvious problems with ethics and compliance in implementing a randomized controlled trial).

In this paper we use propensity score matching (PSM), a statistical technique that involves "twinning" each breastfed baby with one or more babies who were not breastfed, but who in all other observable respects are similar to the breastfed baby. We "twin" babies on a huge range of characteristics: their sex, gestational age, birthweight; their mother's age and marital status; both parents' job status and education; characteristics of their home and their neighbourhood; and many more characteristics. Crucially, we also use parents' attitudes to breastfeeding as measured before birth, to twin babies. Comparing the test scores of groups of children matched in this way, we are effectively estimating the causal effect of breastfeeding. We implement the PSM technique using data from the Avon Longitudinal Study of Parents and Children (ALSPAC), an exceptionally rich data set covering children born in the early 1990s in the Bristol area.

We find that breastfeeding does have a causal effect on children's cognitive outcomes. The "raw" difference between children who were and were not breastfed at four weeks of age is large, at a little over one third of a standard deviation. Most of this difference may be explained by maternal characteristics. However, even after controlling for these, a statistically significant difference remains. This is smaller, at a little over one tenth of a standard deviation. However, it is statistically significant across English, maths and science scores, and it persists at least until age fourteen; indeed, there is some evidence that the effect tends to grow over time.

The Effect of Breastfeeding on Children's Cognitive Development*

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Abstract

This paper uses Propensity Score Matching to investigate the causal effect of breastfeeding on children's cognitive development. There is a strong association between breastfeeding and cognitive outcomes; however, it is notoriously difficult to establish whether this is causal, or whether it arises because mothers who breastfeed tend to be those whose children would do better anyway. Using PSM, we find that breastfeeding for four weeks has a positive and significant effect on test scores, in the order of one tenth of a standard deviation. Thus, interventions which increase breastfeeding rates may improve not only children's health, but also their cognitive skills.

JEL: J12, Z13

Keywords: Breastfeeding, Cognitive Outcomes, Child Development, ALSPAC

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The most valuable of all capital is that invested in human beings; and of that capital the most precious part is the result of the care and influence of the mother.

Alfred Marshall (1890), Paragraph VI.IV.11.

1 Introduction

Recent research shows a significant impact of behavioural and psycho-social outcomes on earnings and education (Duncan and Dunifon 1998; Bowles et al. 2001; Heckman et al. 2006; Mueller and Plug 2006). Differences in children's cognitive development emerge at early ages (Illsey 2002; Feinstein 2003), and the importance of timely parental investments (pre-natal as well as post-natal) is increasingly recognized as a major factor in fostering child development (Carneiro and Heckman 2003; Del Bono et al. 2008). This paper looks at the effect of breastfeeding on children's cognitive outcomes. This is a topic of considerable importance for policy in the UK: the World Health Organization recommends breastfeeding exclusively for six months and alongside solid foods for two years, but in the UK, barely one in three infants is exclusively breastfed during the first four months of life. Given the increasing recognition of the importance of very early interventions in children's development and later outcomes; and given the huge social gradient in breastfeeding rates, with the most privileged mothers currently being many times more likely to breastfeed than the least privileged mothers, breastfeeding may well be a significant route for the intergenerational transmission of human capital. A fuller understanding of the effects of breastfeeding on aspects of child development is therefore crucial for an understanding of the intergenerational transmission of inequality, and for policy-making aimed at reducing inequality.

There is a well-established association between breastfeeding and a range of positive health outcomes in children, such as a lower incidence of asthma, middle ear and urinary tract infections (Dyson et al. 2006). A smaller body of research also shows breastfeeding to be related to better gross motor development (Sacker et al. 2006), and improved cognitive ability (Anderson et al. 1999). Other potential effects of breastfeeding, such as cognitive outcomes of the type investigate here, are much less well researched. This is partly because it is extremely difficult to identify whether the observed relationships are causal, as opposed to arising because breastfeeding is more likely to be practiced by mothers whose characteristics (higher social class, higher IQ, higher levels of human capital, etc.) favor more positive outcomes. For ethical and practical reasons, the implementation of randomized trials is usually not an option in this area of research (although experiments which randomize the provision of facilities to promote breastfeeding are feasible, as discussed by Kramer et al. 2001 and Kramer et al. 2008). Usually, researchers have attempted to address issues of causality studying sibling pairs, using changes in the maternity leave legislation, or using emergency cesarean section as instruments (Der et al. 2006; Baker

and Milligan 2007). However, the extent of the true causal effect of breastfeeding on the favourable outcomes with which it is frequently associated remains an open question.

We address the question of causality by making use of propensity score matching (PSM), a technique developed to establish the causality behind observed relationships. It involves “twinning” each breastfed baby with one or more babies who were not breastfed, but who in all other observable respects are similar to the breastfed baby. In this way, we effectively simulate an experiment by creating matched “treatment” and “control” samples, composed respectively of women who do and who do not breastfeed, but who are identical in every other observable respect (Rosenbaum and Rubin 1984).

PSM rests on the assumption that the important factors affecting an individual’s choice to breastfeed are observable, and there is no significant selection on unobservables¹. This “conditional independence” or “unconfoundedness” assumption is a strong one, and we assess its validity by undertaking sensitivity analysis using a bounding approach similar to that proposed by Rosembaum (2002). In fact, the very rich data we use mean that a high proportion of the propensity to breastfeed is explained by observable factors; the fact that we are able to implement matching to a very high standard means that the risk of bias caused by unobservable heterogeneity is low. PSM and the sensitivity analysis we use are discussed in detail in Section 3 of this paper.

The data we use come from the Avon Longitudinal Study of Parents and Children (ALSPAC). ALSPAC contains a particularly rich set of variables on infant feeding, from which we may establish the duration of breastfeeding and of exclusive breastfeeding; the stage at which formula milk, animal milks and solid foods were introduced; and the types of supplementary foods which were introduced. However, the feature of ALSPAC which make this data particularly attractive for the implementation of PSM is the fact that parents were interviewed several times prior to the birth of their children, and data collected on their attitudes to breastfeeding, whether they themselves had been breastfed as babies, and their intentions in relation to the feeding of their own children. The data are discussed in Section 2.

We find that breastfeeding has an important effect on a child’s cognitive outcomes. This effect is statistically significant and is relatively large, at around one twentieth of a standard deviation at age five, and on average a little over one tenth thereafter. It persists over time, and is common across all the outcome variables we examine. PSM estimates tend to be slightly lower than OLS estimates controlling for the same set of background variables. This suggests that not taking into account the selection effect of breastfeeding may overestimate the actual returns to breastfeeding, but in this case only very slightly.

¹ Thus, PSM differs importantly from Instrumental Variable methods, which rely on the assumption that unobservables are important and difficult to control for regardless of how precise the information on the individual and her environment is. IV is often difficult to implement in the study of breastfeeding, due to a lack of suitable instruments.

This paper significantly contributes to a growing literature on the effect of breastfeeding on children's outcomes in three ways. First, unlike most previous observational research, we use PSM to provide further evidence on the causal effect of breastfeeding on children's cognitive. Second, by examining issues of heterogeneity, – that is, whether some mothers and babies (grouped by socio-economic status or birthweight, for example) stand to benefit more than others from breastfeeding, our work adds to most existing studies on breastfeeding which rely on small sample sizes and are therefore unable to do this effectively. Third, we determine the duration of effect of breastfeeding by using a longitudinal data set where outcomes are observed at ages 5, 7, 11, and 14.

This paper is organized as follows. The data are discussed in Section 2. PSM and the sensitivity analysis we use are discussed in detail in Section 3 of this paper. Baseline results and robustness checks are discussed in Section 4. Section 5 explores heterogeneity effects, and Section 6 concludes.

2 Data and descriptive statistics

The Avon Longitudinal Survey of Parents and Children (ALSPAC) is a longitudinal study of around 12,000 children born in the Avon area in the early 1990s (Golding et al. 2001; Gregg et al. 2005). Mothers were recruited into the sample at the point at which they first reported their pregnancy to their doctors. Data were collected at four points during pregnancy and at several points following birth – from both parents, from the child him/herself, and from the child's teacher and school. Topic areas covered include physical and mental health, socioeconomic status, and child development; school-level data and children's test results are available via merged records. Ethical approval for this study was obtained from the ALSPAC Law and Ethics Committee and the Local Research Ethics Committees.

2.1 Sample

For our analysis, we consider a sample of those children in the “core sample” of ALSPAC. This sample consists of 14,541 pregnancies that resulted in 14,676 known fetuses of which 14,062 were live births and 13,988 were alive at 1 year. This is the number of pregnancies for which the mother enrolled in the ALSPAC study and had either returned at least one questionnaire or attended a “Children in Focus” clinic by 19/07/99. Out of the 14,541 core pregnancies, all but 69 had known birth outcome. Of the remaining 14,472 pregnancies, 195 were twin, 3 were triplet and 1 was quadruplet. For reasons of confidentiality data on the 13 triplet and quadruplet children were not available for analysis.

2.2 Outcome variables

The outcome variables used in this paper are Standard Attainment Test (SATs) scores² at ages 7, 11 and 14³, and the results of school entry tests at age 5. All scores are standardized to have mean zero and standard deviation 1; thus, all the results we present may be interpreted as proportions of a standard error.

In the UK, children generally start school in the September following their fourth birthday, and move up a school year every September. During the years when the ALSPAC cohort were in school, pupils' progress was monitored by compulsory SATs tests, administered at the end of each of the "Key Stages" in schools (See Table 1). When the ALSPAC cohort entered school there were no national compulsory entry assessments. However, the four Local Education Authorities covering the former Avon area (Bristol, South Gloucestershire, Bath & North East Somerset and North Somerset) all used the same entry assessment scheme, which was used by 80% of the local state schools.

Table 1: Structure of UK schools and testing procedures

Class	Age	Key Stage	Tests
--	3 - 4		--
Reception	4 - 5	Foundation	Local entry assessments
Year 1	5 - 6		--
Year 2	6 - 7	1	National tests and tasks in English and Maths
Year 3	7 - 8		--
Year 4	8 - 9		--
Year 5	9 - 10		--
Year 6	10 - 11	2	National tests in English, Maths and Science
Year 7	11 - 12		--
Year 8	12 - 13		--
Year 9	13 - 14	3	National tests in English, Maths and Science
Year 10	14 - 15		Some children take GCSEs
Year 11	15 - 16	4	Most children take GCSEs, GNVQs etc.

Source: Department for Children, Schools and Families (DCSF) at <http://www.dfes.gov.uk/>

The entry-level assessment covers eight areas. We focus on those which form the required element of the tests (language, reading, writing and mathematics); optional areas include social skills, problem solving, large motor skills and small motor skills. The stage achieved by each child in each area is recorded on a scale of 2 (least advanced) to 7 (most advanced). The KS1 battery consists of tasks in

² Scores were matched to ALSPAC data from the National Pupil Database (NPD), a central repository for pupil level educational data established in 2002, which assigns every pupil in England a Unique Pupil Number (UPN).

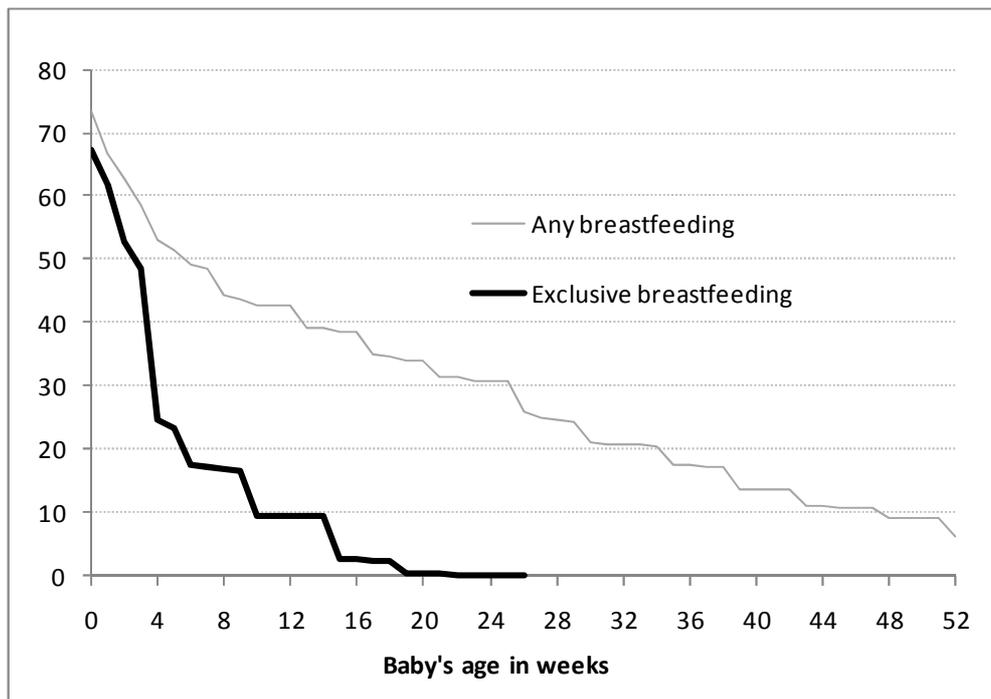
³ SATs are also taken at age 16. However, we do not consider these in this paper, since not all the children in our sample took the same national test at this point.

reading, reading comprehension, writing, spelling and mathematics. Tests at the later Key Stages consist of tasks in English, Maths and Science.

2.3 Breastfeeding variables

For the purposes of this paper, a feature of particular interest in ALSPAC is the very detailed information it contains on breastfeeding. Before their babies are born, both parents are asked about their attitudes to breastfeeding; whether they had been breastfed themselves; and about their intended feeding method for the baby in its first week, its first month, and its first four months. At intervals following their child's birth, mothers are asked how they are feeding their babies, including the stages at which infant formula and solid foods were introduced. From this, we are able to compute the duration of exclusive breastfeeding; the duration of breastfeeding; and to identify babies who were fed supplementary foods generally considered to be unsuitable (for example, coffee, coca-cola and chocolate).

Figure 1: Percentage of babies breastfed (in weeks after child is born)



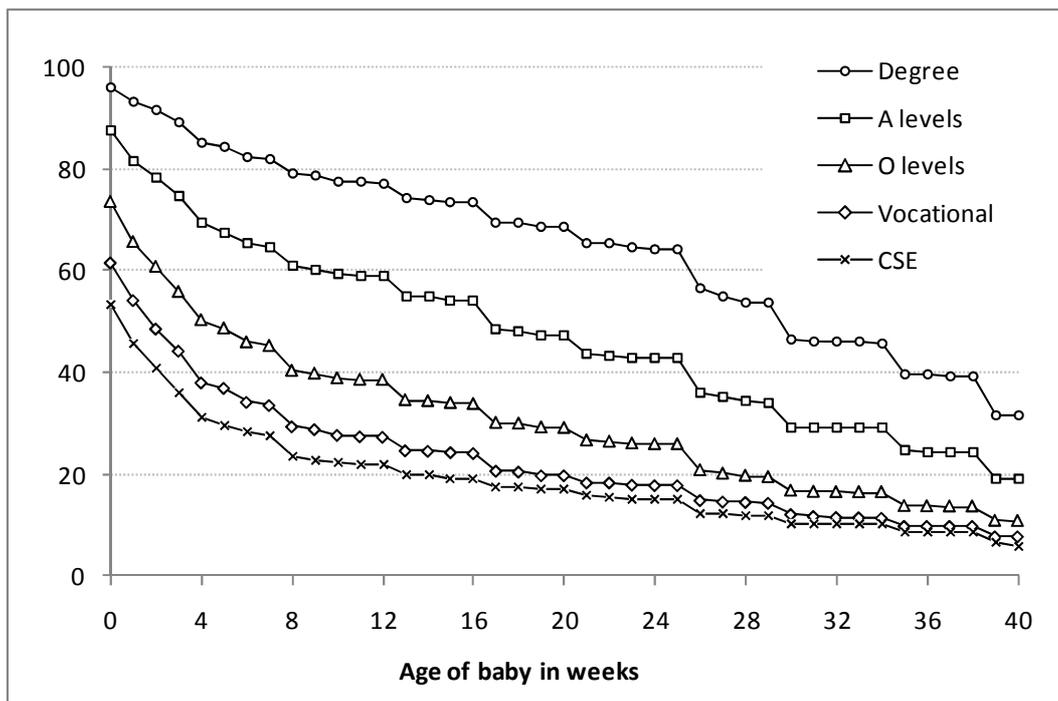
Source: ALSPAC Data, core sample.

Figure 1 shows how breastfeeding rates vary with the age of babies. Almost three-quarters of the mothers in this sample initiate breastfeeding (defined as putting the baby to the breast at least once). However, by four weeks only a little over half of all mothers are still breastfeeding at all, and fewer than

one third are still breastfeeding exclusively. By 4 months (18 weeks), only about one third of mothers are breastfeeding at all, and hardly any are breastfeeding exclusively.

Figure 2 gives an indication of how breastfeeding duration varies with the characteristics of the mother, presenting, for the five different education groups identified in ALSPAC, the percentages of women still breastfeeding by the age of the child (exclusive breastfeeding rates are not shown). The differences between the educational groups are stark. Women with a degree are more likely likely to initiate breastfeeding than women in other groups, and by one week women with a degree are twice as likely to be breastfeeding as women in the lowest educational group (93% versus 46%). These differences increase with the age of the baby: at 7 weeks, women with degrees are three times more likely to be breastfeeding than women with the fewest qualifications (82% versus 28%) while after 17 weeks, mothers with degrees are over four times more likely to be breastfeeding.

Figure 2: Breastfeeding duration by mother's education

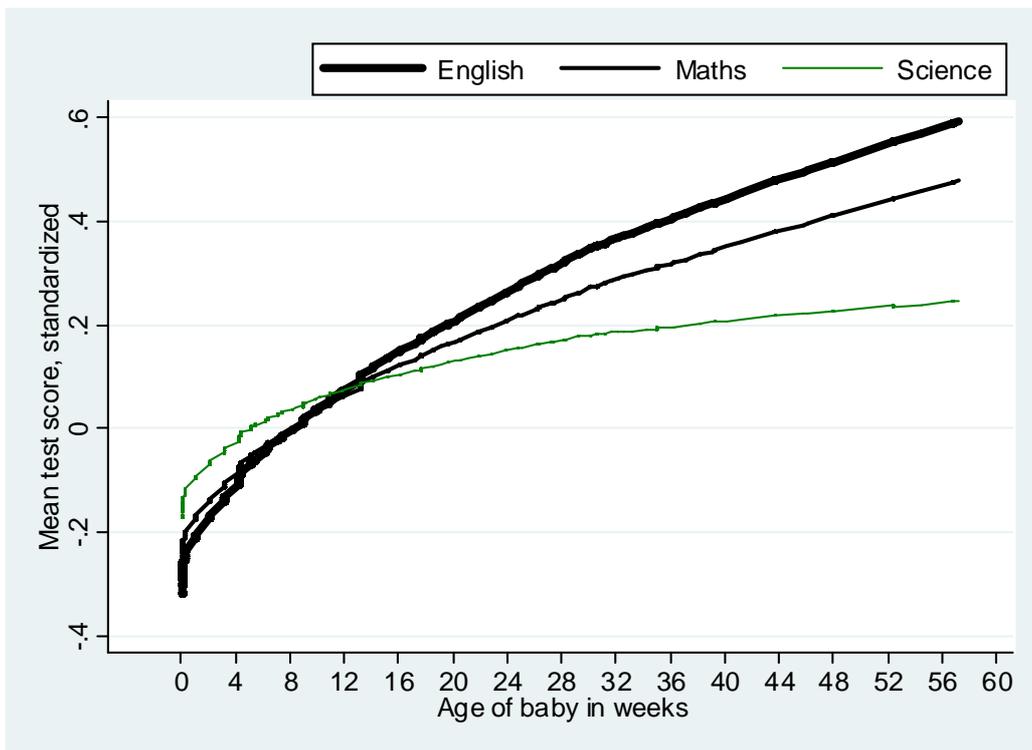


Most of the analysis in this paper is based on whether a mother is breastfeeding (at all) when her baby is four weeks old. This has a number of advantages. First, it splits the sample approximately in half, and provides reasonably large samples both of relatively privileged women who are not breastfeeding at four weeks, and of relatively less privileged women who are still breastfeeding at four weeks. It also

largely circumvents the issue of solid food, as only a tiny percentage of babies are given solid food before four weeks old.

Figure 3 shows the relationship between breastfeeding and academic outcomes at age 14. The three lines on the graph represent test scores in English, Maths and Science; each arises from the Lowess local smoothing procedure. In each of the three areas, the relationship between breastfeeding and higher scores is clear. The relationship is most marked for English, where babies who were not breastfed at all go on to score around one third of a standard deviation below average at age 14, while those who were breastfed for a year go on to score well over half a standard deviation higher. Thus, the raw difference between the outcomes of a child who was never breastfed, and a child who was breastfed for over a year, is in the order of a whole standard deviation. Differences in the other subjects are less stark but still large: in Maths, the difference is around 0.8 of a standard deviation, while in science it is 0.4 of a standard deviation.

Figure 3: Test scores at age 14 by breastfeeding duration: raw relationships



Given what we know from Figure 2 about the relationship between breastfeeding durations and maternal characteristics, it is clearly not the case that the association between breastfeeding and cognitive outcomes is entirely causal; in fact, it is likely that most of the relationship is not causal. What this paper is trying to establish is: is *any* of the relationship causal, and if so, how much?

2.4 *Other control variables*

ALSPAC also contains an extremely rich set of background variables (see Table A in Appendix A for a precise definition of all variables). Table 2 presents the mean and standard errors for each of these variables by breastfeeding status. In general, mothers who do not breastfeed when their babies are 4 weeks old have generally worse pregnancy outcomes, worse health, belong to lower socio-economic groups, are more likely to be in a non-marital relationship, have worse parenting practices. As mentioned before, mothers and fathers of children who are breastfed have higher educational attainments. In particular, parents of breastfed babies are more likely to have a university degree or A-levels than parents of babies who were not breastfed at 4 weeks. Mothers who breastfeed when the baby is 4 weeks old are more likely to work in the labor force when their babies are 18 and 21 weeks respectively. Interestingly however, there does not seem to be a significant difference in terms of the hours of formal childcare when the child is 21 weeks between mothers who breastfeed and who do not breastfeed.

Table 2: descriptive statistics

	Cigarettes at 32w	C-section	Pregnancy Female	Birth weight	Gestation in weeks	Mother's age at birth
No breastfeeding	3.21 (0.078)	0.12 (0.004)	0.48 (0.007)	3,366.42 (17.006)	39.32 (0.185)	27.02 (0.159)
Breastfeeding	1.27 (0.070)	0.10 (0.004)	0.49 (0.007)	3,443.19 (15.866)	39.52 (0.173)	29.45 (0.149)
N	11,402.00	11,761.00	14,146.00	13,901.00	14,619.00	14,663.00
Health						
	Cannabis occasionally	Cannabis often	Alcohol occasionally	Alcohol often	Mother had health	
No breastfeeding	0.02 (0.002)	0.01 (0.001)	0.99 (0.003)	0.00 (0.001)	1.82 (0.012)	
Breastfeeding	0.03 (0.002)	0.01 (0.001)	0.99 (0.003)	0.01 (0.001)	1.72 (0.011)	
N	11,310.00	11,310.00	9,884.00	9,884.00	12,146.00	
Socio-Economic Variables						
	Own house	Private Rented	Number of Rooms	Neighbourhood qual.	Mother in Care	
No breastfeeding	0.67 (0.006)	0.07 (0.004)	1.45 (0.014)	7.98 (0.049)	0.04 (0.002)	
Breastfeeding	0.83 (0.006)	0.07 (0.003)	1.72 (0.013)	8.29 (0.045)	0.02 (0.002)	
N	13,448.00	13,448.00	13,413.00	12,994.00	12,037.00	
Marital Status						
	Mother cohabiting	Mother married				
No breastfeeding	0.24 (0.006)	0.04 (0.002)				
Breastfeeding	0.17 (0.005)	0.02 (0.002)				
N	13,564.00	13,564.00				
Father's Education						
	Father Degree	Father A-levels	ather O-levels	Father vocational	Father CES	
No breastfeeding	0.09 (0.006)	0.28 (0.007)	0.26 (0.007)	0.12 (0.004)	0.25 (0.006)	
Breastfeeding	0.29 (0.005)	0.30 (0.006)	0.22 (0.006)	0.07 (0.004)	0.11 (0.005)	
N	10,772.00	10,772.00	10,772.00	10,772.00	10,772.00	
Mother's Education						
	Mother degree	Mother A-levels	Mother O-levels	Mother vocational	Mother CES	
No breastfeeding	0.05 (0.005)	0.17 (0.006)	0.42 (0.007)	0.14 (0.004)	0.22 (0.005)	
Breastfeeding	0.21 (0.004)	0.30 (0.005)	0.34 (0.006)	0.07 (0.004)	0.08 (0.005)	
N	11,710.00	11,710.00	11,710.00	11,710.00	11,710.00	
Work and Intention to Work						
	Mother work 18w	Mother will work	Hours care at 21w	Mother hours worked 21m		
No breastfeeding	0.57 (0.007)	0.00 (0.000)	24.95 (0.371)	6.34 (0.149)		
Breastfeeding	0.66 (0.007)	0.00 (0.000)	24.74 (0.328)	8.65 (0.139)		
N	11,716.00	470.00	10,533.00	14,663.00		
Parenting Practices						
	Smack at 3y	Shout at 3y	Read at 18m	Father read at 18m		
No breastfeeding	2.87 (0.020)	4.13 (0.020)	3.47 (0.016)	2.47 (0.020)		
Breastfeeding	2.70 (0.017)	4.08 (0.017)	3.63 (0.014)	2.73 (0.018)		
N	9,453.00	9,453.00	11,056.00	10,497.00		
Breastfeeding Attitudes and Intentions						
	Mother Breastfed	Father Breastfed	Mother Breastfeeding Attitudes	Father Breastfeeding Attitudes	Mother intention to breastfeed 4w	
bf_no	0.46 (0.008)	0.59 (0.010)	14.32 (0.070)	14.39 (0.081)	0.38 (0.006)	
bf_yes	0.67 (0.007)	0.72 (0.009)	17.57 (0.063)	16.45 (0.072)	0.90 (0.005)	
N	10,496.00	6,207.00	12,158.00	9,634.00	11,995.00	

3 Empirical Strategy: Propensity Score Matching

We use propensity score matching to estimate the effect of breastfeeding on children's outcomes, and to establish the extent to which the relationship between breastfeeding and children's outcomes is causal, that is, how far children's outcomes are the result of breastfeeding, rather than arising from

heterogeneity or selection. The problem is that the decision to either breastfeed or not cannot be considered exogenous with respect to children's outcomes: it is related to maternal characteristics, which are themselves related to child outcomes. Previous studies using multivariate regression analysis do not take into account this possible endogeneity, and if the decision to breastfeed is indeed endogenous, they will generate biased estimates.

A standard approach to this problem is to implement an Instrumental Variables specification, utilising as instruments variables that are correlated with the endogenous variable (here, whether the baby is breastfed), but independent of the error term. However, it is difficult to find valid and powerful instruments in our application. We therefore take the alternative approach of implementing propensity score matching (PSM) techniques, which are described below; we complement the analysis with sensitivity checks with respect to deviations from the conditional independence assumption following a bounding approach similar to that proposed by Rosebaum (2002).

We implement the propensity score matching procedure using the `psmatch2` and `pstest` modules in STATA (Leuven and Sianesi 2003); the sensitivity testing is implemented using the `mhbounds` module in STATA.

3.1 The principles behind Propensity Score Matching

Our interest lies in estimating the effect of breastfeeding on child outcomes, net of other observed factors which influence these outcomes. Ideally, we would like to compare the outcomes of children who were breastfed, with the outcomes of children who were not breastfed (the “counterfactual” situation). The problem is, of course, that for any given individual the two scenarios are mutually exclusive, preventing a direct comparison between the two. PSM techniques were developed as a means of generating an approximation to the counterfactual situation (Rosenbaum and Rubin 1983). In simple terms, the application of this method for our case is as follows:

A “treatment” is defined, which in this case is having been exclusively breastfed during the first four months since birth. Children are divided into two groups:

- $D_i = 1$, those who undertook the “treatment” (i.e., who were breastfed)
- $D_i = 0$, a “control” group (those who were not breastfed)

Each child in the “treatment” group is then paired with one or more children in the “control” group, who are as similar as possible in terms of a range of observable characteristics measured prior, during, and after the event, and the difference between groups in the child's outcome variable of interest (cognitive or non-cognitive outcome) is measured. If the differences in characteristics between the

“treatment” and “control” groups are captured by the observable covariates, then matching methods yield an unbiased estimate of the average impact of breastfeeding on the treated (i.e. those who actually were breastfed).

Matching is implemented in the following way. From the data, each child is assigned a probability of falling into the treatment group, conditional on a set of covariates X . This probability is estimated using a probit regression. This conditional probability is referred to as the individual’s “propensity score”. The propensity score for individual i is defined as:

$$P(X_i) = Pr(D_i = 1 | X_i) \quad (1)$$

where $P(X_i)$ is the propensity score, and X_i is the vector of explanatory variables measured at time t , prior to the leaving home event. Rosenbaum and Rubin (1983) showed that conditioning on this propensity score is equivalent to conditioning directly on the set of background variables X . If exposure to treatment is random within each cell as defined by X_i , it will also be random within cells defined by the propensity score variable $P(X_i)$. This is commonly referred to as conditional independence or strong ignorability.

3.2 *The Matching Procedure*

At the matching stage, individuals in the treated and control groups are paired according to their propensity scores. There are several different algorithms by which individuals may be matched: these are explained in Becker and Ichino (2002), Smith and Todd (2005) and Caliendo and Kopeinig (2005). We use the “nearest neighbour” algorithm, whereby each individual in the treatment group is matched with the individual(s) in the control group whose propensity score(s) are closest to his or her own. Rather than use a single nearest neighbour, we work with an average of the individual’s five nearest neighbours, in order to reduce the variance of our estimates.⁴ In order to exclude poor “matches”, we impose the restriction (a “caliper”) that all matched pairs must have propensity scores within 0.00025 of each other: individuals in the treatment group without a sufficiently near neighbour are excluded from the sample.

The set of observations which remain in the sample after the matching procedure is called the common support h . The matching procedure we use results in approximately 35% of otherwise valid observations being removed from the sample. Intuitively, this may be thought of as removing from the sample all those breastfeeding mothers who do not have anyone in the non-breastfeeding group sufficiently similar in characteristics to them; members of the non-breastfeeding group will not appear in

⁴ In all PSM algorithms, there is a trade-off between bias and variance. We found that nearest neighbour methods gave the best reduction in bias. Increasing the number of neighbours reduces the variance of estimates (since more information is used), but increases bias (since the mean quality of the matches will be lower). In this analysis, we found that using five neighbours gave the most acceptable balance between reduced variance and increased bias.

the analysis unless they are sufficiently similar (and more similar than other non-breastfeeding mothers) to a breastfeeding mother.

In our analysis, matching is carried out using the following variables: the child’s sex; his or her age relative to others in the same cohort; the baby’s birth weight, gestation and mode of delivery (vaginal or caesarean section); the mother’s age at birth; the parents’ marital status; the education levels of both parents, housing tenure, the size of the home, neighbourhood characteristics, whether the mother had been in care as a child, the mother’s health, whether mother had smoked during pregnancy; the mother’s use of cannabis and alcohol; mother’s labour market participation and future labour market intentions; the father’s employment; whether the child spent time in non-maternal care and for how long; aspect of parenting (how frequently the parents read to the child, and smack, or shout at the child). Additionally – and importantly – we match on whether the mother and father had been breastfed themselves as babies; on their attitudes towards breastfeeding, measured prenatally; and of their stated intentions over how their child would be fed, again recorded prenatally. A precise definition of these variables, together with summary statistics, can be found in the Appendix.

After the matching process, we check that a ‘balancing property’ holds for the matched sample: i.e. that each of the observable covariates within the treatment group has the same average value within the matched control group. Equality of the first moments does not imply equality of the entire distribution of covariates, but for binary variables—and most of the covariates used here are of this type—there is no need to compare higher order moments.

3.3 *Evaluation Parameters*

Propensity score matching generates several evaluation parameters. In this section, we explain two such parameters: the average treatment effect on the treated (ATT) and the average treatment effect on the untreated (ATU).

We may think of an outcome Y , defined under two observed or hypothetical scenarios: Y_0 , which is the outcome in the case that the young person receives the treatment, and Y_1 , which is the outcome in the case that he or she does not receive the treatment.

	Outcome if leaves home	Outcome if stays at home
Treatment group (leavers)	$Y_1/D = 1$ (observed)	$Y_0/D = 1$ (unobserved)
Control group (stayers)	$Y_1 / D = 0$ (unobserved)	$Y_0/D = 0$ (observed)

We are interested in the effect of the ‘treatment’ on both the treatment and the control groups. For the treatment group, this effect is termed ATT (average treatment effect on the treated) and measures

the difference between the average outcome measure for babies who were breastfed, and the average outcome measure for the same group under the hypothetical scenario that they had not been breastfed.

$$ATT = E(Y_i, 1/D_i = 1) - E(Y_i, 0/D_i = 1) \quad (2)$$

However, the second argument in Eq. 2 is not observed, so we replace it with the observed values of Y_0 over the matched sample of children who were not breastfed, estimating

$$ATT = E(Y_i, 1/D_i = 1, i \in \emptyset) - E(Y_i, 0/D_i = 1, i \in \emptyset) \quad (3)$$

Similarly, we may estimate the average treatment effect on the control (untreated) group

$$ATU = E(Y_i, 1/D_i = 1, i \in \emptyset') - E(Y_i, 0/D_i = 1, i \in \emptyset') \quad (4)$$

This measure refers to the group who did not breastfed, and estimates the difference between the average outcome measure in (a) the hypothetical case that they were breastfed, and (b) the actual case in which they were not breastfed. Note that Eq. 4 is identical to Eq. 3, except that it is defined over a different common support (denoted h_0 instead of h). The common support for ATT consists of all ‘‘matchable’’ members of the treatment group, plus the controls which are chosen to match them, whereas the common support for ATU consists of all ‘‘matchable’’ members of the control group, plus those members of the treatment group which are chosen to match them.

Under the assumption of homogeneous treatment effect ATT and ATU should give the same results. However, as Heckman et al. (1997) have shown, treatment effects are rarely homogeneous. We therefore report both sets of estimates⁵.

4 Results: breastfeeding and cognitive outcomes

We begin this section by presenting results from Ordinary Least Squares regressions, as a benchmark against which to compare our PSM results.

⁵ Psmatch2 generates both ATT and ATU estimates in the same step. However, in order to allow the common support to vary between the two parameters, we implement a second set of estimates where the treatment is defined as not having been breastfed during the first four months of life. Here, the estimated ATT is equivalent to the ATU calculated in the first set of estimates, and this way we are able to allow the common support to vary between the parameters, and to verify that the balancing property holds for our estimates of ATU as well as ATT.

4.1 OLS Results

Table 3 presents estimates of the relationship between breastfeeding and test scores from OLS regressions. Three specifications are presented. Each controls for whether the child was breastfed or not at four weeks of age. The first specification includes very few additional controls – only the child’s sex and his or her age at the time of taking the test. The second specification adds in a range of variables indicating parental education, while the third specification controls for the full set of variables described in Section 3. Standard errors are in parentheses, and significance is shown by stars.

Table 3: OLS regressions: coefficients on breastfeeding

		Specification 1	Specification 2	Specification 3
Entry Level	Reading	0.312*** (0.022)	0.140 *** (0.022)	0.102 *** (0.026)
	Writing	0.212*** (0.021)	0.077 ** (0.022)	0.052 (0.027)
	Maths	0.286*** (0.021)	0.106 *** (0.022)	0.041 (0.026)
Key Stage 1	Reading	0.197*** (0.025)	0.091 ** (0.026)	0.057 (0.031)
	Writing	0.338*** (0.020)	0.130 *** (0.020)	0.072 ** (0.023)
	Maths	0.332*** (0.020)	0.141 *** (0.020)	0.112 *** (0.024)
Key Stage 2	English	0.402*** (0.019)	0.141 *** (0.019)	0.088 *** (0.022)
	Maths	0.392*** (0.019)	0.143 *** (0.019)	0.122 *** (0.023)
	Science	0.443*** (0.019)	0.190 *** (0.019)	0.126 *** (0.023)
Key Stage 3	English	0.437*** (0.021)	0.175 *** (0.020)	0.139 *** (0.024)
	Maths	0.354*** (0.021)	0.149 *** (0.022)	0.114 *** (0.026)
	Science	0.231*** (0.021)	0.120 *** (0.022)	0.117 *** (0.027)

Source: ALSPAC core sample. Standard errors in parentheses. Significance denoted by asterisks:
* = 5%, ** = 1%, *** = 0.1%

Estimates in the first specification (essentially the raw relationship, controlling only for the child’s sex and age at testing) indicate that breastfeeding is associated with test scores higher by about one third of a standard deviation, with coefficients ranging from 0.197 (Reading, KS1) to 0.443 (Science, KS2). As

soon as parental education is controlled for (Specification 2) these estimates drop sharply, to approximately one third of their original size. Estimates now range from 0.077 (Writing, entry level) to 0.190 (Science, KS2). As we would expect, controlling for additional factors reduces the estimates still further – but in fact, not by very much. A case in point is the coefficient on English at KS3, which falls from 0.437 to 0.175 between Specifications 1 and 2, but only to 0.139 in Specification 3. This suggests that a very large amount of the heterogeneity between breastfeeding and non-breastfeeding families is captured by parental education, with all the other controls together (including attitudes to breastfeeding and intention to breastfeed) capturing only a small proportion after education is controlled for. The estimates in the third specification are of the order of 10 per cent of a standard deviation; most of the estimates remain statistically significant, although some estimates in the early years are not.

Because of the relationship between maternal characteristics and the likelihood of breastfeeding, we cannot claim that these estimates represent a causal effect: they may simply arise from the endogeneity of the breastfeeding decision. We now present PSM estimates.

4.2 PSM Estimates

Table 4 presents estimates of ATTs obtained via PSM techniques, as explained in the previous section, and compares them to the OLS estimates obtained depicted in Table 3. These PSM estimates are analogous to the first set of figures, in that they represent the improvement in abilities associated with breastfeeding during the first four weeks of a child's life. However, the PSM results control for the mother's selection into breastfeeding, i.e., for the fact that more able mothers (who are more likely to also have more able children) are also the ones who are more likely to breastfeed. Therefore, the difference between the OLS and PSM results gives an indication of the size of the selection effect.

The PSM estimates of the ATT are essentially the same as the OLS coefficients with a large set of control variables. In general the significance levels are a little lower, which may be due to the fact that the PSM estimates are run on the smaller sample of the common support. However, the estimated effects are still significant at all ages after school entry level, confirming our previous result that controlling for a wide range of factors, children breastfed for four weeks or more do better than children breastfed for less than four weeks by about one tenth of a standard deviation (slightly less at younger ages, and slightly more at older ages). The use of the PSM technique to control for heterogeneity suggests that these differences are likely to be causal.

The third column in Table 4 presents results from the ATU. Differences between ATT and ATU would suggest that breastfeeding had different effects on the group of babies who are currently likely to be breastfed, and the group of babies not currently likely to be breastfed. In fact, the ATT and ATU estimates are rather similar, suggesting that to the extent that breastfeeding does have a causal effect on

cognitive outcomes, that effect does not differ on average between children whose mothers are and are not likely to breastfeed them.

Table 4: Comparing OLS and PSM coefficients

		OLS	PSM: ATT	PSM: ATU
Entry Level	Reading	0.102 *** (0.026)	0.101 * (0.046)	0.152 ** (0.044)
	Writing	0.052 (0.027)	0.042 (0.043)	0.077 (0.042)
	Maths	0.041 (0.026)	0.062 (0.043)	0.091 * (0.043)
Key Stage 1	Reading	0.057 (0.031)	0.154 ** (0.050)	0.111 * (0.052)
	Writing	0.072 ** (0.023)	0.097 ** (0.038)	0.080 * (0.038)
	Maths	0.112 *** (0.024)	0.108 ** (0.038)	0.135 *** (0.038)
Key Stage 2	English	0.088 *** (0.022)	0.129 *** (0.036)	0.127 *** (0.035)
	Maths	0.122 *** (0.023)	0.159 * (0.036)	0.108 ** (0.035)
	Science	0.126 *** (0.023)	0.080 * (0.036)	0.114 ** (0.035)
Key Stage 3	English	0.139 *** (0.024)	0.133 ** (0.041)	0.178 *** (0.040)
	Maths	0.114 *** (0.026)	0.119 ** (0.039)	0.124 ** (0.040)
	Science	0.117 *** (0.027)	0.118 ** (0.039)	0.112 ** (0.039)

Source: ALSPAC core sample. Standard errors in parentheses. Significance denoted by asterisks:
* = 5%, ** = 1%, *** = 0.1%

5 Conclusion

This paper aims to rigorously disentangle the effects of breastfeeding from the effects of mother's characteristics and other unobservables in determining children's cognitive and non-cognitive outcomes. Using a very rich longitudinal data, ALSPAC, we implement a PSM technique to pin down the causal effect of breastfeeding on children's cognitive outcomes. We find statistically significant effects of breastfeeding at all ages after school entry level. PSM estimates of the ATT are essentially the same as the OLS coefficients when a large set of observed variables is controlled for, suggesting that children breastfed for four weeks or more do better than children breastfed for less than four weeks by about one tenth of a standard deviation (slightly less at younger ages, and slightly more at older ages). We also fail to find any differences between the ATT and ATU estimates, suggesting that to the extent that

breastfeeding does have a causal effect on cognitive outcomes, that effect does not differ on average between children whose mothers are and are not likely to breastfeed them. Further investigation of heterogeneity among mothers and children is however needed.

Although we view our results as strong evidence that mother's socio-economic background cannot entirely explain the observed effect of breastfeeding on children's cognitive outputs, we acknowledge that unobserved heterogeneity remains an issue. For example, determinants of children's cognitive outcomes not considered in our analysis include the mother's IQ. We note however that the richness of the data allows us to control for observed heterogeneity in a very precise way. Furthermore, we find that a very large amount of the heterogeneity between breastfeeding and non-breastfeeding families is captured by parental education, with all the other controls together (including attitudes to breastfeeding and intention to breastfeed) capturing only a small proportion after education is controlled for.

Our results can provide insights into the short term and long term effects of breastfeeding. The relevance of this research to policy is clear. The World Health Organisation recommends exclusive breastfeeding during the first six months, and the continuation of breastfeeding alongside solid foods for two years (World Health Organisation 2003). The UK Department of Health has identified breastfeeding promotion as a key strategy in reducing inequalities in health, and has funded several initiatives and projects which aim to increase breastfeeding rates, particularly among women from disadvantaged groups (Department of Health 2003). Given the huge social gradient in breastfeeding rates, with the most privileged mothers currently being many times more likely to breastfeed than the least privileged mothers, our results show that breastfeeding may well be a significant route for the intergenerational transmission of human capital, and for policy-making aimed at reducing inequality.

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Appendix A

Table A.1 List of variables used in the analysis

Outcome Variables	
Entry assessment	
Language	
Reading	
Writing	
Mathematics	
Social skills	
Problem solving	
Large motor	
Small motor	
Key Stage 1	
Reading	
Comprehension	
Writing	
Spelling	
Mathematics	
Key Stage 2 and 3	
English	Consists of a writing tasks, a reading tasks, and a spelling task. The writing tasks is made up of a longer task (45 minutes, max. 30 marks) and a shorter task (30 minutes, max. 16 marks). The spelling task is assessed as part of the shorter task (max 4 marks). The reading task is made up of a reading paper (1hr 15 min, max 32 marks) and a Shakespeare paper (45 min, max 18 marks).
Mathematics	Paper 1 (a non-calculator paper) (1hr) (60 marks), a paper 2 (a calculator paper) (1hr) (60 marks), and a mental mathematics test (20mins) (30 marks).
Sciences	2 papers of 1hr each.
Control Variables:	
Breastfeeding variables:	
	<u>Main control:</u> A dummy variable (feed4wany) that takes value 1 if the child was given any breast milk at week 4 after birth.
	<u>Attitudes and intentions:</u> An indicator variable (M_bf) that takes value one if the mother/father was breastfed as a baby, a variable indicating breastfeeding attitudes of the mother and father (M_bfatt), a dummy variable (M_intend_bf4w) that takes value one if the mother/father has intentions to breastfeed at 1 month after the birth,
Age at the time of the test:	
	Four variables (tstEage, tst1age, tst2age, tst3age) that indicate the age of the child (in months) at which he or she sited the test.
Socio-demographic variables (at or during pregnancy):	
	A dummy that takes value 1 if the child is a female (fem), two dummies for house tenure (tenure_own and tenure_rent) that take value 1 if the mother owned the house or rented the house during pregnancy, the number of living rooms in the house during pregnancy (rooms), neighborhood indicators with higher values indicating a better neighborhood (neigh_q), three dummies (mastat) indicating the marital status of the mother at the time of pregnancy (married, cohabiting, or separated/divorce), 5 dummies (M_ed and F_ed) indicating the mother's and

father's education level (CSE, Vocational, O level, A level, degree), indicator variable that takes value 1 if the mother is in local authority care (M_care), an indicator variable (M_work18w) that takes value 1 if the mother was working at 18 weeks of the pregnancy, an indicator variable (M_willw*) that takes value 1 if the mother intends to work after birth, a variable (M_hrswork) indicating the mother's number of hours worked when the child is 21 months old, a variable indicating the number of hours the child is in care at 21 months of age (hrscare).

Pregnancy and delivery information:

Indicator taking value one if the mother is in bad health status (M_badh), mother's age at birth (M_age_b), number of cigarettes a day (measured at 23 weeks of pregnancy, M_ncigs_AN32w), an indicator variable (M_csec*) that takes value 1 if the mother had a cesarean section, a dummy variable indicating whether the mother took cannabis during pregnancy (cann), and a variable indicating whether the mother took alcohol during pregnancy (alcoh).

Parenting styles:

Two variables taking values from 0 to 4 indicating the number of times the mother/father reads to the child at the age of 18 months (M_read18m and F_read18m), two variables (smack and shout) measured when the child is 3 years of age that captures the frequency in which the child is smacked (1 never, 2 rarely, 3 once a month, 4 once a week, and 5 daily).
