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IZA DP No. 13296

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ISSN: 2365-9793

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ABSTRACT

Beyond Birthweight: The Origins of Human Capital*

Birth weight is the most widely used indicator of neonatal health, mainly because it is routinely recorded in birth registries. But are better measures available? We use unique data including fetal ultrasounds to show that more specific measures of the fetus and of the newborn are more informative about the prenatal environment and more predictive of child health and development, beyond birth weight. Our results are robust to correcting for measurement error and accounting for child- and mother-specific unobserved heterogeneity. Our analysis rationalizes a common finding in the early origins literature, that prenatal events can influence postnatal development without aecting birth outcomes.

JEL Classification: I12, J13, J24

Keywords: birth weight, fetal development, child health, developmental origins, measurement

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* Gabriella Conti, Mark Hanson, and Keith Godfrey conceptualised the paper. Gabriella Conti designed and carried out the empirical analysis and wrote the paper. Keith Godfrey provided important feedback at dierent stages of analysis and writing. Sarah Crozier carried out the analysis of the Birthright data. All the authors commented on the final version.

1 Introduction

The importance of the prenatal period in affecting lifecycle outcomes is now documented in a vast interdisciplinary literature, to which economics has provided significant contributions in recent years (see Currie and Almond (2011) and Almond et al. (2018) for reviews). Within this literature, birth weight has been routinely used as measure of neonatal health. Lower birth weight babies have worse health and cognition, lower educational attainment, wages, and longevity.[1] However, apart from what it measures directly, there is little clarity on what birth weight actually represents. Is birth weight *per se* important, or is it a proxy for unmeasured endowments? In this paper we address this important, yet currently unanswered, question. As Almond et al. (2018) put it: "More progress could be achieved if some of the measurement problems could be addressed. Some of our most widely used measures, such as low birth weight, are at best only proxies [...]. Without sensitive and specific measures [...] all we can do is wait and see what the eventual outcome will be".

In this paper we use unique UK data with measures of fetal development from ultrasound scans to open the "black box" of birth weight. Our objective is to examine the information content and the predictive power of key measures of fetal development, which are routinely collected as part of prenatal care in several countries,[2] and also of additional measures of neonatal health. Our analysis proceeds in two steps. In a first step, we investigate the association between measures of fetal head, abdominal and femur size and growth (the "fetal health capital") with a variety of neonatal measurements, including birth weight (the "neonatal health capital"). According to the medical literature, fetal head size is highly correlated with brain growth, abdominal circumference with adiposity accretion and femur size with linear skeletal growth (Godfrey et al., 2012). In a second step, we examine the predictive power of fetal development for child physical and mental health, above and beyond health at birth. While fetal measures from ultrasounds are novel in economics, there is an emerging literature in medicine and epidemiology which shows that they are powerful predictors of child health (see Alkandari et al. (2015) and Larose et al. (2017) for reviews), and that they are associated with different prenatal investments; such literature, however, is limited in the way it has examined predictive validity, dynamics and postnatal effects of fetal development. Hence, with this paper we advance not only the vast literature in economics on the determinants and consequences of early health, but also the related literature in medicine and epidemiology, which has not carried out such an extensive and coherent analysis to date.

While the presence of inequalities at birth is well established, we start by showing that differences in human development can be measured in a meaningful way even before birth. Figure 1, based on the Southampton Women Survey (SWS) data, shows the mean standardised differences for each trimester of gestation in the three measures of fetal size that we study in this paper and in the corresponding measures

[1] See for example Conley et al. (2003); Behrman and Rosenzweig (2004); Almond et al. (2005); Black et al. (2007); Oreopoulos et al. (2008); Royer (2009); Figlio et al. (2014); Bharadwaj et al. (2018). Another influential strand of the economic literature has used height as measure of early health (Case and Paxson, 2010). A detailed review of the papers related to our work is presented in Appendix Section A.

[2] Measures of fetal development from ultrasound scans are recorded in routine prenatal care visits and are increasingly been made available to researchers, see for example the multicentre Fetal Growth Longitudinal Study of the INTERGROWTH-21st Project.

of birth size,[3] by neighbourhood deprivation. The fetuses of mothers living in the more deprived neighbourhoods of Southampton are significantly smaller since early gestation (by as much as a quarter of a standard deviation), and preserve this disadvantage until birth.[4]

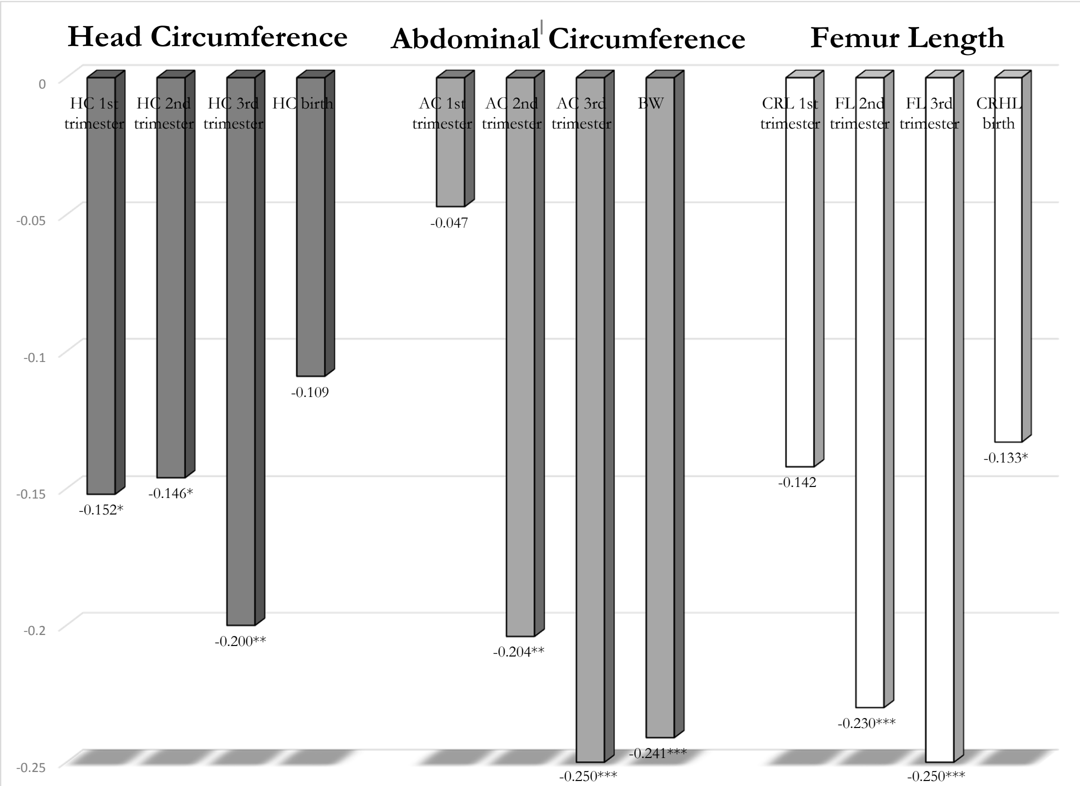

Figure 1: Fetal And Neonatal Health Gradients by Deprivation.

Notes: The graph above is based on the SWS data. Each bar plots the coefficient (displayed at the end of the bar) of a linear regression of a specific fetal measure (by trimester) or birth measure on a binary indicator for mother resident in a neighbourhood in the bottom quartile of the Townsend Deprivation Index (baseline: top quartile). We use a balanced sample of 965 women. HC: Head Circumference; AC: Abdominal Circumference; CRL: Crown-Rump Length; FL: Femur Length; CRHL: Crown- Heel Length; BW: Birth Weight. Here we use crown-rump length rather than femur length for the first trimester because of the smaller number of observations available for the latter, due to the difficulty of measuring it early in gestation.

Motivated by this evidence, in the first part of our analysis we study the relationship between fetal and neonatal health using the SWS data. We provide several novel results. We first show that fetal measures meaningfully predict different birth outcomes, such as birth weight; and that other neonatal measures, such as birth length and head circumference, as well as Apgar scores, are more informative than birth weight

[3]These are birth weight as the corresponding birth measure of fetal abdominal circumference, birth length as that of fetal femur length and birth head circumference as that of fetal head circumference, see the analysis in section 4.1.

[4]Corresponding graphs by prenatal investments are in Figure A1. Here the gaps are even bigger: the fetuses of mothers smoking continuously in pregnancy have a smaller size since the beginning of gestation, and more than double their initial disadvantage, which corresponds to 0.518 and 0.578 of a standard deviation lower weight and shorter length at birth, respectively (panel a). In contrast, the fetuses of mothers gaining excessive weight are significantly bigger since early gestation, and grow significantly more in the second part, so to have a 0.353 of a standard deviation larger abdominal circumference in the third trimester, and a corresponding 0.349 of a standard deviation higher birth weight (panel b).

about different aspects of the prenatal environment. We then show that birth weight primarily reflects the abdominal circumference of the fetus, and that, while fetuses with relatively larger girths have higher birth weights, they also have shorter lengths of gestation and lower Apgar scores; higher birth weight newborns have also more neonatal fat mass. Hence, *birth weight captures both negative as well as positive aspects of fetal health*. Although it provides *some* information about the endpoint of fetal growth, it neither describes the trajectory followed in utero, nor does it reflect the body composition of the fetus: it is a short-term indicator and mostly reflects the uterine environment in the last trimester. Other neonatal measures such as birth length and head circumference, instead, convey information about earlier parts of gestation. These results are robust to controlling for a large set of predetermined covariates and for child-specific unobserved heterogeneity, and to accounting for measurement error in the fetal measures using factor-analytic methods; we also replicate them using another UK dataset with fetal ultrasound scans data (the Birthright study). Lastly, we show that fetal health in the middle of gestation has an effect on health at birth, above and beyond fetal health at the end of gestation; and that patterns of fetal growth - in particular, deviations from a balanced growth trajectory - are important predictors of costly birth outcomes such as low birth weight and prematurity.

In the second part of our analysis, we assess the predictive power of these novel fetal measures for postnatal outcomes. We show that third trimester fetal anthropometrics are predictive of child height and BMI at six years of age, above and beyond measures of size and length at birth, and even postnatally; these results are robust to accounting for individual unobserved heterogeneity using a child fixed effects model. We also show that including multiple measurements matters, since the persistence of health capital varies both depending on the specific measure considered, and over developmental periods. While birth weight is associated with both height and body mass index (BMI), not accounting for birth length overestimates the strength of its association with height and underestimates that with BMI. Using two U.S. data sources - the Children of the National Longitudinal Survey of Youth (CNLSY) and the Pathways to Adulthood (PtA) - and a mother fixed effects approach, we then show that birth length indeed rivals birth weight in predicting child growth and cognition. Last, we show that patterns of fetal growth are predictive of common and costly child physical and mental health conditions - overweight, asthma and hyperactivity - above and beyond poor health at birth.

This paper provides several contributions to the literature on the early origins of health. First, we show what is being measured by birth weight, the most commonly used indicator of early health. Our results suggest that health in utero and at birth is multidimensional, and cannot be easily summarized by one proxy measure. Multiple indicators should be collected and used to achieve a more complete assessment of the causes and consequences of early life health. In particular, adding fetal growth data to routine records is likely to be of value (hospitals in England offer all pregnant women at least two ultrasound scans during their pregnancy), along with birth length. Second, we bridge the two literatures on birth weight and height as markers of early health, by showing that they reflect different aspects of the uterine environment, and as such should not be used interchangeably as markers of early health. Third, we rationalize a common finding in the developmental origins literature, by showing that suboptimal fetal growth patterns can have postnatal consequences on child health and development, without being fully reflected in worse neonatal health. Fourth, our findings have also important implications for the specification of models of child health and development in general, and of height and weight production functions in particular: while the literature commonly assumes a Markovian process, our results suggest the need for a more flexible specification which accounts for richer dynamics early in life.

The paper proceeds as follows. In section 2 we present our empirical framework and in section sec:data we describe the data that we use. The results are presented in section 4. Section 5 concludes.

2 Empirical Framework

We build on the seminal work by Case et al. (2005) and extend their framework to consider three stages of early human development: childhood, birth, and the prenatal period. We specify health in childhood (H^C) as a linear function of health at birth (H^B) and health in the prenatal period (H^P):[5]

$$H^C_{ij} = \beta_0 + \beta_B H^B_{ij} + \beta_P H^P_{ij} + \mathbf{X}'_{ij}\gamma_{\mathbf{X}} + \mu_{ij} + \eta_j + \varepsilon^C_{ij} \tag{2.1}$$

where subscript i refers to the child, subscript j refers to the mother, $\mathbf{X}$ is a vector of predetermined (pre-pregnancy) characteristics, μ_{ij} and η_j are child- and mother-specific time-invariant unobservables, and ε^C_{ij} is an idiosyncratic error term assumed independent of all the other terms in the equation.

We further specify health at birth as a linear function of health *in utero*:

$$H^B_{ij} = \gamma_0 + \gamma_P H^P_{ij} + \mathbf{X}'_{ij}\delta_{\mathbf{X}} + \mu_{ij} + \eta_j + \varepsilon^B_{ij} \tag{2.2}$$

where all the terms are defined as above. Equation 2.1 formalizes one of the central principles of the Developmental Origins of Health and Disease (DOHaD) concept, i.e. that the fetal environment can affect post-natal health and development both indirectly through its effect on birth outcomes, and also directly, for example via epigenetic pathways (Gluckman and Hanson, 2008). Due to data limitations, the economic literature has so far estimated a version of equation 2.1 in which $\beta_P = 0$.[6] In this paper, instead, armed with unique data on fetal measurements from ultrasound scans, we bring to the data equation 2.1, to examine whether fetal development predicts child outcomes above and beyond health at birth (section 4.2). Before doing so, we estimate different versions of equation 2.2 to understand the relationship between fetal and neonatal health capital (section 4.1).

Under the DOHaD hypothesis,[7] we expect that, controlling for health at birth (H^B), prenatal health (H^P) has significant effects on childhood health (H^C) in equation 2.1. Clearly, any association between prenatal,

[5]Linearity is assumed for simplicity and can be relaxed. Health in each period can be multidimensional, e.g. H^C could include height and longstanding conditions of the child; H^B could include indicators of birth size, fetal distress and Apgar scores; and H^P could include indicators of fetal size and growth in different trimesters. The measures we use are described in section 3.

[6]A complementary literature has examined the impacts of shocks and policies in utero (e.g. famines or provision of prenatal care) on birth and postnatal outcomes, see Almond et al. (2018) and Conti et al. (2019) for a review. However, the lack of data on fetal development has limited our understanding of the mechanisms through which these prenatal inputs operate.

[7]In the words of Barouki et al. (2012) "Functional changes result in changed susceptibility to non-communicable diseases that will likely show up later in life, with a latency that may vary from months to years or even decades. [...] Again, the latency before the appearance of health impacts necessitates the development of biomarkers of exposure and the future risk of ill health that can be measured early in life."

birth and postnatal health estimated by ordinary least squares (OLS) might not reflect causal impacts but common unobserved third factors, given the potential correlation of prenatal and birth health with the unobserved endowments μ_{ij} and η_j. We will address this issue using two different strategies: (1) controlling for an extensive set of predetermined variables to act as a proxy for unmeasured endowments and using the Oster (2019) approach; and (2) estimating various fixed effects models. First, given the richness of our data, we are able to control for a wealth of predetermined characteristics, including indicators of socioeconomic background, lifestyles and anthropometric measurements of both parents and grandparents. We show that our estimates are robust to conditioning on this large set of controls. Second, we exploit the availability of multiple and repeated anthropometric measures at birth and pre- and post-natally to estimate fetus/child fixed effects models in the SWS, to account for unobserved individual heterogeneity.[8] Even if each strategy has limitations, all the evidence we produce shows a coherent picture of the importance of prenatal development and the value of fetal and neonatal measures, in addition to birth weight, in models of human capital.

3 Data

Our main data source is the Southampton Women's Survey (SWS, Inskip et al. (2006)), a survey of 12,583 non-pregnant women in Southampton (UK) aged 20-34 years, who were recruited and interviewed between 1998 and 2002 about diet, body composition, physical activity, socioeconomic circumstances and lifestyles. It is the only population-based cohort study in which the mothers were recruited before conception, and it has been widely used to study determinants and consequences of fetal development. Women who subsequently became pregnant were followed-up. Extensive information on both mother and child was collected in early and late gestation, at birth, 6 months, 1 year, and 2, 3, 4 and 6 years.

In the SWS, 3,158 women became pregnant and gave birth between 1999 and 2007. Experienced ultrasonographers used high-quality Acuson 128 XP, Aspen and Sequoia ultrasound machines calibrated to 1540 m/s, to perform fetal measurements almost at the end of the first trimester of pregnancy (11 weeks), in the middle of the second trimester (19 weeks), and in the middle of the third trimester (34 weeks of gestation). Figure A2 presents screenshots of different bodily parts of the fetus from ultrasounds which show how the three anthropometric indicators we use are measured. Of all the women with recorded fetal measurements, for our analysis we use data on the 1,982 who belong to the "fetal growth sample". This sample, according to the SWS protocol, only includes women with reliable menstrual data, i.e. with estimated date of conception derived either from declared date of conception (if not on hormonal treatment), or from detailed last menstrual period (LMP) data, ascertained soon after the woman's first positive pregnancy test, and subsequently verified by scan data (this is the majority of cases with n=1,966).[9] The remaining 1,174 women not in the fetal growth sample were excluded because their menstrual data was deemed unreliable, either

[8]In our analysis of the relative importance of birth weight and length for child health and cognitive development, we also estimate mother fixed effects models on CNLSY and PtA data.

[9]Trivially, if the date of conception is established from the size of the fetus at the first visit (with reference to either internal or external growth charts) - for example because the woman does not recall the date of her last menstrual period, or she has an irregular period - one cannot use that fetus as a reference for size at a certain gestational age.

Table 1: Summary Statistics: Fetal Development.

	(1) Mean	(2) SD	(3) Min.	(4) Max.	(5) N
Head Circumference 11w	70.00	9.18	43.00	102.30	1,255
Head Circumference 19w	168.42	8.63	143.10	199.00	1,941
Head Circumference 34w	317.70	10.78	282.60	360.50	1,846
Abdominal Circumference 11w	55.90	7.66	32.00	85.30	1,175
Abdominal Circumference 19w	146.27	9.08	117.40	177.30	1,932
Abdominal Circumference 34w	307.70	15.30	256.30	383.90	1,920
Femur Length 11w	7.11	1.90	3.15	14.30	468
Femur Length 19w	30.63	2.09	23.80	37.80	1,943
Femur Length 34w	64.85	2.69	55.20	73.70	1,918

Notes: Own calculations from the SWS data. Each fetal anthropometric indicator is the unweighted average of three different measurements. All measures are in mm. SD=Standard Deviation. Min.=Minimum. Max.=Maximum. N=sample size. w=week.

because the estimated date of conception had to be derived from the scan data (n=1,079), because they were on hormonal treatment, or because the scan data were not in range.[10]

As mentioned, our main measures of interest are the head circumference, the abdominal circumference and the femur length of the fetus. Each fetal anthropometric indicator we use is the unweighted average of three different measurements. Summary statistics are reported in Table 1. The table shows that the head of the fetus is larger than the abdomen, and that both double in circumference at each stage of gestation; the femur instead grows by a multiple of four between the first and the second trimester, and doubles between the second and the third.

Table A2 reports the summary statistics for the derived prenatal measures (panel A, H^P in equations 2.1 and 2.2), for the birth measures (panel B, H^B in equations 2.1 and 2.2), and for the postnatal outcomes (panel C, H^C in equation 2.1)[11] that we use in the analysis. The measures of fetal size and growth have been internally standardized for gestational age according to the method developed by Royston (1995), which has been used extensively in the medical literature.[12] The average birth weight in our sample is 3.45 kg and the prevalence of low birth weight (<2,500 grams) is 4% - lower than the official one recorded for the South East of England for 2010, i.e. 6.7%.[13] The proportion of small-for-gestational age (SGA) babies (below the

[10]In Table A1 we compare the background (pre-pregnancy) characteristics of the fetal and non-fetal growth samples. Unsurprisingly, the mothers in the fetal growth sample are positively selected under different socioeconomic characteristics and health behaviours, less so in terms of health and anthropometric outcomes. While these differences do not invalidate the internal validity of our results, they somewhat limit their external validity.

[11]All the birth and postnatal anthropometric measures have been converted into z-scores, using the Child Growth Foundation (CGF) charts (Cole et al., 1998), which are the standard for UK measurements.

[12]See Royston and Altman (1995), the WHO multicentre study by Merialdi et al. (2014), and Pike et al. (2010) for a detailed description of the methods for the derivation of the fetal growth variables. We have also checked that the *z*-scores derived using the Royston (1995) method are highly correlated with those derived using the Cole et al. (1990) LMS method.

[13]Source: Office for National Statistics. The South East of England is the region where Southampton is located, and 2010 is the first year in which this statistic is available.

10th percentile of the birth weight-by-gestational age distribution) is twice that of low birth weight babies, i.e. 8%. At the other end of the distribution, 13% and 9% of the newborns have high birth weight (>4,000 grams) and are large-for-gestational age (LGA, above the 90th percentile), respectively, in line with the overall trend in England.[14] Table A3 reports summary statistics for preconception characteristics collected at recruitment.[15]

The women in the SWS are predominantly of white ethnicity and on average 31 years old at delivery (they are born between 1963 and 1981) and for 52% of them this is the first birth; a quarter of them have a university degree, 42% belong to social class I or II, and 12% of the families receive welfare benefits. Additionally, their average BMI is at the overweight threshold (25 $\frac{kg}{m^2}$), 18% of them report being in 'fair' or 'poor' health, and almost half report to have experienced some stress in the last 4 weeks. Before pregnancy, the majority of them (81%) worked, about a quarter of them smoked (25%), 55% drank more than 4 units of alcohol per week, more than 60% exercised weekly, and the average daily intake was 2,090 calories. We have also ascertained that the SWS is broadly representative of the English population, by comparing the characteristics of the SWS participants to those of the women in the 1970 British Cohort Study (BCS).[16] The other datasets used in this paper - the UK Birthright Study, and the US CNLSY and PtA - are described in Appendix Section B.

4 Results

4.1 Understanding Health at Birth

In this section we begin to open the "black box" of fetal development by examining the relationship between birth weight and fetal health capital. We start by estimating different versions of equation 2.2. We present in Table 2 conditional associations between the three measures of fetal size and birth weight in kilograms (columns 1a-1c), gestational age at birth (columns 2a-2c), and birth weight z-score (columns 3a-3c), separately by trimester of gestation. Here we condition on a minimal set of covariates: gender, ethnicity, being a first born and year and month of birth.[17] Each cell presents the estimated coefficient from an OLS regression of a birth measure on a fetal measure. We make several observations. First, we notice that, across all the dimensions considered, each measure of fetal size has a positive association with birth weight, whose strength

[14] Ghosh et al. (2018), using vital statistics of all live, singleton births, document that in 2012 the percentage of low and high birth weight babies was 5.77 and 8.84 respectively, lower and higher than the corresponding figures in 1986 (6.39 and 6.72).

[15] A limited number of these characteristics, which we use in the models where we control for an extensive set of covariates, has missing data for some observations. In these cases, we replace missing values for the binary variables with zeros; and we replace missing values for the continuous variables with the sample means of the non-missing observations. In all the analyses, when we use these variables we also include binary indicators which take value one when the original observation has a missing value. The prevalence of missing data varies between a minimum of 3% for mother Social Class to a maximum of 24% for mother's partner Social Class, with most imputed variables having missing data in 12%-15% of the observations.

[16] The two samples are remarkably similar at age 30: 40% of the BCS women belong to Social Class I and II, 45% are single, 49% are married, 5% separated, divorced or widowed, and their average BMI is 24 $\frac{kg}{m^2}$; the corresponding figures for the SWS women are 42%, 45%, 50%, 5% and 25, respectively.

[17] Conditioning on being a primiparous is important because maternal supply capacity differs between first and subsequent pregnancies. This is due to the action of the fetal trophoblast cells, which invade the arteries of the endometrium and convert the uterine spiral arteries into uteroplacental arteries; as result, the arteries become completely dilated and distended, able to accommodate the increased blood supply for the placenta.

increases throughout gestation:[18] fetuses with a one standard deviation larger abdominal circumference at 11 weeks are 39 grams heavier at birth (column 1a, upper panel); the magnitude of this association almost triples to 118 grams in the second trimester (column 1b, upper panel) and then to 277 grams in the third trimester (column 1c, upper panel).

Table 2: Conditional Associations Between Measures Of Fetal And Neonatal Health: Birth Weight And Gestational Age.

	Birth Weight (kg)			Gestational Age (weeks)			Birth Weight (*z*-score)		
	TR1	TR2	TR3	TR1	TR2	TR3	TR1	TR2	TR3
Fetal Measure	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
Abdominal Circumf. (*z*)	0.039***	0.118***	0.277***	-0.402***	-0.362***	-0.118***	0.261***	0.422***	0.647***
	(0.015)	(0.013)	(0.010)	(0.047)	(0.045)	(0.037)	(0.027)	(0.021)	(0.016)
R^2	[0.079]	[0.105]	[0.376]	[0.077]	[0.054]	[0.021]	[0.143]	[0.228]	[0.512]
Semi-partial R^2 AC	0.005	0.041	0.309	0.048	0.034	0.006	0.072	0.176	0.457
N	*1,160*	*1,906*	*1,902*	*1,169*	*1,922*	*1,914*	*1,160*	*1,906*	*1,902*
Head Circumference (*z*)	0.026*	0.096***	0.231***	-0.465***	-0.381***	-0.068*	0.263***	0.379***	0.520***
	(0.015)	(0.013)	(0.011)	(0.045)	(0.042)	(0.037)	(0.027)	(0.021)	(0.020)
R^2	[0.080]	[0.093]	[0.267]	[0.085]	[0.059]	[0.017]	[0.137]	[0.200]	[0.329]
Semi-partial R^2 HC	0.002	0.028	0.199	0.057	0.039	0.002	0.068	0.147	0.273
N	*1,238*	*1,915*	*1,829*	*1,249*	*1,931*	*1,840*	*1,238*	*1,915*	*1,829*
Femur Length (*z*)	0.017	0.091***	0.190***	-0.310***	-0.320***	-0.081**	0.179***	0.342***	0.441***
	(0.026)	(0.013)	(0.011)	(0.089)	(0.041)	(0.036)	(0.041)	(0.021)	(0.020)
R^2	[0.101]	[0.090]	[0.209]	[0.086]	[0.049]	[0.017]	[0.144]	[0.178]	[0.263]
Semi-partial R^2 FL	0.001	0.027	0.142	0.032	0.029	0.003	0.032	0.126	0.209
N	*466*	*1,917*	*1,900*	*468*	*1,933*	*1,912*	*466*	*1,917*	*1,900*

Notes: This table shows the estimated coefficients from OLS regressions of three measures of health at birth (top row) on three measures of fetal size (first column), by trimester of gestation. The results in each cell come from separate regressions of each birth measure on each fetal measure separately. All models include binary indicators for white ethnicity, male, being a first born and year and month of birth. Birth weight is measured in kilograms; gestational age in weeks; birth weight *z*-score has been computed using the Child Growth Foundation standards. The fetal size *z*-scores have been computed according to the Royston (1995) method. TR1=11 weeks; TR2=19 weeks; TR3=34 weeks. AC=Abdominal Circumference; HC=Head Circumference; FL=Femur Length. *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

Second, we observe that birth weight is indeed correlated with various fetal measures, however it shows a stronger association with abdominal circumference than with head circumference (middle panel) or femur length (bottom panel). This is reflected not only in the magnitude of the estimated coefficients - fetuses with one standard deviation larger abdominal circumference at 34 weeks are on average 277 grams (column 1c, upper panel) or 0.647 of a standard deviation (column 3c, upper panel) heavier at birth - but also in the amount of explained variation, which ranges from 31% for the semi-partial R^2 of birth weight in kilograms (column 1c, upper panel) to 46% for birth weight standardised by gestation (column 3c, upper panel). While reported here for the first time in economics, the strong association between abdominal circumference and birth weight is known in the medical literature. Indeed, the prediction of birth weight from abdominal cir-

[18]Complementary graphical evidence is presented in Figure A3, where we plot the mean birth weight for different (binned) values of the measures of fetal size.

cumference was first proposed by Campbell and Wilkin (1975), and subsequently refined by Smith et al. (1997), who showed that the predictive power is not significantly improved when femur length is also included in the equation. This can be explained by the fact that the rate of fetal growth in weight increases exponentially, so that most of the weight is gained during the third trimester (7 to 9 months) of pregnancy, while the fetus grows in length mainly in the second trimester (4 to 6 months, see Schoenwolf et al. (2014)). However, the weight provides information accruing from all the tissues together, so that greater weight does not necessarily imply healthier growth: it may be achieved at the cost of liquid retention or fat accretion. Although birth weight provides *some* information about the endpoint of fetal growth, it neither describes the trajectory followed in utero, nor does it reflect the body composition of the fetus. The fact that the association between abdominal circumference and birth weight is stronger at the end of gestation is consistent with evidence from the epidemiological literature on the Dutch Hunger Winter, which finds a reduction in birth weight among women exposed to the famine in the last trimester (Stein et al., 2004); and also with more recent evidence from economics showing that the largest improvements in birth weight occur with interventions in the third trimester (see e.g. (Almond et al., 2011)).

Thirdly, we uncover a negative association between the measures of fetal size and gestational age at birth, which - opposite to that seen for birth weight - is decreasing throughout gestation (columns 2a-2c). In other words, women with bigger fetuses in the early stages of gestation have on average shorter pregnancies.[19] Thus, the counterbalancing effects of fetal size on weight at birth and on length of gestation explain why we detect associations of greater magnitude and statistical significance between the fetal measures and birth weight when we standardize it by the age of completed gestation (especially in the first trimester, compare cols. 3a and 1a). Lastly, the associations between fetal and neonatal health capital are unchanged when we condition on our extensive set of controls (Table A6).

While being the most widely used, birth weight is not the only measure of neonatal health. Developmental plasticity in response to the uterine environment manifests itself in other physiological processes than fetal weight growth, which are likely not captured by birth weight alone. Additional indicators of neonatal health convey information about other aspects of the prenatal environment: birth length (a longer-term cumulative indicator of nutrition), head circumference (a marker of brain development), and the Apgar score (a scale from 0 to 10 providing a quick summary of the health of the newborn).[20] While these other measures are known in the medical literature (and have also been used in economics papers, for example birth length in (Black et al., 2007) and the Apgar score in (Almond et al., 2005)), we are the first to systematically investigate their relationship with different measures of fetal size and growth, and what is their informational content as compared to that of birth weight.

We start by presenting some graphical evidence in Figure A4, where we see that, while birth weight is strongly associated with the abdominal circumference of the fetus (panel a), birth length exhibits the strongest association with fetal femur length (panel e), and birth head circumference with fetal head circumference (panel i). The results on the association between fetal health capital and other measurements

[19] We have checked that this is not driven by differences in the method of delivery: this result holds also restricting the sample to children with normal onset of labour.

[20] The Apgar score evaluates the newborn under five criteria: Appearance, Pulse, Grimace, Activity and Respiration. More information on these measures is in Appendix Section C.

of neonatal health are displayed in Table 3, where, differently from Table 2 (where we separately include each of them), we condition on the three fetal anthropometrics at the same time: this is crucial to correctly infer the associations between the various measures. We only present results for the second and the third trimester measures.[21] In columns (1a) and (1b) we look again at birth weight standardised by gestation. In comparison to columns (3b) and (3c) in Table 2, the estimated coefficients on abdominal circumference are smaller in absolute magnitude, but more than twice the size of those on the other two fetal dimensions. Along the same lines, columns (2a) and (2b) show that birth length is more strongly associated with fetal femur length, and columns (3a) and (3b) that birth head circumference is more strongly associated with fetal head circumference, both in terms of the estimated coefficients and the amount of explained variation. A fetus with a one standard deviation longer femur in the middle and towards the end of gestation is, respectively, a 0.204 and 0.344 standard deviation longer newborn. A fetus with a one standard deviation larger head circumference in the second and in the third trimester has, respectively, a 0.426 and 0.626 larger head circumference at birth. A different pattern emerges, instead, with respect to the Apgar score: fetuses with a larger head circumference at the end of gestation have a higher score, while fetuses with a larger abdomen have a lower one (for example because of obstructed labour or shoulder dystocia). As already seen for Table 2, conditioning on an extensive set of biological and socioeconomic characteristics and lifestyles measured at study intake does not significantly change the estimated coefficients (Table A7). We also provide a formal test of the extent to which omitted variables could bias the relationship between the fetal measurements and birth weight using the method recently formalised by Oster (2019), following Altonji et al. (2005), which uses movements in the coefficient of interest and in the R^2 after adding observable controls to learn about the likely impact of the unobservables. The results are shown in columns (1c) and (1d) of Table A7. The estimates of the bias-corrected coefficients for the abdominal circumference β_c[22] are very similar to the controlled ones in columns (1a) and (1b), and those of the related coefficients of proportionality (δ) are all above one, implying that unobservables would have to be more important than observables for the coefficient to be zero.[23] Interestingly, though, the bias-corrected coefficients of femur length and head circumference in the third trimester in the birth weight regression (column 1d) have a negative sign and a smaller magnitude, and the related coefficients of proportionality (δ) in this case are below 1. This additional evidence provides further support to our finding that birth weight proxies for the abdominal circumference of the fetus. Lastly, we confirm that different birth outcomes capture different timings of development by showing that, conditional on the third trimester measures, the second trimester fetal measures are only predictive of birth length and head circumference, not of birth weight (Table A8). This provides evidence that two dimensions of newborn health other than weight convey information about earlier parts of gestation.

[21] For the first trimester, the very high correlation among the fetal measures makes it difficult to detect meaningful associations. We have checked that the correlation among the fetal measures in the second and third trimesters is not problematic in two ways. First, in all cases the Variance Inflation Factor is smaller than 10 (the value used as rule of thumb to detect multicollinearity). Second, we have simulated data with the same sample size and correlation structure among the variables as in the SWS data, and verified that the coefficients of the relationship between birth weight and the three fetal measures in the third and second trimester estimated on the simulated data are remarkably similar to those estimated using the real data (results available upon request).

[22] Computed assuming an equal degree of selection on observables and unobservables.

[23] All the computations are made using as Rmax (the R^2 from including the unobservables) the R^2 from the models in columns (1a) and (1b), multiplied by 1.3 (Oster, 2019).

Table 3: Conditional Associations Between Measures Of Fetal And Neonatal Health: Birth Weight, Length And Head Circumference, And Apgar Score.

	Birth Weight (z-score)		Birth Length (z-score)		Birth Head Circ. (z-score)		APGAR 1M	
	TR2	TR3	TR2	TR3	TR2	TR3	TR2	TR3
Fetal Measure	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)
Abdominal Circumference (z)	0.273***	0.480***	0.140***	0.242***	0.108***	0.190***	0.008	-0.120***
	(0.034)	(0.019)	(0.032)	(0.020)	(0.034)	(0.018)	(0.061)	(0.046)
Head Circumference (z)	0.128***	0.172***	0.095***	0.147***	0.426***	0.626***	0.080	0.119**
	(0.035)	(0.019)	(0.031)	(0.019)	(0.034)	(0.019)	(0.064)	(0.046)
Femur Length (z)	0.071**	0.169***	0.204***	0.344***	-0.060**	0.013	-0.055	0.012
	(0.031)	(0.018)	(0.029)	(0.018)	(0.030)	(0.015)	(0.060)	(0.043)
R^2	[0.241]	[0.565]	[0.231]	[0.479]	[0.256]	[0.621]	[0.018]	[0.022]
Semi-partial R^2 AC	0.028	0.157	0.009	0.047	0.004	0.025	0.000	0.004
Semi-partial R^2 HC	0.006	0.020	0.004	0.017	0.067	0.261	0.001	0.003
Semi-partial R^2 FL	0.002	0.024	0.023	0.120	0.002	0.000	0.000	0.000
N	*1,901*	*1,828*	*1,774*	*1,728*	*1,793*	*1,744*	*1,845*	*1,784*

Notes: This table shows the estimated coefficients from OLS regressions of four measures of health at birth (top row) on three measures of fetal size (first column), by trimester of gestation. The results in each column come from separate regressions of each birth measure on the three fetal measures. All models include binary indicators for white ethnicity, male, being a first born and year and month of birth. The birth measures z-scores have been computed using the Child Growth Foundation standards. The fetal size z-scores have been computed according to the Royston (1995) method. TR2=19 weeks; TR3=34 weeks. AC=Abdominal Circumference; HC=Head Circumference; FL=Femur Length. *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

We then perform one further analysis to evaluate the informational content of birth weight, length and head circumference: we investigate their association with three measures of body composition of the newborn - fat and lean mass, and the proportion of body fat from DXA (dual-energy X-ray absorptiometry) - and thigh subcutaneous tissue thickness from the skinfolds (see Appendix Section C). The results (Table A9) show that the three neonatal anthropometrics are positively associated with the four measures of body composition when entered separately (columns 1-3 and 5-7), but birth weight displays the strongest association and accounts for more of the explained variation in all cases. When the three birth measures are entered simultaneously (columns 4 and 8), birth weight is still positively associated with all the four measures of neonatal body composition, while birth length and head circumference are negatively associated with measures of fatness, and positively associated with lean mass. Once more, the estimated associations are virtually unchanged after controlling for an extended set of socioeconomic and biological determinants and lifestyles measured before conception (Table A10).

We have tested in multiple ways the robustness of these results. First, rather than using the average of three fetal measurements as indicator at each time point, we have constructed a factor, hence accounting for measurement error using structural equation modelling methods. The results on the association between fetal and neonatal health, presented in Table A11 (cols. 4-6), are remarkably similar to those reported in Table 3. Additionally (columns 2-3), the three indicators of the same fetal anthropometric measure have very similar coefficients (so-called loadings), reassuring us on the quality of our data, and on the validity of our choice of using an unweighted average of the three measurements. Second, we have performed a replication exercise on the Birthright data. The results (Tables A12-A13) confirm that birth weight proxies for the abdominal circumference of the fetus (cols. 1b and 2b of Table A12, and col. 1 of Table A13), which is negatively correlated with the Apgar score (col. 4 of Table A13); and that birth head circumference and length are more strongly associated with their respective fetal counterparts (cols. 2 and 3 of Table A13). Third, we have checked the robustness of our results to unobserved heterogeneity. Our findings so far suggest that the three fetal measures (abdominal and head circumference, and femur length) are capturing both an underlying common component ("fetal health") and specific components related to the different body parts. This naturally lends itself to using a fetus fixed effects estimator, where we exploit the measure-specific deviations from the common component. In other words, our findings suggest the following relationship between dimension-specific fetal and neonatal measures H_{imt} and latent health H^*_{it}: $H_{imt} = H^*_{it} + \upsilon_{imt} + \varepsilon_{imt}$, where $m = 1, 2, 3$, $t = tr1, tr2, tr3, birth$; υ_{imt} is the deviation at developmental time t of the dimension-specific measure m from the general latent health, independent and identically distributed across dimensions and children, but not independently distributed across ages for the same dimension; ε_{imt} is a random measurement error. To assess the validity of these assumptions, we first run an exploratory factor analysis of the three measures at each developmental stage. The results, reported in Panel A of Table A14 (cols.1-4), show that the first factor explains on average 64% of the variance of the fetal and neonatal measures, and therefore support a single-factor model.[24] We then estimate a structural equation model with one factor, separately for each developmental period. Panel B of Table A14 reports the factor loadings for the three measures, where the loading for the measure of size (abdominal circumference in pregnancy, and weight at birth) is constrained to be 1. The results show that the factor loadings for the head and the length are very close to 1 in early and mid-pregnancy, but of a smaller magnitude in late pregnancy and birth - again, providing evidence that the three measures are capturing increasingly differentiated dimensions. This increase in specificity is also reflected in the uniquenesses, which are higher in the third trimester and at birth than in the first two trimesters.[25] Lastly, in Panel D of Table A14 we report the estimated covariances between the dimension-specific components of the fetal and neonatal indicators for a model with correlated errors, and we show that they are indeed 0.

In sum, all this evidence supports our interpretation of the fetal and neonatal indicators as proxies for one general latent fetal-neonatal health construct, and also specific sub-dimensions; hence, we estimate a fetus/newborn fixed effects model.[26] The results, reported in Table 4, suggest that the associations between fetal and neonatal health displayed in Table 3 can be interpreted as causal, and not merely reflecting unobserved common factors.[27] On average, 1 standard deviation (SD) improvement in fetal health in the third

[24] Interestingly, the percentage of explained variation is as high as 79% in the early stages of pregnancy, and declines to 43% in the last trimester, suggesting an increased differentiation and specificity of the fetal measures.

[25] Complementary evidence in Appendix Table A15 shows that the correlations across developmental stages between indicators of the same dimension (e.g. the correlation between head circumference in the third trimester and at birth) are stronger than those between indicators of different dimensions at the same developmental stages (e.g. the correlation between head circumference and femur length in the third trimester) for late gestation and birth, but not for early and mid-gestation.

[26] This approach is similar to the one adopted in the education literature for the estimation of cognitive ability production functions.

[27] We also find that, even conditional on the fixed effect, the fetal measures in the third trimester (col. 2) have slightly different

Table 4: Effects Of Fetal Health On Birth Health.

	Health at Birth			
	(1)	(2)	(3)	(4)
Fetal Size TR2	0.194***		0.053***	
	(0.017)		(0.018)	
Fetal Head TR2	0.233***		0.073***	
	(0.020)		(0.020)	
Fetal Length TR2	0.188***		0.076***	
	(0.019)		(0.019)	
Fetal Health TR2				0.068***
				(0.015)
Fetal Size TR3		0.293***	0.286***	0.278***
		(0.013)	(0.014)	(0.014)
Fetal Head TR3		0.375***	0.356***	0.358***
		(0.016)	(0.018)	(0.017)
Fetal Length TR3		0.253***	0.232***	0.236***
		(0.015)	(0.017)	(0.016)
Fetus FE	✓	✓	✓	✓
Test for equality of lagged terms (p-value)				
TR2	0.047		0.375	
TR3		0.000	0.000	0.000

Notes: This table shows the estimated coefficients from OLS regressions of health at birth (weight, length and head circumference) on fetal health in the 2^{nd} and 3^{rd} trimester of gestation, controlling for a fetus fixed effect. The size measure we use is abdominal circumference for the 2^{nd} and 3^{rd} trimester, and weight at birth; the length measure we use is femur length for the 2^{nd} and 3^{rd} trimester, and body length at birth. In the cols. 1-3 we allow the measures of fetal health to have different effects on the measure of birth health; column 4 restricts the measures of fetal health in the 2^{nd} trimester to have the same effects. The models also include binary indicators for type of measure. All the measures are z-scores. N=5,622 (cols. 1-3) and 5,505 (col. 4); number of children=1,962 (cols. 1-3) and 1,924 (col. 4). TR2=2^{nd} trimester (19 weeks); TR3=3^{rd} trimester (34 weeks). *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses are clustered at the level of the child.

trimester leads to a 0.3 SD improvement in neonatal health (cols. 2-4). Conditional on fetal health in the third trimester, a 1 SD improvement in fetal health in the second trimester leads to a 0.07 SD improvement in neonatal health (cols. 3-4).

Our analysis so far has provided robust evidence that the fetal environment affects health at birth, but we have focused on measures at single timepoints. The medical literature suggests that fetal growth is also important in determining birth outcomes, however it mostly considers linear models with growth measured

effects on health at birth. However, conditional on the third trimester measures, we cannot reject the equality of the coefficients of the second trimester measures. This is unsurprising, given that we had already seen in Table 3 that the measures have different persistence across developmental stages.

as change in fetal size between two periods (Larose et al., 2017). Here, instead, we highlight the importance of considering richer dynamics, by showing how deviations from balanced fetal growth trajectories in abdominal circumference in middle and late gestation (conditional on fetal growth in the other two measures, see Table A16 for the full results) predict adverse and costly birth outcomes: low birth weight (birth weight below 2,500 grams), small-for-gestational age (SGA, <10th centile of birth weight for gestational age), high birth weight (birth weight above 4,000 grams), large-for-gestational age (LGA, >90th centile of birth weight for gestational age) and prematurity (birth before 37 weeks of completed gestation).

Table 5: In Utero Growth Patterns And Birth Outcomes.

	LBW	**SGA**	**HBW**	**LGA**	**Preterm**
	(1)	(2)	(3)	(4)	(5)
AC Stable Low Trajectory	0.047***	0.142***	-0.167***	-	0.021*
	(0.009)	(0.014)	(0.040)	(-)	(0.012)
AC Declining Trajectory	0.030***	0.070***	-0.066***	-0.026	0.021*
	(0.009)	(0.014)	(0.024)	(0.021)	(0.011)
AC Increasing Trajectory	0.009	0.010	0.089***	0.076***	0.022*
	(0.011)	(0.017)	(0.017)	(0.016)	(0.012)
AC Stable High Trajectory	-0.017	-0.117***	0.154***	0.180***	0.041***
	(0.017)	(0.043)	(0.018)	(0.016)	(0.012)
AUC_X	0.676	0.632	0.630	0.645	0.573
$\text{AUC}_X + fetal$	0.906	0.817	0.799	0.817	0.704
p	*0.000*	*0.000*	*0.000*	*0.000*	*0.002*
N	*1,781*	*1,781*	*1,781*	*1,553*	*1,792*

Notes: This table shows average marginal effects from probit models of five measures of health at birth (top row) on patterns of fetal growth between the 2^{nd} and the 3^{rd} trimester. All models include binary indicators for white ethnicity, gender, being a first born and year and season of birth, and the trajectory variables for head circumference and femur length. Full results are displayed in Table A16. LBW=Low Birth Weight; SGA=Small-for-Gestational Age; HBW=High Birth Weight; LGA=Large-for-Gestational Age. See the text for the definitions. "AC Stable Low Trajectory" is a binary indicator which takes value 1 if the fetus is in the lower quartile of the Abdominal Circumference distribution both in the 2^{nd} and in the 3^{rd} trimester. "AC Declining Trajectory" is a binary indicator which takes value 1 if the fetus is in the lower quartile of the distribution of the difference between the 3^{rd} and the 2^{nd} trimester AC. "AC Increasing Trajectory" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the distribution of the difference between the 3^{rd} and the 2^{nd} trimester AC. "AC Stable High Trajectory" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the AC distribution both in the 2^{nd} and the 3^{rd} trimester. *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. AUC_X=Area under the ROC curve for a model which does not include the fetal measures. $\text{AUC}_X + fetal$=Area under the ROC curve for a model which also includes the fetal measures. *p*=*p*-value for the Null Hypothesis that both models have equal AUC values (bootstrapped with 1,000 replications).

First of all, column (1) of Table 5 reveals that two different abdominal growth patterns can lead to low birth weight: fetuses who are both continuously small[28] and also fetuses who become much smaller[29]

[28] We classify fetuses as small or large if their abdominal circumference falls below the 25th or above the 75th percentile.

[29] More precisely, fetuses who are in the lower quartile of the distribution of the difference between the third and the second trimester abdominal circumference. Table A17 column 1 shows that fetuses displaying a declining trajectory in any measure are

between the second and the third trimester of gestation have an increased probability of having a weight at birth less than 2.5 kilograms (of 4.7 p.p. and 3 p.p., respectively), as compared to fetuses with continuous normal size. Column (2) shows that both fetuses who are continuously small, and those who become much smaller, between the second and the third trimester, are 14.2 p.p. and 7 p.p. more likely to be born SGA, respectively. Conversely, the fetuses who become much bigger, and especially those who are continuously big in mid- and late gestation, are 9-8 p.p. and 15-18 p.p. more likely to be born high birth weight and LGA, respectively. Last, column 5 shows that any deviation from a balanced growth trajectory increases by 2-4 p.p. the probability of being born preterm. This finding is particularly important since preterm birth complications are the leading cause of death for children under five, and the role of various risk factors in the aetiology of prematurity remains unclear (Muglia and Katz, 2010). Additionally, we compute the area under the ROC curve for two sets of models, one with and one without the fetal measures, and show that (bottom of Table 5) the predictive ability of the model is significantly improved: for example, the area under the curve (AUC) goes from 0.676 to 0.906 for low birth weight. As seen previously, the estimated associations are virtually unchanged after including an extended set of controls (Table A17), and the increase in predictive power from the inclusion of the fetal measures is still sizeable.

In sum, so far we have shown that fetal health since mid-gestation is robustly associated with health at birth, that different fetal and neonatal measures capture both a general and a specific health component, and that birth weight is only one imperfect indicator, capturing both positive and negative aspects of health.

4.2 Beyond Birth Weight

In this section we examine the predictive power of fetal and neonatal health capital for child health and development. We start by examining conditional associations between fetal and neonatal measures and height and BMI at age 6. For ease of interpretation, all the anthropometric measures are z-scores.[30] The OLS results for height are reported in the upper panel of Table 6. Columns (1a)-(1b) and (2a)-(2b) display the results of models where we only include birth weight and length as measures of early health, respectively, one measure at a time; columns (3a)-(3b) display the results of models where we include the three measures of neonatal health at the same time (i.e. birth weight, length and head circumference);[31] columns (4a)-(4b) include the three measures of fetal size in the third trimester of gestation as indicators of early health (i.e. abdominal and head circumference, and femur length); columns (5a)-(5b) display the results of models where we condition on all the six fetal and neonatal measures. By comparing column (1a) and column (2a), we see that birth length is a stronger predictor of height than birth weight, both in terms of the magnitude of the association - a one standard deviation increase in birth length is associated with a 0.529 standard deviation increase in height, while the coefficient on birth weight is 0.310 - and in terms of the amount of explained variation (the semi-partial R^2 are 0.211 versus 0.085). Moreover, the semi-partial R^2 for birth weight falls to zero when the three birth measures are added to the regression (column 3a), while the one for

more likely to be born low birth weight.

[30]Just as reported in Black et al. (2007) (footnote 13), we find that alternative continuous measures of birth weight (both in levels and in logs) produce very similar results. All results using alternative measures of birth weight are available upon request.

[31]Full results are reported in Table A18.

birth length is 0.135. Crucially, upon conditioning on length at birth, the association between birth weight and height becomes negative. Lastly, birth length remains predictive of child height even upon conditioning on postnatal growth in the first year of life (Table A18, column 7). Our results confirm the findings of Black et al. (2007) (footnote 13), who had noted that, when including both birth weight and length in a height regression, birth length was a more important predictor than birth weight; we add to their results by providing new evidence on the role of fetal development as predictor of height, above and beyond length at birth. Indeed, in column (4a) we show that the fetal femur length rivals birth weight, both in terms of the magnitude of its association with height (0.355 of a standard deviation, versus 0.310) and of the explained variation (0.097 versus 0.085). Even upon conditioning on birth length, the femur length of the fetus at the end of gestation is predictive of child height at 6 years, with a magnitude equal to 0.178 of a standard deviation for each standard deviation increase in femur length (column 5a). These estimated associations are robust to the inclusion of an extended set of pre-pregnancy socioeconomic and biological characteristics and lifestyles (see columns 1b, 2b, 3b, 4b, 5b). Additionally, we formally test the extent to which omitted variables could bias the estimated associations between fetal femur length and height, again using the Oster (2019) method. The bias-corrected coefficients (computed assuming equal selection) are 0.154 and 0.073 for the models in columns (4b) and (5b), hence two thirds of the fully controlled ones, and the related coefficients of proportionality are above 2 (2.324 and 2.100, respectively), implying that unobservables would have to be much more important than observables for the femur length coefficient to go to zero. Lastly, femur length remains predictive of child height even upon conditioning on postnatal growth in the first year of life (Table A18, column 7). We obtain similar results (available upon request) if we use as dependent variable bone mineral content (BMC), which is a measure of bone health; in other words, early life length is associated not only with longer, but also healthier bones. These first results suggest that the intrauterine environment has consequences for child growth which are not entirely captured by different measures of health at birth. Our findings also have important implications for the specification of height production functions: while the literature commonly assumes a Markovian process,[32] whereby height in the previous period is a sufficient statistic for past growth, they suggest the need for a more flexible specification with additional lags, at least for the perinatal period. Additionally, our results show that birth weight and height proxy for different dimensions of the fetal health capital, and should not be used interchangeably as measures of early health.

We next examine the conditional associations between fetal and neonatal health capital and childhood BMI (bottom panel of Table 7).[33] Birth weight displays a sizeable and significant association with BMI (column 1a), which is robust upon conditioning on neonatal (column 3a) and fetal health (column 5a): a one standard deviation higher birth weight is associated with a 0.297 standard deviation higher BMI at 6 years of age. A similar result had been previously reported in Black et al. (2007), who found that a 10% increase in birth weight led to a higher BMI by 0.11 $\frac{kg}{m^2}$ and to a 0.9 p.p. higher probability of being overweight; again, we add to their results by providing new evidence on the role of fetal development as predictor of BMI, above and beyond weight at birth. The positive association of birth length with BMI in the baseline model (column 2a), instead, becomes negative upon conditioning on the other measures of

[32]One exception is Puentes et al. (2016), who specify, estimate and test the fit of several flexible specifications for the growth paths of height in Guatemala and in the Philippines.

[33]The full set of results is in Table A18.

Table 6: Estimated Effects Of Fetal And Neonatal Health On Height And BMI At 6 Years.

	Height (*z*-score)									
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)	(5a)	(5b)
Birth Weight (*z*)	0.310***	0.175***			-0.130**	-0.135***			-0.080	-0.114**
	(0.031)	(0.030)			(0.051)	(0.049)			(0.055)	(0.054)
Birth Length (*z*)			0.529***	0.361***	0.649***	0.466***			0.548***	0.406***
			(0.031)	(0.031)	(0.049)	(0.047)			(0.052)	(0.051)
Fetal Femur Length TR3 (*z*)							0.355***	0.231***	0.178***	0.125***
							(0.033)	(0.031)	(0.034)	(0.032)
Full controls		✓		✓		✓		✓		✓
R^2	[0.116]	[0.357]	[0.243]	[0.411]	[0.251]	[0.416]	[0.168]	[0.379]	[0.274]	[0.427]
Semi-partial R^2 BW	0.085	0.022			0.005	0.005			0.001	0.003
Semi-partial R^2 BL			0.211	0.075	0.135	0.059			0.081	0.039
Semi-partial R^2 FFL							0.097	0.035	0.019	0.009

	BMI (*z*-score)									
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)	(5a)	(5b)
Birth Weight (*z*)	0.262***	0.222***			0.380***	0.296***			0.297***	0.233***
	(0.032)	(0.034)			(0.051)	(0.053)			(0.058)	(0.059)
Birth Length (*z*)			0.109***	0.085**	-0.256***	-0.206***			-0.245***	-0.198***
			(0.037)	(0.039)	(0.050)	(0.052)			(0.054)	(0.055)
Fetal Abdominal Circ. TR3 (*z*)							0.236***	0.188***	0.141***	0.112**
							(0.036)	(0.037)	(0.043)	(0.044)
Full controls		✓		✓		✓		✓		✓
R^2	[0.086]	[0.235]	[0.034]	[0.204]	[0.109]	[0.248]	[0.087]	[0.232]	[0.119]	[0.254]
Semi-partial R^2 BW	0.061	0.035			0.040	0.022			0.020	0.011
Semi-partial R^2 BL			0.009	0.004	0.021	0.011			0.016	0.009
Semi-partial R^2 FAC							0.037	0.021	0.010	0.005

Notes: The table shows the estimated coefficients from OLS regressions of height and BMI at 6 years on birth and fetal measures in the third trimester of gestation (34 weeks). Height, BMI and the birth measures have been standardized using the Child Growth Foundation standards; the fetal measures have been standardized according to the Royston (1995) method. Each column comes from a separate regression. Columns (1a) and (1b) display results from a model where birth weight is the only measure of early health. Columns (2a) and (2b) display results from a model where birth length is the only measure of early health. Columns (3a) and (3b) display selected coefficients from a model where all the three measures of neonatal health (birth weight, length and head circumference) are included. Columns (4a) and (4b) display selected results from a model where the three measures of fetal health at 34 weeks (femur length, abdominal circumference and head circumference) are included. Columns (5a) and (5b) display selected results from a model with all the six measures of fetal and neonatal health. Full results with all the estimated coefficients are reported in Table A18. The models in columns (1a), (2a), (3a), (4a) and (5a) include binary indicators for white ethnicity, gender, being a first born, year and month of birth. The models in columns (1b), (2b), (3b), (4b) and (5b) also add a binary indicator for mother's age at birth and the following controls measured at baseline (before conception): binary indicators for the number of children, whether the mother has a degree-level education, belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), owns the house, is single, separated, divorced or widowed, receives welfare benefits, is in fair, bad or very bad health, has been under stress in the last four weeks, was working last week, is a current smoker, drinks more than 4 units of alcohol per week, does any strenuous exercise in the week, does any moderate exercise in the week, whether the mother's partner belongs to high or low social class , whether the mother's father belongs to high or low social class; continuous variables for mother's birth weight, pre-pregnancy weight, height, BMI, head circumference, leg length, waist circumference, skinfolds (sum of triceps, biceps, subscapular and suprailiac) and her daily energy intake (kcal), paternal height, weight and birth weight, grandmaternal and grandpaternal height and weight, and the Townsend Deprivation Index; missing values for social class of the mother, the mother's father and the mother's partner have been replaced with zeros and a binary indicator for missing is included; missing values for maternal birth weight and head circumference, for paternal height, weight and birth weight, for grandmaternal weight and grandpaternal height and weight are replaced with the sample means of the non-missing observations and binary indicators for missing are included. *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. All models are estimated on a balanced sample of 1,067 observations. BW=Birth Weight; BL=Birth Length; FFL=Fetal Femur Length; FAC=Fetal Abdominal Circumference.

neonatal (column 3a) and fetal health (column 5a), with a one standard deviation increase in birth length associated with a 0.245 standard deviation lower BMI. Differently from what reported above for height, birth weight explains more of the variation in BMI than birth length. Lastly, even upon conditioning on the three birth measures, the abdominal circumference of the fetus at the end of gestation is predictive of child BMI, with a standard deviation increase being associated with a 0.141 standard deviation higher BMI (col. 5a).[34] As seen before, the results are robust to conditioning on an extensive set of pre-pregnancy biological and socioeconomic characteristics and lifestyles (cols. 1b, 2b, 3b, 4b and 5b). We have also used once more the Oster (2019) method to gain some insights on the role played by unobservables in the association between fetal abdominal circumference and BMI: the bias-corrected coefficients are 0.160 and 0.091, very similar to the fully controlled ones (cols. 4b and 5b), and the related coefficients of proportionality are around 4 (4.092 and 3.939, respectively), reassuring us on the importance of prenatal size for child BMI, even upon conditioning on health at birth. We obtained very similar results (available upon request) with alternative measures of central adiposity, such as the waist-hip and the waist-height ratio (more clinically useful than BMI when assessing metabolic disease risk) and the mid-upper arm circumference (MUAC, especially valuable in low-resource settings): birth weight and fetal abdominal circumference are strongly associated with all measures of fatness, the other neonatal and fetal measures are not.

Lastly, we exploit the availability of IQ measures in a subsample at age 4 to study the prenatal correlates of cognition. Given the small sample size, we focus only on one measure - head circumference - which has been shown to be significantly correlated with brain volume (Lindley et al., 1999), and we investigate whether the first or the second part of gestation is a more sensitive period. The results, reported in Table A19, show that language and verbal ability in childhood are more strongly associated with head circumference growth in the first part of gestation than with head circumference growth in second part of gestation or postnatally, or with head circumference at birth. This is consistent with recent evidence (Black et al., 2019) which shows that environmental shocks (radiation exposure) in early gestation have negative impacts on cognitive and educational outcomes.

The results obtained so far show robust associations between fetal anthropometric measures and child height and BMI at age 6, even upon conditioning on newborn anthropometric measures. However, although we have shown their robustness by conditioning on an extensive set of biological and socioeconomic factors, they can still be biased by unobserved heterogeneity, either at the child level, or at the mother level; in other words, H^P_{ij} can be correlated with μ_{ij} or η_j in equation 2.1. We then perform additional analyses to address both concerns.

First, we extend to the postnatal period the same child fixed effect approach adopted for the prenatal period, and consider the three anthropometric indicators of body, length and head size as proxies for both a general latent health construct, and dimension-specific components.[35] The results, displayed in Table 7, support a causal interpretation of the conditional associations reported in Table 6: fetal health in the third

[34]When we condition on postnatal growth, the coefficient on fetal abdominal circumference is still of a meaningful magnitude, but our estimate becomes imprecise (Table A18, where we also present the results on child weight).

[35]In Table A14 we see that the structural equation model for the postnatal measures deliver similar results as for the prenatal and birth measures: high loadings for the length and head dimensions, but also high uniquenesses, with the model normalised on the size measures (i.e. the loading on the size measures is constrained to 1). This supports the interpretation that they capture both a general latent health factor, and dimension-specific health components.

trimester of gestation has a strong and significant impact on child health at 6 years of age, over and above newborn health (col. 3) and child health at 1 year (col. 4), and conditional on a child fixed effect. They also show that the persistence of health capital varies both depending on the specific measure considered, and over developmental periods.

Table 7: Effects of Pre- and Postnatal Health On Child Health.

	Health at Year 6			
	(1)	(2)	(3)	(4)
Fetal Size TR3	0.192***		0.138***	0.069***
	(0.022)		(0.025)	(0.023)
Fetal Head TR3	0.361***		0.063*	-0.003
	(0.028)		(0.035)	(0.026)
Fetal Length TR3	0.253***		0.171***	0.088***
	(0.024)		(0.025)	(0.021)
Birth Size		0.415***	0.331***	0.160***
		(0.027)	(0.032)	(0.027)
Birth Head		0.670***	0.643***	0.263***
		(0.032)	(0.042)	(0.035)
Birth Length		0.489***	0.397***	0.173***
		(0.031)	(0.034)	(0.028)
Postnatal Size Y1				0.417***
				(0.021)
Postnatal Head Y1				0.626***
				(0.025)
Postnatal Length Y1				0.475***
				(0.022)
Fetus/Child FE	✓	✓	✓	✓
Test for equality of lagged terms (p-value)				
TR3	0.000		0.031	0.013
Birth		0.000	0.000	0.014
Y1				0.000

Notes: This table shows the estimated coefficients from OLS regressions of health at 6 years (weight, height and head circumference) on postnatal (1 year of age), birth and fetal (3^{rd} trimester of gestation) health, controlling for a child fixed effect. The size measure we use is abdominal circumference for the 3^{rd} trimester, and weight at birth and postnatally; the length measure we use is femur length for the 3^{rd} trimester, and body length at birth and postnatally. All columns allow all measures of fetal, birth and year 1 health to have different effects on the measure of health at age 6. The models also include binary indicators for type of measure. All the measures are z-scores. N=3,846; number of children=1,289. *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses are clustered at the level of the child. TR3=3^{rd} trimester (34 weeks); Y1=1 year of age.

Second, given the unavailability of siblings data in the SWS, we resort to the CNLSY and the PtA data to account for mother-level unobserved heterogeneity. Given that these data do not contain fetal measures from ultrasound scans, we focus on understanding the effects of birth weight and length on child anthropometric and cognitive outcomes, by estimating different versions of equation 2.1 without the inclusion of H^P . The CNLSY results are reported in Table A20. Panel A shows that birth length has a positive and significant association with height, which rivals that of birth weight. The magnitude of this association - one standard deviation increase in each birth measure leading to a 0.125-0.101 higher SD in height (col. 6) - is similar to the one obtained by Case and Paxson (2010) on the same data. While birth length has a significant effect on height, within families it is not associated with BMI. Panel B shows that the heavier - not the longer - sibling at birth has a significantly higher BMI in childhood, with a 1 SD higher birth weight leading to an increase in BMI by 0.215 of a standard deviation. In panels C-F we present the test scores results. In three out of four cases, i.e. for the PPVT, PIAT Math and the WISC Memory Digit Span tests, it is the longer - not the heavier - sibling at birth who has the higher test score (col. 6). These results are robust to controlling for maternal investments in pregnancy (col. 7, using the same maternal variables as in Case and Paxson (2010)).[36]

As an additional robustness test, we estimate the same model on the Pathways to Adulthood data, which also include comparable birth anthropometrics, and childhood measures of growth and cognitive development. The results, reported in Table A21, confirm that the longer - not the heavier - sibling at birth is the taller child and has the higher test scores (in four out of five cases, the difference between the birth weight and the birth length coefficients is statistically significant). In sum, the CNLSY and PtA results show the importance of accounting for mother-specific unobserved heterogeneity and for different dimensions of newborn health.

The evidence presented so far in this section has shown the importance of the prenatal period for child physical and cognitive development, however it has mostly focused on measures of size. Our analysis of the prenatal determinants of poor health at birth (Table 5) has pointed to the importance of patterns of in utero growth, hence we now extend it to study their predictive power for three common (and costly) childhood health conditions: overweight (>85th percentile BMI-for-age), asthma (doctor-diagnosed in the last 12 months), and hyperactivity (score >5 in the hyperactivity subscale of the mother-reported Strengths and Difficulties Questionnaire).[37] Given the numerosity of the measures of prenatal growth which can be computed using the three measures of fetal size, we use lasso methods (Belloni et al., 2014) to select them.[38]

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[36]The corresponding OLS results are reported in columns 1, 3 and 5: the within-family estimates of the effects of birth length on the cognitive test scores are greater than the OLS estimates.

[37]It has been shown that the SDQ predicts clinically meaningful changes in the odds of ADHD in a UK sample, see Algorta et al. (2016).

[38]This is a major advancement with respect to the epidemiological literature, which uses different measures (of linear growth) in different studies, often with inconsistent results (Larose et al., 2017). We use the Akaike Information Criterion to select among the different models. We consider 21 predictors constructed from the fetal measurements: abdominal, head circumference and femur length in the 2^{nd} trimester; conditional growth between the 2^{nd} and the 3^{rd} trimester, and between the 3^{rd} trimester and birth; slow, fast and accelerated growth between the 2^{nd} trimester and birth; excess (asymmetric) growth in abdomen (head) as compared to head (abdomen), and symmetric growth in the head with respect to the abdomen and the femur, respectively. We define slow growth as below the 25th percentile, and fast growth as above the 75th percentile of the respective distributions. We define accelerated and excess growth as the difference in two growth measures being above the 75th percentile. We further consider 13 predictors constructed from the neonatal measurements: birth weight, length, head circumference, low and high birth weight, SGA, LGA and preterm (as in Table 5), low Apgar (less than 8) at 1 and 5 minutes, small head circumference (<35.36 cm (Barker et al., 1993)),

Table 8: Fetal Growth Patterns And Newborn and Child Health.

	Panel A: Overweight at 6 Years					
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)
Fetal Abdominal Circumference TR2 (*z*)	0.033***	0.030***			0.025	0.018
	(0.012)	(0.012)			(0.015)	(0.015)
Fetal Abdomen Growth TR2-TR3 (*z*)	0.060***	0.045***			0.043**	0.027
	(0.014)	(0.013)			(0.018)	(0.017)
Fetal Abdomen Growth TR3-Birth (*z*)	0.036***	0.022*			0.020	0.004
	(0.014)	(0.013)			(0.018)	(0.017)
Fetal Abdomen Slow Growth TR2-Birth	0.151***	0.126**			0.133**	0.115**
	(0.056)	(0.054)			(0.056)	(0.055)
Fetal Abdomen Fast Growth TR2-Birth	-0.117**	-0.134***			-0.114**	-0.129**
	(0.054)	(0.052)			(0.055)	(0.053)
Birth Weight (*z*)			0.081***	0.069***	0.038	0.043
			(0.020)	(0.020)	(0.028)	(0.025)
Birth Length (*z*)			-0.043**	-0.029	-0.031	-0.020
			(0.020)	(0.020)	(0.022)	(0.022)
Full Controls		✓		✓		✓
AUC	0.686	0.794	0.666	0.773	0.696	0.795
p-value AUC					*0.020*	*0.011*
	Panel B: Asthma (GP-Diagnosed) at 6 Years					
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)
Fetal Abdomen Fast Growth TR2-Birth	-0.168**	-0.190***			-0.127*	-0.144**
	(0.069)	(0.070)			(0.072)	(0.072)
Fetal Head Accelerated Growth TR2-Birth	-0.073**	-0.069**			-0.080**	-0.075**
	(0.033)	(0.032)			(0.032)	(0.032)
Fetal Abdomen Symmetric Growth TR2-TR3	-0.064**	-0.054*			-0.073**	-0.063**
	(0.031)	(0.031)			(0.031)	(0.031)
Low Birth Weight			0.234**	0.206**	0.233**	0.212**
			(0.092)	(0.086)	(0.093)	(0.087)
High Birth Weight			-0.083**	-0.106**	-0.066	-0.076*
			(0.040)	(0.042)	(0.042)	(0.044)
Low Apgar 1M			0.073**	0.076**	0.080**	0.083**
			(0.034)	(0.034)	(0.034)	(0.034)
Small Birth Head Circumference			0.076**	0.076	0.080**	0.078**
			(0.035)	(0.035)	(0.035)	(0.035)
Full Controls		✓		✓		✓
AUC	0.619	0.695	0.631	0.691	0.662	0.714
p-value AUC					*0.018*	*0.015*
	Panel C: Hyperactivity Problems (SDQ) at 3 Years					
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)
Fetal Head Fast Growth TR2-Birth	-0.081*	-0.105**			-0.079	-0.108**
	(0.048)	(0.051)			(0.050)	(0.054)
Fetal Head Accelerated Growth TR2-Birth	-0.053**	-0.062**			-0.054**	-0.062**
	(0.026)	(0.025)			(0.026)	(0.026)
Fetal Head Symmetric Growth TR2-TR3	-0.035*	-0.044**			-0.034*	-0.043**
	(0.020)	(0.020)			(0.020)	(0.020)
Short Birth Length			0.065*	0.066*	0.033	0.031
			(0.038)	(0.038)	(0.040)	(0.039)
Asymmetric SGA			0.043	0.046	0.023	0.013
			(0.047)	(0.046)	(0.049)	(0.047)
Full Controls		✓		✓		✓
AUC	0.629	0.705	0.594	0.683	0.629	0.705
p-value AUC					*0.008*	*0.022*

Notes: This table shows selected average marginal effects from probit models for three child outcomes on patterns of fetal growth and birth outcomes. The controls are the same as in Table 6. See Table A2 for the summary statistics and the text (footnote 38) for the definition of the various measures. Sample sizes vary between 1,035 and 1,428. Full results are shown in Tables A22A24. *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. AUC=Area under the ROC curve. *p*=*p*-value for the Null Hypothesis that the models in (2a) and (3a), and in (2b) and (3b), respectively, have equal AUC values (bootstrapped with 1,000 replications).

The main results for child overweight at age 6 are presented in Panel A of Table 8. The fetal measures which are significant predictors of child overweight are (unsurprisingly) all related to the fetal abdominal circumference. Additionally, the fetal measures *per se* have greater predictive power than the birth measures, both in the basic model (AUC=0.686 in col. 1a versus AUC=0.666 in col. 2a) and in the extended-controls model (AUC=0.794 in col. 1b versus AUC=0.773 in col. 2b). Several dimensions of fetal development predict child overweight. Fetuses with both a larger abdomen in mid-gestation, and faster linear growth in the second and third trimester, have a 2.2 to 4.5 p.p higher probability of ending up as overweight children (col. 1b); however, these associations are not robust to the inclusion of birth measures (cols. 3a and 3b), suggesting that size and linear growth of fetal abdomen in the prediction of obesity are adequately captured by neonatal measures. Instead, sustained slow (<25th percentile) or fast (>75th percentile) abdomen growth since mid-gestation are strongly associated with child overweight (the average marginal effects are 0.115 and -0.129, respectively, see col. 3b), even above newborn measures - pointing to the importance of studying trajectories. Second, adding measures of fetal development significantly improves the predictive ability of the model for overweight, as compared to the model which only includes birth measures: the AUC increases from 0.666 to 0.696 (p=0.020) for the basic model (cols. 2a and 3a), and from 0.773 to 0.795 (p=0.011) for the model with extended controls (cols. 2b and 3b); furthermore, including measures of fetal development improves the prediction of child overweight even in the model with postnatal linear growth in the first year of life: the AUC increases from 0.821 to 0.836 (p=0.019, see cols. 4a and 4b in Table A22).[39]

The main results for respiratory health are displayed in Panel B of Table 8. Here the lasso selects a relatively greater number of neonatal than fetal predictors.[40] Still, the inclusion of the fetal measures adds predictive power to the model which includes the birth measures only: the AUC increases from 0.631 to 0.662 (p=0.018) in the basic model (cols. 2a and 3a), and from 0.691 to 0.714 (p=0.015) in the extended model (cols. 2b and 3b); and also to the model with the postnatal growth measures: the AUC increases from 0.694 to 0.719 (p=0.010, cols. 4a and 4b in Table A23). Three fetal trajectories since mid-gestation until birth are significant predictors of a lower probability of developing asthma: fast growth in abdominal circumference (likely related to lung development), accelerated growth in head circumference, and symmetric abdomen/head circumference growth (by 14.4 p.p., 7.5 p.p. and 6.3 p.p. respectively, see col. 3b). Among the birth measures, being born at a low birth weight, low Apgar at 1 minute or with a small head increases the likelihood of developing asthma at 6 years (by 21.2 p.p.,[41] 8.3 p.p. and 7.8 p.p., respectively); conversely, high birth weight infants are less likely to develop a respiratory condition (by 7.6 p.p, col. 3b, also likely related to lung development). Given the difficulties associated with identifying which children will have asthma, and its financial burden (Sullivan et al., 2017), fetal measures might be usefully considered for inclusion in prediction models.

short birth length (<47 cm (Tuvemo et al., 1999), and asymmetric SGA (birth weight-for-gestational age <10th percentile and head circumference-for-gestational age >10th percentile).

[39]Note that the AUC values are in line with those reported in the literature for models including birth weight and postnatal growth as main predictors of obesity, see Druet et al. (2012).

[40]See Table A23 for the full results.

[41]Similar magnitude is found in the meta-analysis by Xu et al. (2014).

Last, the main results for child hyperactivity are in Panel C of Table 8.[42] Again, the inclusion of the measures of fetal development significantly adds predictive power both to the model with birth outcomes only (the p-values for the difference in AUCs are 0.008 and 0.022 for the models with the basic and the extended set of controls, respectively, see cols. 3a and 3b), and to the model which also includes postnatal outcomes (p-value=0.012, see col. 4b in Table A24). Unsurprisingly, prenatal head growth is a key predictor of the development of hyperactivity: fetuses with fast, accelerated and symmetric head growth have a lower probability of suffering of hyperactivity problems by age 6 (respectively, by 10.8, 6.2 and 4.3 p.p., see col. 3b). Additionally, being born short and as an asymmetric SGA baby increases the probability of becoming hyperactive by age 6; however, the estimates lack statistical precision. Given the substantial costs entailed by hyperactivity disorders (Guevara et al., 2001), the use of fetal measures to improve prediction is likely to be cost-effective, given that they are routinely collected during prenatal care.

In sum, our results show that measures of fetal growth patterns significantly improve the predictive power of models of child physical and mental health conditions, above and beyond indicators of health at birth and postnatal growth. These results are consistent with a substantial body of literature which shows adverse long-term effects of suboptimal in utero conditions, even in the absence of any observed impact at birth. Our results highlight the need to supplement the use of birth weight - so far central in the economics literature - with that of other measures, which contain information on other aspects of the fetal environment: on a more practical level, the fetal measurements which are collected in routine ultrasound scans could be profitably made available to researchers.

5 Conclusions

Health at birth is a crucial link in the transmission of advantage and disadvantage, both along the life course and across generations. Economists have routinely used birth weight to measure neonatal health, given its widespread availability in several datasets. However, recent advances in measurements have made possible the collection of additional measures of fetal (and newborn) health. The informational content and predictive value of birth weight, as compared to these alternative measures, is an important question which has not been investigated. In this paper we have used unique UK data with fetal measures from ultrasound scans, and we have provided several important insights, advancing not only the vast literature in economics on the production of early health, but also the related literature in medicine and epidemiology, which has not carried out such an extensive and coherent analysis to date.

In the first part of our analysis, we have shown that our novel fetal measures meaningfully predict different birth outcomes, and that other neonatal measures, such as birth length and head circumference, as well as Apgar scores, are more informative than birth weight about different aspects of the prenatal environment. Birth weight primarily reflects the abdominal circumference of the fetus and while low circumference is related to negative outcomes, high circumference is associated with prematurity and low Apgar scores. We have also shown that birth weight predicts newborn fat mass, while birth length and head circumference do not. Hence, birth weight captures both negative as well as positive aspects of fetal health. Our results are

[42] See Table A24 for the full results.

robust to controlling for a large set of predetermined covariates and to accounting for measurement error in the fetal measures using factor-analytic methods, and for child-specific unobserved heterogeneity; we have also replicated them using another UK dataset with fetal ultrasound scans data (the Birthright study). While birth weight is a short-term indicator and mostly reflects the fetal environment in late pregnancy, we have shown that fetal development since early gestation - even conditional on late gestation - affects health at birth; and that patterns of fetal growth - in particular, deviations from a balanced growth trajectory - are important predictors of costly birth outcomes such as low birth weight and prematurity.

In the second part of our analysis, we have assessed the predictive power of these novel fetal measures for postnatal outcomes. We have shown that third trimester fetal anthropometrics are predictive of child height and BMI at six years of age, above and beyond measures of size and length at birth, and even postnatally. These results are robust to accounting for individual unobserved heterogeneity using a child fixed effects model. While birth weight is associated with both height and body mass index (BMI), not accounting for birth length overestimates the strength of its association with height and underestimates that with BMI. Using two complementary U.S. data sources and a mother fixed effects approach, we have shown that birth length indeed rivals birth weight in predicting growth and cognition in childhood. Last, we have shown that patterns of fetal growth are predictive of common and costly child physical and mental health conditions - overweight, asthma and hyperactivity - above and beyond health at birth.

Our results suggest that health in utero and at birth is a complex and multidimensional entity, which cannot be easily summarized by one proxy. Although birth weight provides some information about the endpoint of fetal growth, it neither describes the trajectory followed in utero, nor it reflects the body composition of the fetus. The lack of a strict correspondence between birth weight and neonatal health is further supported by historical evidence which shows that, in the industrialized world, average birth weight has been remarkably stable between the mid-nineteenth century and today, despite substantial changes in social conditions and in front of significant increases in average height and massive reductions in infant mortality. At the same time, it is likely that substantial differences exist between populations; therefore, adopting universal standards of optimal fetal growth might lead to inadvertently harmful interventions. Our results also suggest that multiple perinatal indicators should be routinely collected and used to gain a more complete assessment of the causes and consequences of early life health. Birth weight should be re-considered as the sole potential target for prenatal interventions: since it acts as a proxy for other, usually unobserved, endowments, policies aimed at increasing it might not lead to improvements in later outcomes, especially if implemented at the end of gestation. Along the same lines, failing to find an impact of an intervention on birth weight might not necessarily imply the inability for a certain policy to improve later health.

While the developmental origins of health and disease (DOHaD) literature has made great strides in recent years, especially in establishing robust associations of early environmental exposures and later health risks, the key challenge is to understand how early experiences have long-term consequences, in order to establish effective pathways to remediate the effects of early adversity. Two promising avenues are currently being pursued. The first, to which the current work belongs, focuses on more accurate measurements and modelling of early life health (including records of the mother's health) and specific proxies for various exposures, including epigenetic markers. The second aims at disentangling biological mechanisms from behavioural responses, by estimating production functions in addition to reduced-form impacts. The use and interpretation of novel measurements requires nonetheless an understanding of the specific inputs generating them, hence an important area of work - currently ongoing - is the study of human development since the prenatal period, with the estimation of in utero production functions. In this way, we can improve our understanding of the causes and consequences of early life circumstances, and the complex interplay of biology, shocks, investments, and policies, with resulting benefits for public health.

6 Acknowledgments

This work was supported by grants from the Medical Research Council (MC-UP-A620-1017, MC-ST-U12055), British Heart Foundation (RG/07/009), European Union's Seventh Framework Programme (FP7/2007-2013, project EarlyNutrition under grant agreement n.289346), UK Food Standards Agency, Arthritis Research UK, National Osteoporosis Society, International Osteoporosis Foundation, Cohen Trust, NIHR Southampton Biomedical Research Centre, University of Southampton and University Hospital Southampton NHS Foundation Trust, British Lung Foundation and NIHR Musculoskeletal Biomedical Research Unit, University of Oxford. KMG is supported by the UK Medical Research Council (MC-UU-12011/4), the National Institute for Health Research (NIHR Senior Investigator (NF-SI-0515-10042), NIHR Southampton 1000DaysPlus Global Nutrition Research Group) and NIHR Southampton Biomedical Research Centre), the European Union (Erasmus+ Programme Early Nutrition eAcademy Southeast Asia-573651-EPP-1-2016-1-DE-EPPKA2-CBHE-JP), the US National Institute On Aging of the National Institutes of Health (Award No. U24AG047867) and the UK ESRC and BBSRC (Award No. ES/M00919X/1). Gabriella Conti has been supported by the European Union H2020 (grant no. 633595 - DynaHEALTH) and the European Research Council (grant agreement No. 819752 - ERC-CoG-2018 - DEVORHBIOSHIP). Jiaqi Li provided excellent research assistance in the analysis of the CNLSY and PtA data. We thank Orazio Attanasio, Jere Behrman, Janet Currie, Angus Deaton, Matthew Gillman, Victor Lavy, Cheti Nicoletti, Stavros Poupakis and seminar participants at the 2013 NBER Summer Institute Children Program Meeting, 2014 NBER Cohort Studies Group Meeting, 2014 NBER Summer Institute Health Economics Program Meeting, 2014 "Beyond Birthweight" Workshop at the University of Sussex, 2015 Essen Health Conference, 4th Toulouse Economics and Biology Workshop, 2016 Essex Workshop "Health and Gender", 2016 Barcelona GSE Summer Forum "Children's Health, Well-Being and Human Capital Formation", EDePo and IDB workshop "The Early Years: Child Well-being and the Role of Public Policy", "Power of Programming" 2016 Conference, Royal Economic Society 2017 "EJ Special Session: Early Investments and Life Cycle Outcomes", at University of Bonn and at University College London for valuable comments.

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Appendices

Appendix A Early Life Health In The Economic Literature

In this section we review key papers in the economic literature which have examined the consequences of early life health. We mainly focus on the papers which have studied birth weight using a twins fixed effects approach, and also, we briefly review some papers that have examined height.

Birth weight has been routinely used in the economic literature as measure of birth endowment, both as a determinant of later outcomes, when examining the long-term consequences of early life health (Behrman and Rosenzweig, 2004; Black et al., 2007; **?**) and as an outcome itself, when analyzing the impact of maternal behaviours in pregnancy (Rosenzweig and Schultz, 1983; Grossman and Joyce, 1990; Rosenzweig and Wolpin, 1991, 1995), and of prenatal policies (e.g. Currie and Gruber (1996); Hoynes et al. (2015)). Although there is a consensus in the literature that birth weight has significant effects on a variety of outcomes, these effects are not fully consistent across studies, and appear larger in the long-run than in the short-run;[43] this suggests that, beyond the differences in sample composition and econometric specification across studies, birth weight might act as a proxy for other unmeasured fetal and neonatal endowments, and so affect different outcomes through different mechanisms.

Behrman and Rosenzweig (2004) use a sample of female twins from the Minnesota Twins study, who were followed-up at an average age of 46 years by means of a mailed questionnaire (achieving a return rate of over 60%). Differently from most of the literature, they use overall birth weight divided by gestational length as their measure of early health. They find that an increase of 0.4 oz./week (corresponding to an increase in birth weight of 1 lb.) results in almost a third of a year more of schooling, a 0.6 in. increase in adult height and a 7% increase in earnings - and no effect on BMI, or on the birth weight of the children of the twins. Interestingly, for schooling and wages, their fixed effects estimates are bigger than the Ordinary Least Squares (OLS) estimates, which suggests a negative correlation between birth weight and unobserved endowments.

Almond et al. (2005) are the first to use large administrative data from the United States Vital Statistics to estimate the impact of low birth weight on hospital costs, infant mortality, assisted ventilator use and Apgar scores. Unlike Behrman and Rosenzweig (2004), their twin fixed effects estimates are much smaller than the ordinary least squares ones: a one standard deviation increase in birth weight (667 grams) reduces 1-year and neonatal mortality by 0.078 and 0.061 of a standard deviation, respectively; and increases 5-minutes Apgar score by 0.056 of a standard deviation. When the authors exclude twin pairs in which one or both twins have a congenital abnormality, the fixed effects estimates are further reduced in magnitude and for half of the outcomes are no longer significant.[44] Additionally, the size and the statistical significance of

[43] One interesting area of research (see Almond and Mazumder (2013) for a review) investigates the extent to which differences in initial endowments might be exacerbated or mitigated by parents who make investments and resource allocation decisions within the household in a reinforcing or compensatory manner. See also Torche and Conley (2016) for a recent assessment of the literature on the use of birth weight as measure of early endowments.

[44] Conley et al. (2006) further elaborate on this point, by showing that within-twin genetic variation may be largely responsible for the higher mortality risk faced by a smaller twin only in the case of full-term pregnancies, while within-twin variation in the prenatal environment seems more important in accounting for differences in infant mortality in the case of pregnancies that lasted

the impacts tend to decrease along the birth weight distribution. Almond et al. (2005) also exploit a different source of variation in birth weight than the random exposure to different environmental inputs in the womb occurring within twin pairs, i.e. the one driven by maternal smoking in pregnancy. Using a propensity score matching approach, they find that newborns of smoking mothers have lower birth weight, but no discernible differences in infant mortality or Apgar scores.[45] Thus, Almond et al. (2005) make the important point that low birth weight might (or not) have negative consequences, depending on what caused it in the first place (for example, poor nutrition or smoking). Hence, some policies may be effective in raising birth weight, but not in improving immediate outcomes, depending on the nature of the intervention itself.

Black et al. (2007) examine both short- and long-run effects of birth weight, using large administrative data from Norway. They find that, while the twin fixed effects estimates are smaller than the OLS estimates for the short-run outcomes, the opposite is true for the long-run outcomes, thus reconciling the results of Behrman and Rosenzweig (2004) and of Almond et al. (2005). Their results show that a 10% increase in birth weight translates into about 0.57 cm of additional height at age 18, a 0.06 increase in the IQ score (measured on a scale from one to nine), a 1 p.p. (percentage point) increase in high school completion, a 1% increase in full-time earnings and a 1.5% increase in the birth weight of the first child. While there are significant non-linearities in the relationship between birth weight and mortality (with significantly larger effects for smaller babies), the relationship between birth weight and the other outcomes is remarkably constant across the distribution, as already seen in Almond et al. (2005). Interestingly, they find that the returns to birth weight have increased across cohorts, possibly because advances in medical technologies have allowed more twins to survive. Lastly, although the authors show that the cross-sectional relationships between birth weight and the outcomes studied are very similar for twins and singletons, they rightly point out that the source of variation in birth weight, and the mechanisms through which later outcomes are affected, might still differ across the two groups, with consequences for the external validity of twin-based studies.

Oreopoulos et al. (2008) analyze three neonatal measures (birth weight, gestational age and Apgar score) using administrative data from Canada, and examine outcomes both within siblings and within twin pairs. They confirm for Canada the results by Almond et al. (2005) for the United States, i.e. that higher birth weight reduces one-year mortality only for very low birth weight babies. The results on the longer-term outcomes differ somewhat between the siblings and the twins sample, although in general they are not sensitive to the newborn measure used within each sample.[46]

Royer (2009) uses administrative data on a sample of female twins from California and finds, instead, that the twin fixed effects estimates are consistently smaller than the ordinary least squares results for both short- and long- run outcomes: in her sample, a one kilogram increase in birth weight is associated with an increase in education by 0.16 of a year, and with an increase in own child's birth weight by 70 grams. She

less than 37 weeks. See also Conley et al. (2003) for an extensive study of the determinants and consequences of low birth weight.

[45]The authors also show that the Apgar score outperforms birth weight in predicting within twin-pair differences in both one-day and one-year mortality.

[46]In their siblings - but not twins - fixed effects estimates, both birth weight and the Apgar score are significant predictors of mortality between 1 and 17 years and of reaching grade 12 by age 17, while the opposite is the case for social assistance take-up. No significant impacts are instead detected on the Language Arts Score and on the number of total physician visits between the ages 12 and 17, regardless of the model and measure used.

also uses data from the Early Childhood Longitudinal Study Birth Cohort, and finds that a one kilogram increase in birth weight translates into a 0.09 standard deviation increase in the mental score, and into a 0.15 standard deviation increase in the motor score. Importantly, she finds significant evidence of nonlinearities, whereby the effects of increasing birth weight are stronger on health (infant mortality and adult hypertension) below the 2,500 grams threshold, but larger on education above it - potentially suggesting that birth weight might proxy for different prenatal endowments and affect later outcomes through different mechanisms at various points in its distribution.[47]

Figlio et al. (2014) use administrative data from Florida and find that a 10% increase in birth weight is associated with a 0.044 standard deviation increase in test scores at grades 3-8, with effects present as early as age 5 and stable until the middle school years. Importantly, this additional increase is associated with moving children from below to above the average of the test scores, rather than away from the tails of the distribution. As in previous studies, the estimated coefficients on log birth weight are very similar in the twin fixed effects specification and when using the population of singletons (upon restricting birth weight to the gestational age range observed for twins). Additionally, the relationship between birth weight and test scores is qualitatively similar across the birth weight and the discordance distributions, and does not vary substantially with measures of school quality. It does vary, nevertheless, by parental background: the authors find that the birth weight effects are somewhat bigger for children in high socioeconomic status families, suggesting that neonatal health and parental resources are to some degree complementary.[48] Crucially however, the test scores differences associated with variation in birth weight are extremely small compared to those associated with mother's education: these latter are ten times larger, and also constant throughout the school years.

Lastly, a recent paper by Bharadwaj et al. (2018) examines the long-run effects of birth weight using data on Swedish twins born between 1926-1958. The authors find that birth weight has a significant and economically meaningful impact on permanent income, sickness benefits take-up, hospitalizations, and mortality (the latter only for males). They also show that birth weight is less important for early life health outcomes across more recent cohorts, but the labour market effects remain quite stable over time.

This short review reveals that, while the recent economic literature has significantly advanced our knowledge on the effects of birth weight on a variety of outcomes, it has also left unanswered questions. One key question is the following: is birth weight per se important, or is it a proxy for other prenatal endowments which differ among the twins, and which are reflected, for example, in differences in birth length or head circumference? Almond et al. (2005) rightly point out that birth weight might not be in itself a relevant policy variable, and that "while some interventions may indeed succeed in both raising birth weight and improving health outcomes, others may only be effective in raising birth weights, with little or no effects on health". Thus, "other methods of infant health assessment may need to be developed". Apart from the present work, we are only aware of two other papers which have explored alternative measures: *robinson2013sound*, who has studied symmetric and asymmetric growth restriction on neonatal anthropometrics (in particular head circumference) and Anand and Chen (2018), the only other paper we are aware of who has used fetal data

[47] She also confirms the similarity in the cross-sectional relationship between birth weight and several outcomes across the singleton and twins samples already seen in Black et al. (2007).

[48] Royer (2009) also reports suggestive evidence that parents offer more resources to the heavier twin.

from ultrasound scans (from China). Another key question left unanswered concerns the external validity of the twin design: given that twins are usually smaller than singletons, how informative are the twin-based estimates about marginal increases in birth weight at higher points of the distribution? Behrman and Rosenzweig (2004) rightly point out that the effect of fetal growth on earnings can be overstated when estimated on twins, by showing that the within-MZ estimate (referring to monozygotic twins) on log earnings is statistically significant for the bottom third of the U.S. singleton distribution of fetal growth rates, but not for the top third.[49] While several papers show that the cross-sectional profiles are identical for the populations of singletons and twins, Almond et al. (2005) rightly notice that this can be the case even if the relationship between birth weight and the outcome of interest is subject to different omitted variables in the two groups. In this paper we aim to advance this literature by addressing the first question.

Another influential strand of the economic literature which has studied the causes and consequences of early life health has used height as measure of early endowments. The inverse relationship between adult height and morbidity and mortality rates was first observed by *waaler1984height*,[50] and subsequently by many others (see e.g. Fogel (1993)). Economic historians have long considered height to be one of the best indicators of standards of living (Steckel, 1995) and individual productivity (Fogel, 1987); and *gowin1917executive* was the first to link it with labour market status. Height has then become a topic of interest to economists in recent years because of its importance as predictor of wages Persico et al. (2004); Case and Paxson (2008b), well-being (Deaton and Arora, 2009), health and cognitive function (Case and Paxson, 2008a). Within this literature, the paper closest to ours is Case and Paxson (2010), which traces the differences in height among children back to birth and to the prenatal period. The authors show that part of the height differences between siblings stems from differences in their weights and lengths at birth, which are themselves attributable to differences in mothers' behaviours during pregnancy.

While both literatures briefly surveyed above have significantly advanced our understanding of the causes and consequences of early life health, they have proceeded in a somewhat parallel fashion. In this paper we also attempt to unite them, by comparing the fetal correlates and the predictive power of birth weight and birth length, respectively as neonatal precursors of weight and height.

Appendix B Data

In this section we describe the other three data sources we use in the paper, in addition to the Southampton Women's Survey.

Birthright The Birthright Study recruited a sample of pregnant women to examine maternal nutrition and fetal growth. These women were of age 16 years or older with singleton pregnancies and known menstrual data, and attended the antenatal booking clinic at the Princess Anne Hospital in Southampton before 17 weeks of gestation in the years 1993 to 1995 (see for example Cole et al. (2009)). We use the Birthright data to replicate the SWS results on the association between fetal anthropometrics and birth outcomes.

[49] When carrying out this exercise, the authors reweigh their sample using the US singleton distribution of fetal growth rates.

[50] In a study of the adult population of Norway during the period 1963-1975, Waaler found that, for both sexes and for all ages, mortality risk declines as body height rises, possibly with an exception for the very tall.

Children of the National Longitudinal Survey of Youth Since 1986, the women who were originally included in the National Longitudinal Survey of Youth (NLSY79) have been interviewed bi-annually about their children. The CNLSY (Children of the NLSY) has been used extensively to study the determinants and consequences of child development (e.g. Case and Paxson (2010)).

We select our analytical sample as follows. First, we select only the white children born between 1975 and 2000, to enhance comparability with the SWS sample. Second, to minimise measurement error,[51] we only keep those children for whom the birth length is reported as not being an estimate; we further remove a few outliers in birth weight and birth length using Tukey's method.[52] We then standardise birth weight and birth length for gestational age using the growth chart developed by Olsen et al. (2010) for the United States;[53] we further remove those z-scores resulting in values less than -4 or more than 4 standard deviations. Lastly, we only consider children with measurements between the ages 7-12 years.[54]

Summary statistics for our analytical sample of 3,224 children with non-missing z-scores for both birth weight and birth length for the years 1996-2014 are reported in Table A4. The mean birth weight in the CNLSY sample is comparable to that of the SWS sample, while the average birth length is 1.4 cm higher; from the z-scores we see that the sample is on average heavier and longer at birth than the reference population. As child outcomes, we focus on height and BMI (both standardised using the 2000 Center for Disease Control and Prevention (CDC) growth standards) and the following four tests: the Peabody Picture Vocabulary Test (PPVT),[55] the Wechsler Intelligence Scale for Children (WISC) Memory for Digit Span total standard score,[56] the Peabody Individual Achievement Test (PIAT) Mathematics and Reading Recognition assessments.[57]

Pathways to Adulthood The fourth and last dataset that we use is the Pathways to Adulthood (PtA; Hardy and Shapiro (1998)), which includes data on three generations of families living in the inner-city area of Baltimore.[58] In particular, we use data on the Second-Generation (G2) children born in the years 1960-1965 at John Hopkins Hospital. Our analytical sample includes information on birth outcomes and maternal characteristics at delivery, and anthropometric measurements and cognitive assessments at ages 7-8. We follow the same procedure as in the CNLSY to construct z-scores for the birth outcomes.

Summary statistics for the analytical sample of 1,422 children with non-missing z-scores for both birth

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[51] Differently from the SWS, the Birthright and the PtA, in the CNLSY all the anthropometric measures are self-reported.

[52] We remove observations which are smaller than the lower quartile, or larger than the upper quartile, by more than three times the interquartile range, respectively.

[53] The Olsen charts are only available for gestational ages between 23 and 41 weeks.

[54] This choice is dictated by the fact that this is a common window during which all our tests of interest are administered.

[55] The PPVT measures an individual's receptive (hearing) vocabulary for standard American English, and provides, at the same time, a quick estimate of verbal ability or scholastic aptitude.

[56] This is a component of the WISC and measures short-term memory in children.

[57] The PIAT Math subscale measures a child's attainment in mathematics as taught in mainstream education. The PIAT Recognition subscale measures word recognition and pronunciation ability. For all the tests, we use the age-specific standard scores provided (with a mean of 100 and standard deviation of 15). We don't use the PIAT comprehension since it has been seldom used in the literature, as it was administered only if PIAT reading exceeded a certain minimum score.

[58] The sample comprising the PtA is a subsample of the John Hopkins Collaborative Perinatal Study (JHCPS) which was selected for an adult follow-up. Of the JHCPS participants, 2,694 were eligible to participate in PtA.

weight and birth length are reported in Table A5. This sample is quite different from the SWS and the CNLSY: the average birth weight is 2.99 kg, 400 grams lower, and the average birth length is 48.93, 2.34 cm shorter than the average newborn in the CNLSY sample; from the z-scores we also see that the sample is lighter and shorter than the reference population. As child outcomes, we focus again on height and BMI, and on five cognitive tests administered by a child psychologist at ages 7-8 which measure the same domains as those in the CNLSY: the WISC Verbal Comprehension and Verbal Digit Scales, the Wide Range Achievement Test (WRAT) Math and Reading Scales, and the PPVT.[59]

[59]The Comprehension and Digit Span assessments are two of the four verbal subtests of the WISC. The WRAT Math and Reading Scales evaluated the child academic performance as measured by arithmetic computation, and reading, word recognition and pronunciation.

Appendix C Measures of Neonatal Health

In addition to birth weight, other neonatal anthropometric measures, such as birth length and head circumference, are of value. These measures are routinely collected in the birth records of the Scandinavian countries, and are also available in some survey-based datasets.[60] Birth length in particular is a measure of increasing interest in the public health literature as a marker of nutrition and fetal growth. While birth weight is a short-term indicator and mainly reflects the nutritional environment around the time of measurement (i.e. in the last weeks of gestation), birth length is a longer-term cumulative indicator. For example, Neufeld et al. (2004) have shown that maternal weight gain from the first to the second trimester, not from the second to the third, is associated with fetal linear growth (fetal femur length at 17 and 30 weeks) and with infant length at birth.[61] Chong et al. (2015) have found that maternal protein intake at 26-28 weeks of gestation is associated with birth length, but not with birth weight. These findings echo those of much earlier work, such as Burke et al. (1943), one of the first studies on maternal nutrition in pregnancy and birth size. **?** have also shown that the effect of energy supplementation in pregnancy in a community characterized by chronic energy deficiency is of greater magnitude on height than on weight. Morris et al. (1998) have shown that birth length has a strong association with development at 12 months in the Brazilian cohort Pelotas. More recently, Adu-Afarwuah et al. (2016) have shown that small-quantity, lipid-based nutrient supplements provided to women during pregnancy and 6 months postpartum and to their infants from 6 months of age increase the mean attained length of 18-month-old children in semi-urban Ghana. Lastly, a recent trial on preconception nutrition (Hambidge et al., 2019) has selected birth length as its primary outcome, and confirmed the importance of nutrition early in pregnancy on linear growth. This is also consistent with recent evidence from molecular genetics, which has shown that SNPs associated with adult height influence birth length (van der Valk et al., 2015), and that by age 10 years they explain approximately 5% of the variance in height (Paternoster et al., 2011), which is half of that explained in adults (i.e. approx. 10%, see Lango et al. (2010)).

The other neonatal anthropometric measure we study is head circumference. This is recognized in several studies as a marker of brain development, especially in early childhood (see e.g. Bartholomeusz et al. (2002)). Heritability estimates from twin studies (Smit et al., 2010) suggest that common environmental effects on head circumference other than pregnancy duration (e.g. maternal behaviours in pregnancy) play an important role in the earliest stages of life, but quickly give way to subsequent growth that is highly genetically determined.

In addition to these anthropometric measurements, another neonatal indicator routinely collected in the birth records of many countries - such as Scandinavia, U.S. and Canada - is the Apgar score. This is a method to quickly summarize the health of newborns, which was developed by the anaesthetist Virginia Apgar in 1952.[62]. The newborn is evaluated on five simple criteria (Appearance, Pulse, Grimace, Activ-

[60] For example, in the Avon Longitudinal Study of Parents and Children (ALSPAC) and the Born in Bradford (BiB) data for the UK, and in the Generation R data for the Netherlands.

[61] Complementary evidence is provided in Wander et al. (2015), who find that late pregnancy gestational weight gain is associated with greater increase in birth weight than early pregnancy gestational weight gain.

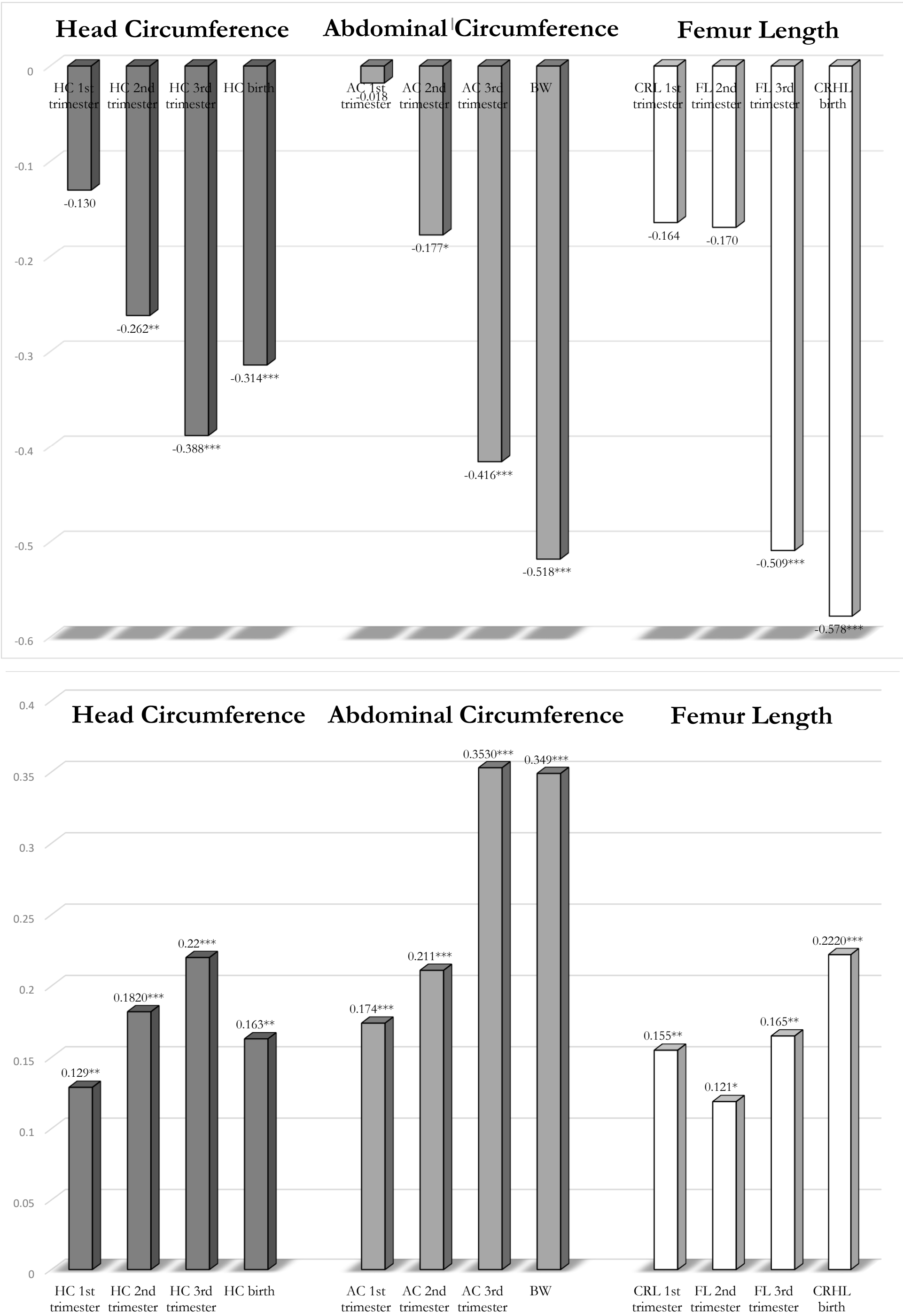
[62] She validated the scale by assessing the mortality rates of 2,096 newborn infants with low, moderate, and high Apgar scores Apgar (1952); Apgar et al. (1958); Apgar (1966)

ity, Respiration) which reflect physiological parameters, each on a scale from zero to two; the five values obtained are summed up, in a score which can range from 0 to 10. The test is generally performed at one and five minutes after birth, and may be repeated later if the score is low. Its continuing value for assessing newborns has been shown repeatedly over the years (see e.g. Casey et al. (2001); Iliodromiti et al. (2014); Persson et al. (2018).[63]

We further study three measures of body composition from DXA (dual-energy X-ray absorptiometry) - fat and lean mass, and the proportion of body fat - and one measure of thigh subcutaneous tissue thickness from the skinfolds. DXA is an indirect method to assess body composition safely and non-invasively using the principle of X-ray beam attenuation by the different body tissues, and to differentiate between fat and lean mass (de Vargas Zanini et al., 2015). The measurement of subcutaneous tissue thickness by skinfold calipers is also a safe and non-invasive method, which has been used for more than fifty years (Edwards et al., 1955). We focus on the thigh skinfold since previous research has shown that it is the most repeatable and representative of the skinfolds (Farmer, 1985); however, we obtain identical results when using the other skinfolds (biceps, triceps and subscapular).

[63] It is important that the Apgar is measured in a standardized way, to enhance its comparability across different settings, see for example Gupta et al. (2017).

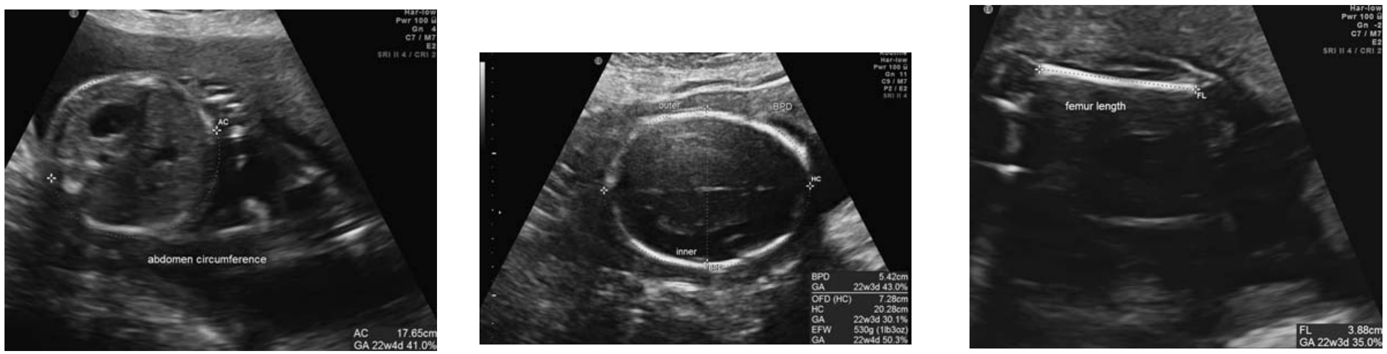
Figure A1: Gradients In Fetal And Neonatal Health Capital.



Notes: The graphs above are based on the SWS data. Each bar in each graph plots the coefficient (the number displayed at the end of the bar) of a linear regression of a specific fetal or birth measure on a different exposure (without including additional controls): (a) Mother smoking both in the early and late part of pregnancy; (b) Mother with excessive weight gain in pregnancy (Institute of Medicine 2009 definition). We use balanced samples of 850 (panel a) and 827 women (panel b), respectively. CRL: Crown-Rump Length; HC: Head Circumference; AC: Abdominal Circumference; FL: Femur Length; CRHL: Crown- Heel Length; BW: Birth Weight. Each fetal anthropometric indicator is the unweighted average of three different measurements. Here we use crown-rump length rather than femur length for the first trimester since the smaller number of observations for the latter (due to the difficulty of measuring it early in gestation) would lead to a severe reduction in size for the balanced sample.

Figure A2: Fetal Measurements from Ultrasound Scans.

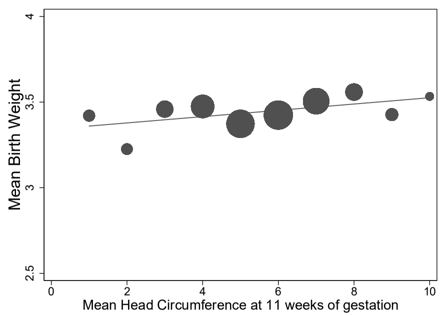
(a) Abdominal Circumference (b) Head Circumference (c) Femur Length



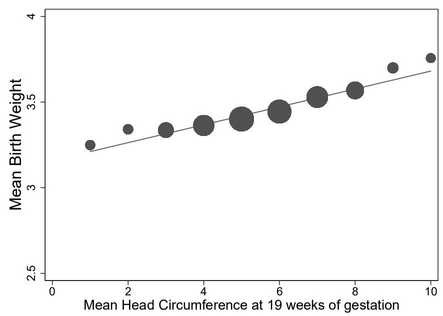
Notes: These ultrasounds are not based on the SWS sample, and are shown for illustrative purposes only.

Figure A3: Birth Weight And Fetal Health Capital In The Three Trimesters Of Pregnancy.

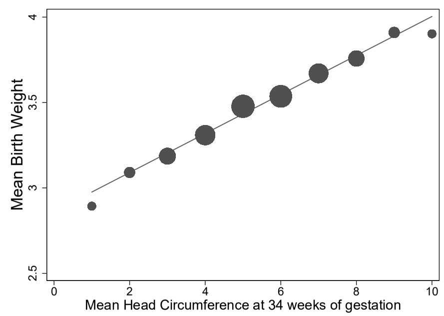
(a) Bw vs. Head Circumference 11w



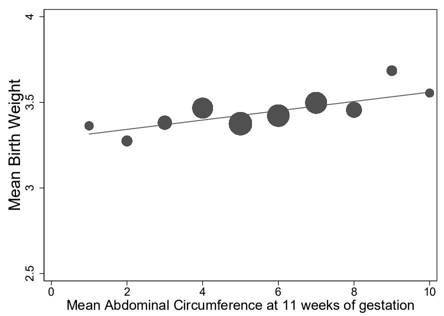
(b) Bw vs. Head Circumference 19w



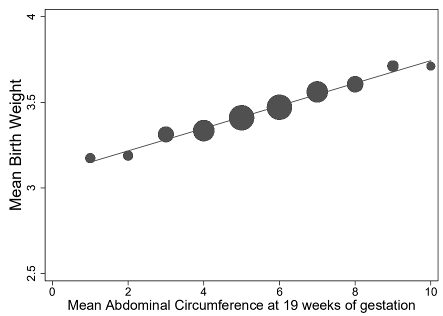
(c) Bw vs. Head Circumference 34w



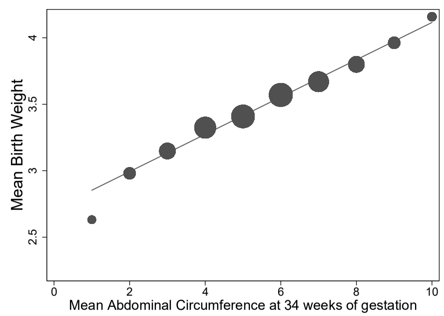
(d) Bw vs. Abdominal Circumference 11w



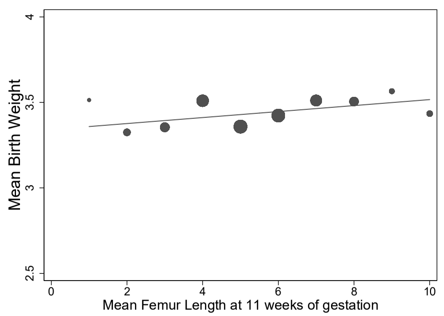
(e) Bw vs. Abdominal Circumference 19w



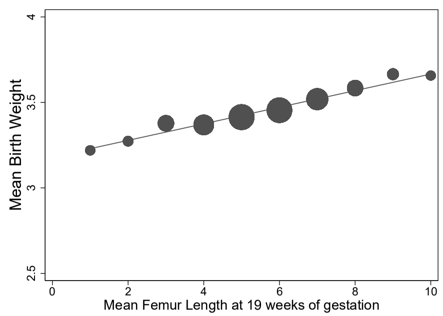
(f) Bw vs. Abdominal Circumference 34w



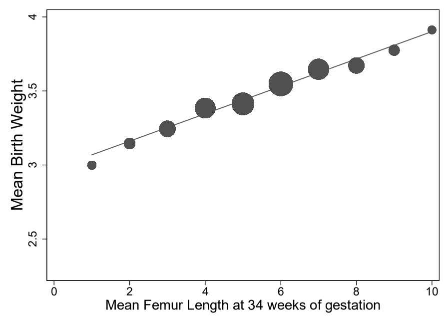
(g) Bw vs. Femur Length 11w



(h) Bw vs. Femur Length 19w

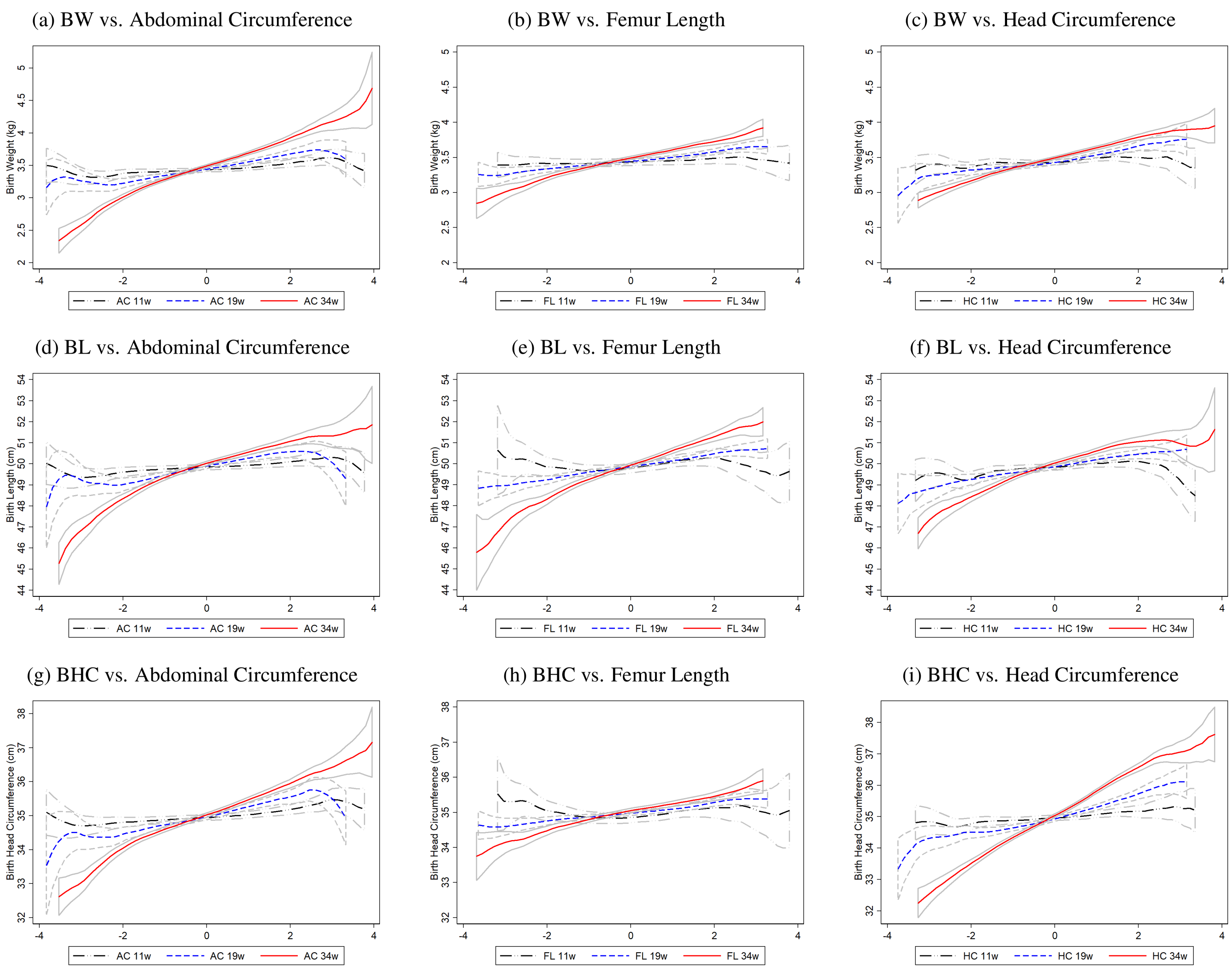


(i) Bw vs. Femur Length 34w



Notes: The graphs above are based on the fetal growth sample, SWS data. Each circle represents the mean birth weight (in kilograms) for each of the ten bins in which the fetal measures (expressed as *z*-scores) have been grouped, as follows: 1=-4 to -2; 2=-2 to -1.5; 3=-1.5 to -1; 4=-1 to -0.5; 5=-0.5 to 0; 6=0 to 0.5; 7=0.5 to 1; 8=1 to 1.5; 9=1.5 to 2; 10=2 to 4. The size of the dots is proportional to the number of observations in each bin. The lines represent fitted values from an ordinary least squares regression of birth weight on the respective (binned) fetal measure. Abbreviations: bw=birth weight; w=weeks.

Figure A4: Birth Health Capital and Fetal Health Capital in the Three Trimesters of Pregnancy



Notes: The graphs above are based on the fetal growth sample, SWS data. Each panel shows kernel-weighted local polynomial smoothing graphs with bandwidth 0.8 and with confidence intervals of one anthropometric birth measure (birth weight in kilograms in panels a-c, birth length in centimetres in panels d-f, birth head circumference in centimetres in panel g-i) on one fetal anthropometric measure (abdominal circumference in panels a-d-g, femur length in panels b-e-h, head circumference in panels c-f-i), for each of the three periods of gestation at which it has been measured (11, 19 and 34 weeks). Abbreviations: BW=Birth Weight; BL=Birth Length; BHC=Birth Head Circumference.

Table A1: Baseline (pre-pregnancy) Characteristics, Fetal and Non-Fetal Growth Samples

	(1) Mean FGS	(2) N FGS	(3) Mean NFGS	(4) N NFGS	(5) *p*-value
Child is male	0.51	1,973	0.53	1,167	0.217
Mother's Age at Birth	30.92	1,974	30.24	1,167	0.000
Child is Firstborn	0.52	1,981	0.50	1,172	0.180
White Ethnicity	0.95	1,982	0.96	1,173	0.701
No. of Children	0.68	1,981	0.76	1,172	0.028
Mother has a University Degree	0.25	1,978	0.17	1,169	0.000
Mother is High Social Class	0.42	1,982	0.33	1,174	0.000
Mother is Low Social Class	0.19	1,982	0.26	1,174	0.000
Partner is High Social Class	0.31	1,982	0.27	1,174	0.013
Partner is Low Social Class	0.36	1,982	0.36	1,174	0.772
Mother's Father is High Social Class	0.21	1,982	0.17	1,174	0.012
Mother's Father is Low Social Class	0.53	1,982	0.57	1,174	0.027
Mother is Single	0.45	1,982	0.51	1,172	0.001
Mother is Separated/Divorced/Widowed	0.05	1,982	0.07	1,172	0.035
Family Receives Welfare Benefits	0.12	1,982	0.20	1,173	0.000
Townsend Deprivation Index	-0.06	1,969	0.30	1,164	0.002
House Owner	0.66	1,981	0.55	1,172	0.000
Mother Birth Weight	3.25	1,982	3.25	1,174	0.987
Mother Weight (kg)	67.19	1,967	67.24	1,164	0.925
Mother Height (cm)	163.41	1,968	162.89	1,171	0.030
Mother Body Mass Index	25.14	1,964	25.30	1,164	0.372
Mother Head Circumference (cm)	55.08	1,982	55.01	1,174	0.207
Mother Leg Length (cm)	98.54	1,964	98.35	1,164	0.303
Mother Waist Circumference (cm)	79.94	1,960	80.35	1,161	0.306
Mother Sum of Skinfolds (mm)	72.05	1,949	71.81	1,152	0.830
Mother in Fair, Bad or Very Bad Health	0.18	1,982	0.27	1,173	0.000
Mother is Stressed	0.46	1,978	0.47	1,172	0.528
Father Birth Weight (kg)	3.41	1,982	3.38	1,174	0.086
Father Height (cm)	179.38	1,982	178.59	1,174	0.002
Father Weight (kg)	83.27	1,982	82.73	1,174	0.236
Mother's Mother Weight (kg)	57.23	1,982	57.43	1,174	0.516
Mother's Mother Height (cm)	162.93	1,946	162.28	1,144	0.013
Mother's Father Weight (kg)	82.25	1,982	82.31	1,174	0.894
Mother's Father Height (cm)	176.45	1,982	176.13	1,174	0.263
Mother Works (last week)	0.81	1,982	0.78	1,172	0.048
Mother Smokes	0.25	1,982	0.32	1,171	0.000
Mother Drinks >4 units Alcohol/w	0.55	1,982	0.53	1,172	0.253
Kilocalories per day	2.09	1,982	2.17	1,172	0.002
Any Strenuous Exercise in the week	0.66	1,968	0.63	1,169	0.098
Any Moderate Exercise in the week	0.65	1,980	0.64	1,173	0.473

Notes: Own calculations from the SWS data. The SWS uses the measure of Social Class based on Occupation (SC, formerly Registrar General's Social Class): I is Professional, II is Management and technical, IIIN is Skilled non-manual, IIIM is Skilled manual, IV is Partly skilled and V is Unskilled. High Social Class is defined as I or II, low Social Class as IIIM, IV or V. The sum of skinfolds includes triceps, biceps, subscapular and suprailiac. The variable "mother in fair, bad or very bad health" is constructed on the basis of the following variable "How is your health in general? Would you say..." Answers "very good" or "good" are coded as 0, answers "fair", "bad" and "very bad" are coded as 1. The variable "mother is stressed" is constructed on the basis of the following variable "How much stress in daily living in the last 4 weeks?" Answers "none" or "just a bit" are coded as 0, answers "a good bit", "quite a lot" and "a great deal" are coded as 1. Missing values for social class of the mother, the mother's father and the mother's partner have been replaced with zeros; missing values for maternal birth weight and head circumference, for paternal height, weight and birth weight, for mother's mother weight and mother's father height and weight have been replaced with the sample means of the non-missing observations in the overall sample. See footnote 15 in the text. In column (5) we report *p*-values for two-sided *t*-tests for differences in means (with unequal variances) for the continuous variables, and tests for the equality of proportions for the binary variables between the fetal and non-fetal growth sample. Abbreviations: N=sample size. FGS=Fetal Growth Sample. NFGS=Non-Fetal Growth Sample.

Table A2: Summary Statistics: Prenatal, Birth and Postnatal Development

	(1) Mean/Prop.	(2) SD	(3) Min.	(4) Max.	(5) N
Panel A: Prenatal					
Head Circumference 11w (*z*-score)	0.01	0.96	-3.48	3.36	1,255
Head Circumference 19w (*z*-score)	0.03	1.01	-3.75	3.16	1,941
Head Circumference 34w (*z*-score)	-0.01	1.01	-3.27	3.83	1,846
HC Declining Trajectory	0.25	-	0	1	1,811
HC Increasing Trajectory	0.25	-	0	1	1,811
HC Conditional Growth 11-19w (*z*-score)	0.12	0.90	-2.77	2.97	1,247
HC Conditional Growth 19-34w (*z*-score)	-0.03	1.06	-4.02	4.70	1,818
HC Conditional Growth 34w-birth (*z*-score)	0.01	0.98	-2.80	3.35	1,748
HC Slow Growth 19w-birth	0.06	-	0	1	1,722
HC Fast Growth 19w-birth	0.06	-	0	1	1,722
HC Accelerated Growth 19w-birth	0.25	-	0	1	1,722
Abdominal Circumference 11w (*z*-score)	0.02	0.99	-3.84	3.78	1,175
Abdominal Circumference 19w (*z*-score)	0.01	0.97	-3.89	3.33	1,932
Abdominal Circumference 34w (*z*-score)	0.01	1.02	-3.53	3.96	1,920
AC Declining Trajectory	0.25	-	0	1	1,871
AC Increasing Trajectory	0.25	-	0	1	1,871
AC Stable Low Trajectory	0.13	-	0	1	1,871
AC Stable High Trajectory	0.13	-	0	1	1,871
AC Conditional Growth 11-19w (*z*-score)	0.06	0.89	-2.48	2.70	1,167
AC Conditional Growth 19-34w (*z*-score)	0.00	1.05	-3.79	4.07	1,878
AC Conditional Growth 34w-birth (*z*-score)	0.00	1.00	-4.45	3.47	1,813
AC Slow Growth 19w-birth	0.06	-	0	1	1,777
AC Fast Growth 19w-birth	0.06	-	0	1	1,777
Asymmetric HC/AC Growth 19-34w	0.25	-	0	1	1,808
Asymmetric AC/HC Growth 19-34w	0.25	-	0	1	1,808
Symmetric AC/HC Growth 19-34w	0.50	-	0	1	1,808
Femur Length 11w (*z*-score)	-0.01	1.01	-3.18	3.80	468
Femur Length 19w (*z*-score)	0.03	1.00	-3.64	3.28	1,943
Femur Length 34w (*z*-score)	0.00	1.00	-3.69	3.16	1,918
FL Declining Trajectory	0.25	-	0	1	1,880
FL Increasing Trajectory	0.25	-	0	1	1,880
FL Slow Growth 19w-birth	0.05	-	0	1	1,765
FL Fast Growth 19w-birth	0.05	-	0	1	1,765
FL Accelerated Growth 19w-birth	0.25	-	0	1	1,765
Symmetric HC/FL Growth 19-34w	0.50	-	0	1	1,811
Panel B: Birth					
Weight (kg)	3.45	0.54	0.48	5.41	1,957
Weight CGF (*z*-score)	0.03	0.95	-3.69	3.73	1,957
Low Birth Weight (<2,500 grams)	0.04	-	0	1	1,957
Small-for-gestational-age (SGA)	0.08	-	0	1	1,957
SGA Asymmetric	0.05	-	0	1	1,982
High Birth Weight (≥4,000 grams)	0.13	-	0	1	1,957
Large-for-gestational-age (LGA)	0.09	-	0	1	1,957
Gestational Age (weeks)	39.77	1.83	26.29	43.00	1,974
Premature (<37 weeks gestation)	0.06	-	0	1	1,974
Crown-Heel Length (cm)	49.88	2.04	41.30	56.23	1,824
Crown-Heel Length CGF (*z*-score)	-0.41	0.86	-3.83	2.51	1,823
Short Crown-Heel Length (<47cm)	0.08	-	0	1	1,824
Head Circumference (cm)	34.99	1.36	29.60	40.93	1,842
Head Circumference CGF (*z*-score)	0.09	0.95	-2.81	4.39	1,842
Small Head Circumference (<35.36cm)	0.66	-	0	1	1,842
Percent Fat from DXA	0.15	0.04	0.04	0.32	625
Fat Mass (kg)	0.53	0.20	0.08	1.56	625
Lean Mass (kg)	2.92	0.31	1.97	3.95	625
Thigh Skinfold (*z*-score)	0.01	1.00	-2.46	4.58	1,834
Apgar Score 1 minute	8.29	1.56	0	10	1,900
Panel C: Postnatal Period					
Height CGF 6y (*z*-score)	0.18	0.97	-2.79	3.46	1,281
BMI CGF 6y (*z*-score)	0.15	0.99	-2.83	4.16	1,276
Overweight 6y	0.17	-	0	1	1,276
Asthma (GP diagnosed) or Wheezing 6y	0.22	-	0	1	1,294
Hyperactivity Problems (SDQ) 3y	0.19	-	0	1	1,649
WPPSI Verbal Scale 4y	112.57	14.63	59	153	174
WPPSI General Language Scale 4y	103.82	11.61	70	131	174
NEPSY Sentence Repetition Scale 4y	10.60	2.32	4	18	168

Notes: Own calculations from the SWS data. "AC/HC/FL Declining Trajectory" is a binary indicator which takes value 1 if the fetus is in the lower quartile of the distribution of the difference between the third and the second trimester AC/HC/FL. "AC/HC/FL Increasing Trajectory" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the distribution of the difference between the third and the second trimester AC/HC/FL. "HC/FL Accelerated Growth 19w-birth" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the distribution of the difference in the Head Circumference/Length growth between week 34 and birth and between weeks 19-34. "AC Stable Low Trajectory" is a binary indicator which takes value 1 if the fetus is in the lower quartile of the Abdominal Circumference distribution both in the second and in the third trimester. "AC Stable High Trajectory" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the Abdominal Circumference distribution both in the second and in the third trimester. "AC/HC/FL Slow Growth 19w-Birth" is a binary indicator which takes value 1 if the fetus is in the lower quartile of the Abdominal Circumference/Head Circumference/Femur Length growth distribution both between weeks 19-34 and between week 34 and birth. "AC/HC/FL Fast Growth 19w-Birth" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the Abdominal Circumference/Head Circumference/Femur Length growth distribution both between weeks 19-34 and between week 34 and birth. "Asymmetric HC/AC Growth 19-34w" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the distribution of the difference between the Head Circumference growth and the Abdominal Circumference growth between weeks 19 and 34. "Symmetric HC/FL Growth 19-34w" is a binary indicator which takes value 1 if the fetus is between the lower and the upper quartile of the distribution of the difference between the Head Circumference growth and the Femur Length growth between weeks 19 and 34. "Short Crown-Heel Length" at birth is a binary indicator which takes value 1 if the Crown-Heel Length is shorter than 47 cm. "Small Head Circumference" at birth is a binary indicator which takes value 1 if the Head Circumference is smaller than 35.56 cm. Abbreviations: SDQ=Strengths and Difficulties Questionnaire. WPPSI=Wechsler Preschool & Primary Scale of Intelligence. NEPSY = Neuropsychological Assessment. Prop.=proportion. SD = Standard Deviation (only reported for continuous variables). Min. = Minimum. Max. = Maximum. N = sample size. CGF = Child Growth Foundation. y=years.

Table A3: Summary Statistics: Baseline (preconception) Characteristics

	(1) Mean/Prop.	(2) SD	(3) Min.	(4) Max.	(5) N
Panel A: Preconception Parental Demographic and Socioeconomic Characteristics					
Child is male	0.51	-	0	1	1,973
Mother's Age at Birth	30.92	3.75	21	42	1,974
Child is Firstborn	0.52	-	0	1	1,981
White Ethnicity	0.95	-	0	1	1,982
No. of Children	0.68	0.89	0	8	1,981
Mother has a University Degree	0.25	-	0	1	1,978
Mother is High Social Class	0.42	-	0	1	1,982
Mother is Low Social Class	0.19	-	0	1	1,982
Partner is High Social Class	0.31	-	0	1	1,982
Partner is Low Social Class	0.36	-	0	1	1,982
Mother's Father is High Social Class	0.21	-	0	1	1,982
Mother's Father is Low Social Class	0.53	-	0	1	1,982
Mother is Single	0.45	-	0	1	1,982
Mother is Separated/Divorced/Widowed	0.05	-	0	1	1,982
Family Receives Welfare Benefits	0.12	-	0	1	1,982
Townsend Deprivation Index	-0.06	3.06	-5.83	8.22	1,969
House Owner	0.66	-	0	1	1,981
Panel B: Preconception Parental Physical and Mental Health					
Mother Birth Weight (kg)	3.25	0.52	0.91	5.31	1,982
Mother Weight (kg)	67.19	13.40	40	146	1,967
Mother Height (cm)	163.41	6.34	142.00	188.30	1,968
Mother Body Mass Index	25.14	4.65	16.42	48.84	1,964
Mother Head Circumference (cm)	55.08	1.43	50.40	60.30	1,982
Mother Leg Length (cm)	98.54	4.85	82.00	118.20	1,964
Mother Waist Circumference (cm)	79.94	10.65	58.10	134.30	1,960
Mother Sum of Skinfolds (mm)	72.05	29.96	19.10	196.00	1,949
Mother in Fair, Bad or Very Bad Health	0.18	-	0	1	1,982
Mother is Stressed	0.46	-	0	1	1,978
Father Birth Weight (kg)	3.41	0.51	0.96	5.44	1,982
Father Height (cm)	179.38	6.57	152.40	203.20	1,982
Father Weight (kg)	83.27	12.38	50.79	148.00	1,982
Mother's Mother Weight (kg)	57.23	8.20	37.80	125.00	1,982
Mother's Mother Height (cm)	162.93	6.92	134.60	185.40	1,946
Mother's Father Weight (kg)	82.25	12.37	38.10	190.70	1,982
Mother's Father Height (cm)	176.45	7.47	148.00	208.30	1,982
Mother Works (last week)	0.81	-	0	1	1,982
Mother Smokes	0.25	-	0	1	1,982
Mother Drinks >4 units Alcohol/week	0.55	-	0	1	1,982
Kilocalories per day	2.09	0.59	0.51	5.04	1,982
Any Strenuous Exercise in the week	0.66	-	0	1	1,968
Any Moderate Exercise in the week	0.65	-	0	1	1,980

Notes: Own calculations from the SWS data. The SWS uses the measure of Social Class based on Occupation (SC, formerly Registrar General's Social Class): I is Professional, II is Management and technical, IIIN is Skilled non-manual, IIIM is Skilled manual, IV is Partly skilled and V is Unskilled. High Social Class is defined as I or II, low Social Class as IIIM, IV or V. The sum of skinfolds includes triceps, biceps, subscapular and suprailiac. The variable "mother in fair, bad or very bad health" is constructed on the basis of the following variable "How is your health in general? Would you say..." Answers "very good" or "good" are coded as 0, answers "fair", "bad" and "very bad" are coded as 1. The variable "mother is stressed" is constructed on the basis of the following variable "How much stress in daily living in the last 4 weeks?" Answers "none" or "just a bit" are coded as 0, answers "a good bit", "quite a lot" and "a great deal" are coded as 1. Missing values for social class of the mother, the mother's father and the mother's partner have been replaced with zeros; missing values for maternal birth weight and head circumference, for paternal height, weight and birth weight, for mother's mother weight and mother's father height and weight have been replaced with the sample means of the non-missing observations in the overall sample. See footnote 18 in the text. The prevalence of missing data varies between 3% for mother Social Class to a maximum of 24% for mother's partner Social Class; most of these variables are missing in 12%-15% of the observations. Abbreviations: Prop.=proportion. SD = Standard Deviation (only reported for continuous variables). Min.=Minimum. Max.=Maximum. N=sample size. CGF=Child Growth Foundation.

Table A4: Summary Statistics CNLSY

	(1) N	(2) Mean	(3) SD	(4) Min.	(5) Max.
Panel A: Birth Variables					
Birth Weight (g)	3,224	3392.58	553.54	1020.58	5159.61
Birth Length (cm)	3,224	51.27	3.28	33.02	60.96
Birth Weight (z-score)	3,224	0.25	0.97	-3.99	3.89
Birth Length (z-score)	3,224	0.51	1.17	-3.85	3.95
Panel B: Child Outcomes					
Height (cm)	7,237	137.59	12.68	101.60	180.34
Height (z-score)	7,237	0.33	1.14	-3.93	4
BMI	7,218	18.23	7.01	11.69	378.58
BMI (z-score)	7,218	0.26	1.22	-3.98	3.40
PPVT	3,585	101.97	16.48	20	160
PIAT Math	7,130	106.04	13.14	65	135
Memory for Digit Span	5,613	10.36	3.02	0	19
PIAT Reading Recognition	7,124	107.70	13.55	65	135
Age at measurement	8,684	9.45	1.69	7	12
Panel C: Base Controls					
Male	3,224	0.51	-	0	1
Birth order	3,224	1.74	0.90	1	5
Gestational age	3,224	38.54	1.82	27	41
Mother ≤ 20y	3,224	0.20	-	0	1
Mother > 35y	3,224	0.04	-	0	1
Panel D: Maternal Investments in Pregnancy					
Prenatal Care 1^{st} trimester	3,158	0.85	-	0	1
Drinking ≥ 1 day/week	3,221	0.04	-	0	1
Smoking < 1 pack/day	3,218	0.21	-	0	1
Smoking ≥ 1 pack/day	3,218	0.11	-	0	1
Gestational Weight Gain (kg)	3,224	14.51	6.42	0	48.53
Pre-Pregnancy Weight (kg)	3,224	61.06	13.81	37.65	226.80

Notes: Birth weight and birth length have been standardized using the growth chart developed by Olsen et al. [2010] for the United States. Only those cases reporting that birth length is not an estimate have been included. Values lying outside three times the interquartile range from the first or third quartile of the birth weight and birth length distribution have been removed as extreme outliers (Tukey's method). Additionally, values of the Olsen z-scores smaller than -4 or greater than 4 have been removed. Height, weight and BMI have been converted in z-scores using the 2000 CDC Growth Reference. The cognitive test scores are derived on an age-specific basis from the child's raw score using national norming samples. The sample only includes children of white ethnicity. PPVT: Peabody Picture Vocabulary Test. PIAT: Peabody Individual Achievement Test. SD = Standard Deviation (only reported for continuous variables). Min. = Minimum. Max. = Maximum. N = sample size.

Table A5: Summary Statistics PtA

	(1) N	(2) Mean	(3) SD	(4) Min.	(5) Max.
Panel A: Birth Variables					
Birth Weight (kg)	1,422	2.992	0.547	0.992	4.933
Birth Length (cm)	1,422	48.93	2.76	37	59
Birth Weight (z-score)	1,422	-0.366	1.101	-3.722	3.854
Birth Length (z-score)	1,422	-0.259	1.036	-3.734	3.479
Panel B: Child Outcomes					
Height (cm)	1,396	123.55	5.85	102	141
BMI	1,335	15.56	1.48	11.50	21.41
PPVT	1,383	58.50	7.88	11	89
WISC Verbal Comprehension Scale	1,408	8.44	2.37	2	18
WISC Verbal Digit Scale	1,409	9.08	2.89	2	20
WRAT Reading Scale	1,393	31.44	10.05	0	71
WRAT Math Scale	1,395	19.28	3.98	0	31
Panel C: Base Controls					
Male	1,422	0.454	-	0	1
White	1,422	0.180	-	0	1
First born	1,415	0.304	-	0	1
Gestational age	1,422	38.28	2.45	27	41
Mother $\leq$ 20y	1,422	0.350	-	0	1
Mother > 35y	1,422	0.089	-	0	1
Previous births	1,415	2.23	2.30	0	13
Year of birth	1,422	62.7	1.5	60	65
Age at anthro measurement (y)	1,363	7.3	0.5	6	10
Age at cognitive measurement (y)	1,353	6.3	0.5	6	9
Age at cognitive measurement (m)	1,353	7.9	4.4	0	11

Notes: Birth weight and birth length have been standardized using the growth chart developed by Olsen et al. [2010] for the United States. Values lying outside three times the interquartile range from the first or third quartile of the birth weight and birth length distribution have been removed as extreme outliers (Tukey's method). PPVT: Peabody Picture Vocabulary Test. WISC: Wechsler Intelligence Scale for Children. WRAT: Wide Range Achievement Test. SD = Standard Deviation (only reported for continuous variables). Min. = Minimum. Max. = Maximum. N = sample size.

Table A6: Conditional Associations between Measures of Fetal and Neonatal Health: Birth Weight and Gestational Age, Extended Set of Covariates

	Birth Weight (kg)			Gestational Age (weeks)			Birth Weight (*z*-score)		
	TR1	TR2	TR3	TR1	TR2	TR3	TR1	TR2	TR3
Fetal Measure	(1a)	(1b)	(1c)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
Abdominal Circumference (*z*)	0.035**	0.103***	0.259***	-0.392***	-0.371***	-0.129***	0.246***	0.394***	0.614***
	(0.016)	(0.013)	(0.010)	(0.051)	(0.047)	(0.040)	(0.029)	(0.022)	(0.017)
R^2	[0.230]	[0.220]	[0.452]	[0.148]	[0.105]	[0.080]	[0.282]	[0.332]	[0.564]
Semi-partial R^2 AC	$0.004^{\dagger}$	$0.029^{\dagger}$	$0.240^{\dagger}$	$0.042^{\dagger}$	$0.033^{\dagger}$	$0.007^{\dagger}$	$0.058^{\dagger}$	$0.143^{\dagger}$	$0.369^{\dagger}$
N	*1,097*	*1,794*	*1,790*	*1,105*	*1,808*	*1,801*	*1,097*	*1,794*	*1,790*
Head Circumference (*z*)	0.027*	0.080***	0.209***	-0.450***	-0.404***	-0.062	0.256***	0.352***	0.471***
	(0.016)	(0.013)	(0.012)	(0.050)	(0.045)	(0.039)	(0.027)	(0.022)	(0.021)
R^2	[0.207]	[0.208]	[0.355]	[0.131]	[0.113]	[0.073]	[0.272]	[0.307]	[0.397]
Semi-partial R^2 HC	0.002	$0.018^{\dagger}$	$0.145^{\dagger}$	$0.050^{\dagger}$	$0.041^{\dagger}$	$0.001^{\dagger}$	$0.059^{\dagger}$	$0.118^{\dagger}$	$0.200^{\dagger}$
N	*1,169*	*1,803*	*1,717*	*1,179*	*1,817*	*1,727*	*1,169*	*1,803*	*1,717*
Femur Length (*z*)	-0.005	0.075***	0.166***	-0.338***	-0.334***	-0.091**	0.140***	0.313***	0.396***
	(0.026)	(0.013)	(0.012)	(0.088)	(0.044)	(0.042)	(0.043)	(0.022)	(0.022)
R^2	[0.353]	[0.206]	[0.305]	[0.239]	[0.101]	[0.075]	[0.368]	[0.285]	[0.339]
Semi-partial R^2 FL	0.000	$0.017^{\dagger}$	$0.093^{\dagger}$	$0.030^{\dagger}$	$0.029^{\dagger}$	$0.003^{\dagger}$	$0.016^{\dagger}$	$0.097^{\dagger}$	$0.145^{\dagger}$
N	*445*	*1,805*	*1,788*	*446*	*1,819*	*1,799*	*445*	*1,805*	*1,788*

Notes: This table shows the estimated coefficients from ordinary least squares regressions of three measures of health at birth (as reported in the top row) on three measures of fetal size (as reported in the first column), by trimester of gestation. The results in each cell come from separate regressions of each birth measure on each fetal measure separately. All models include binary indicators for white ethnicity, male, being a first born, year and month of birth and mother's age at birth, and the following controls measured at baseline (before conception): binary indicators for the number of children, whether the mother has a degree-level education, belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), owns the house, is single, separated, divorced or widowed, receives welfare benefits, is in fair, bad or very bad health, has been under stress in the last four weeks, was working last week, is a current smoker, drinks more than 4 units of alcohol per week, does any strenuous exercise in the week, does any moderate exercise in the week, whether the mother's partner belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), whether the mother's father belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled); continuous variables for mother's birth weight, pre-pregnancy weight, height, BMI, head circumference, leg length, waist circumference, skinfolds (sum of triceps, biceps, subscapular and suprailiac) and her daily energy intake (kilocalories), paternal height, weight and birth weight, grandmaternal and grandpaternal height and weight, and the Townsend Deprivation Index; missing values for social class of the mother, the mother's father and the mother's partner have been replaced with zeros and a binary indicator for missing is included; missing values for maternal birth weight and head circumference, for paternal height, weight and birth weight, for grandmaternal weight and grandpaternal height and weight are replaced with the sample means of the non-missing observations and binary indicators for missing are included. Birth weight is measured in kilograms; gestational age in weeks; birth weight *z*-score has been computed using the Child Growth Foundation standards. The fetal size *z*-scores have been computed according to the Royston [1995] method. TR1=11 weeks; TR2=19 weeks; TR3=34 weeks. AC=Abdominal Circumference; HC=Head Circumference; FL=Femur Length. *** $p<0.01$, ** $p<0.05$, * $p<0.1$, † $p<0.1$. Robust standard errors in parentheses.

Table A7: Conditional Associations between Measures of Fetal and Neonatal Health: Birth Weight, Length and Head Circumference, and Apgar Score, Extended Set of Covariates

	Birth Weight (z-score)				Birth Length (z-score)		Birth Head Circ. (z-score)		APGAR 1M	
	TR2	**TR3**	**TR2**	**TR3**	**TR2**	**TR3**	**TR2**	**TR3**	**TR2**	**TR3**
Fetal Measure	(1a)	(1b)	(1c)	(1d)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)
Abdominal Circumference (z)	0.263***	0.476***	β_c:0.247	β_c:0.483	0.135***	0.251***	0.106***	0.186***	0.028	-0.080
	(0.034)	(0.020)	δ:7.420	δ:1.539	(0.032)	(0.020)	(0.034)	(0.020)	(0.067)	(0.049)
Head Circumference (z)	0.127***	0.152***	β_c:0.127	β_c:-0.013	0.090***	0.122***	0.428***	0.607***	0.059	0.106**
	(0.036)	(0.020)	δ:19.783	δ:0.950	(0.031)	(0.019)	(0.035)	(0.020)	(0.067)	(0.050)
Femur Length (z)	0.049	0.139***	β_c:0.034	β_c:-0.160	0.170***	0.293***	-0.094***	0.012	-0.058	-0.002
	(0.031)	(0.020)	δ:2.680	δ:0.636	(0.029)	(0.019)	(0.031)	(0.017)	(0.065)	(0.046)
R^2	[0.342]	[0.598]			[0.374]	[0.551]	[0.341]	[0.642]	[0.065]	[0.075]
Semi-partial R^2 AC	0.025†	0.140†			0.008†	0.046†	0.004†	0.021†	0.000	0.001
Semi-partial R^2 HC	0.006†	0.014†			0.003†	0.011†	0.065†	0.231†	0.000	0.003†
Semi-partial R^2 FL	0.001†	0.014†			0.014†	0.076†	0.004†	0.000	0.000	0.000
N	*1,789*	*1,716*			*1,668*	*1,621*	*1,686*	*1,636*	*1,735*	*1,674*

Notes: This table shows the estimated coefficients from ordinary least squares regressions of four measures of health at birth (as reported in the first row) on three measures of fetal size (as reported in the first column), by trimester of gestation, in columns (1a), (1b), (2a), (2b), (3a), (3b), (4a) and (4b). Columns (1c) and (1d) report the bias-corrected coefficients β_c (computed assuming an equal degree of selection between observables and unobservables), and the coefficients of proportionality δ, following Oster [2017]; both sets of coefficients have been computed assuming R^{max}=1.3× R^2 in columns (1a) and (1b). All models include binary indicators for white ethnicity, male, being a first born, year and month of birth and mother's age at birth, and the following controls measured at baseline (before conception): binary indicators for the number of children, whether the mother has a degree-level education, belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), owns the house, is single, separated, divorced or widowed, receives welfare benefits, is in fair, bad or very bad health, has been under stress in the last four weeks, was working last week, is a current smoker, drinks more than 4 units of alcohol per week, does any strenuous exercise in the week, does any moderate exercise in the week, whether the mother's partner belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), whether the mother's father belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled); continuous variables for mother's birth weight, pre-pregnancy weight, height, BMI, head circumference, leg length, waist circumference, skinfolds (sum of triceps, biceps, subscapular and suprailiac) and her daily energy intake (kilocalories), paternal height, weight and birth weight, grandmaternal and grandpaternal height and weight, and the Townsend Deprivation Index; missing values for social class of the mother, the mother's father and the mother's partner have been replaced with zeros and a binary indicator for missing is included; missing values for maternal birth weight and head circumference, for paternal height, weight and birth weight, for grandmaternal weight and grandpaternal height and weight are replaced with the sample means of the non-missing observations and binary indicators for missing are included. The birth measures z-scores have been computed using the Child Growth Foundation standards. The fetal size z-scores have been computed according to the Royston [1995] method. TR2=19 weeks; TR3=34 weeks. AC=Abdominal Circumference; HC=Head Circumference; FL=Femur Length. *** p<0.01, ** p<0.05, * p<0.1, † p<0.1. Robust standard errors in parentheses.

Table A8: Conditional Associations between Measures of Fetal (Second and Third Trimester) and Neonatal Health: Birth Weight, Length and Head Circumference, and Apgar Score

	Birth Weight (z-score)		Birth Length (z-score)		Birth Head Circ. (z-score)		APGAR 1M	
Fetal Measure	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)
Abdominal Circumference TR2 (z)	-0.005	-0.002	-0.022	-0.019	-0.033	-0.032	0.042	0.047
	(0.027)	(0.028)	(0.027)	(0.028)	(0.025)	(0.027)	(0.068)	(0.073)
Head Circumference TR2 (z)	-0.005	0.006	0.004	0.011	0.110***	0.128***	0.062	0.037
	(0.028)	(0.030)	(0.027)	(0.027)	(0.026)	(0.027)	(0.070)	(0.071)
Femur Length TR2 (z)	0.026	0.023	0.071***	0.065**	-0.002	-0.026	-0.102	-0.107
	(0.027)	(0.028)	(0.027)	(0.027)	(0.024)	(0.025)	(0.067)	(0.073)
Abdominal Circumference TR3 (z)	0.477***	0.469***	0.237***	0.245***	0.180***	0.177***	-0.124**	-0.087*
	(0.020)	(0.022)	(0.021)	(0.022)	(0.020)	(0.022)	(0.050)	(0.052)
Head Circumference TR3 (z)	0.175***	0.152***	0.144***	0.117***	0.597***	0.573***	0.098**	0.093*
	(0.021)	(0.021)	(0.021)	(0.021)	(0.020)	(0.022)	(0.049)	(0.052)
Femur Length TR3 (z)	0.158***	0.127***	0.315***	0.265***	-0.002	0.007	0.035	0.040
	(0.021)	(0.023)	(0.020)	(0.021)	(0.017)	(0.020)	(0.048)	(0.052)
Full controls		✓		✓		✓		✓
R^2	[0.564]	[0.599]	[0.483]	[0.556]	[0.628]	[0.648]	[0.026]	[0.075]
N	*1,781*	*1,671*	*1,687*	*1,582*	*1,703*	*1,597*	*1,738*	*1,630*

Notes: This table shows the estimated coefficients from ordinary least squares regressions of four measures of health at birth (as reported in the first row) on six measures of fetal size (as reported in the first column), in the second and third trimester of gestation. All models include binary indicators for white ethnicity, male, being a first born and year and month of birth. Models in columns (1b), (2b), (3b) and (4b) also include mother's age at birth, and the following controls measured at baseline (before conception): binary indicators for the number of children, whether the mother has a degree-level education, belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), owns the house, is single, separated, divorced or widowed, receives welfare benefits, is in fair, bad or very bad health, has been under stress in the last four weeks, was working last week, is a current smoker, drinks more than 4 units of alcohol per week, does any strenuous exercise in the week, does any moderate exercise in the week, whether the mother's partner belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), whether the mother's father belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled); continuous variables for mother's birth weight, pre-pregnancy weight, height, BMI, head circumference, leg length, waist circumference, skinfolds (sum of triceps, biceps, subscapular and suprailiac) and her daily energy intake (kilocalories), paternal height, weight and birth weight, grandmaternal and grandpaternal height and weight, and the Townsend Deprivation Index; missing values for social class of the mother, the mother's father and the mother's partner have been replaced with zeros and a binary indicator for missing is included; missing values for maternal birth weight and head circumference, for paternal height, weight and birth weight, for grandmaternal weight and grandpaternal height and weight are replaced with the sample means of the non-missing observations and binary indicators for missing are included. The birth measures z-scores have been computed using the Child Growth Foundation standards. The fetal size z-scores have been computed according to the Royston [1995] method. TR2=19 weeks; TR3=34 weeks. *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

Table A9: Conditional Associations Between Neonatal Anthropometrics And Measures Of Body Composition At Birth.

	Fat Mass (kg)				Lean Mass (kg)			
Birth Measure	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Weight (z)	0.151***			0.186***	0.242***			0.147***
	(0.007)			(0.012)	(0.009)			(0.015)
Length (z)		0.107***		-0.035***		0.238***		0.095***
		(0.008)		(0.009)		(0.010)		(0.013)
Head Circumference (z)			0.105***	-0.015**			0.201***	0.038***
			(0.009)	(0.009)			(0.011)	(0.011)
R^2	[0.576]	[0.305]	[0.324]	[0.588]	[0.668]	[0.585]	[0.493]	[0.707]
N	*623*	*622*	*624*	*620*	*623*	*622*	*624*	*620*
	Thigh Skinfold (z-score)				**Body Fat (%)**			
Birth Measure	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Weight (z)	0.717***			0.984***	0.023***			0.034***
	(0.019)			(0.034)	(0.002)			(0.003)
Length (z)		0.452***		-0.276***		0.015***		-0.008***
		(0.024)		(0.030)		(0.002)		(0.003)
Head Circumference (z)			0.437***	-0.102***			0.013***	-0.007***
			(0.023)	(0.026)			(0.002)	(0.002)
R^2	[0.496]	[0.215]	[0.232]	[0.528]	[0.346]	[0.201]	[0.193]	[0.367]
N	*1,828*	*1,816*	*1,833*	*1,811*	*623*	*622*	*624*	*620*

Notes: This table shows the estimated coefficients from OLS regressions of four different measures of newborn body composition on three neonatal anthropometrics (birth weight, birth length and birth head circumference), standardized using the Child Growth Foundation (CGF) standards. The measures of body composition are fat and lean mass in kg and body fat proportion, all measured using DXA (Dual-energy X-ray absorptiometry); and thigh skinfold, standardized within SWS. Each column in each panel comes from a separate regression. All models include binary indicators for white ethnicity, gender, being a first born and birth year and month. *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses.

Table A10: Conditional Associations between Neonatal Anthropometrics and Measures of Body Composition at Birth, Extended Set of Covariates.

	Fat Mass (kg)				Lean Mass (kg)			
Birth Measure	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Weight (z)	0.149***			0.181***	0.238***			0.158***
	(0.007)			(0.014)	(0.010)			(0.017)
Length (z)		0.105***		-0.030***		0.231***		0.085***
		(0.009)		(0.011)		(0.012)		(0.014)
Head Circumference (z)			0.096***	-0.017*			0.187***	0.033**
			(0.009)	(0.010)			(0.012)	(0.013)
R^2	[0.644]	[0.443]	[0.442]	[0.653]	[0.727]	[0.648]	[0.582]	[0.752]
N	*587*	*586*	*588*	*584*	*587*	*586*	*588*	*584*
	Thigh Skinfold (z-score)				**Body Fat (%)**			
Birth Measure	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Weight (z)	0.730***			0.968***	0.023***			0.033***
	(0.020)			(0.036)	(0.002)			(0.003)
Length (z)		0.460***		-0.243***		0.015***		-0.007**
		(0.027)		(0.034)		(0.002)		(0.003)
Head Circumference (z)			0.411***	-0.107***			0.012***	-0.008***
			(0.026)	(0.027)			(0.002)	(0.003)
R^2	[0.534]	[0.281]	[0.285]	[0.558]	[0.446]	[0.336]	[0.322]	[0.465]
N	*1,719*	*1,708*	*1,724*	*1,703*	*587*	*586*	*588*	*584*

Notes: This table shows the estimated coefficients from ordinary least squares regressions of four different measures of newborn body composition on three neonatal anthropometrics (birth weight, birth length and birth head circumference), standardized using the Child Growth Foundation (CGF) standards. The measures of body composition are fat and lean mass in kilograms and proportion of body fat, all measured using DXA; and thigh skinfold, standardized within the SWS. Each column in each panel comes from a separate regression. All models include binary indicators for white ethnicity, gender, being a first born, year and month of birth and mother's age at birth, and the following controls measured at baseline (before conception): binary indicators for the number of children, whether the mother has a degree-level education, belongs to high social class (I: professional or II: management and technical), or low to social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), owns the house, is single, separated, divorced or widowed, receives welfare benefits, is in fair, bad or very bad health, has been under stress in the last four weeks, was working last week, is a current smoker, drinks more than 4 units of alcohol per week, does any strenuous exercise in the week, does any moderate exercise in the week, whether the mother's partner belongs to high social class (I: professional or II: management and technical), or low to social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), whether the mother's father belongs to high social class (I: professional or II: management and technical), or low to social class (IIIM: skilled manual, IV: partly skilled or V: unskilled); continuous variables for mother's birth weight, pre-pregnancy weight, height, BMI, head circumference, leg length, waist circumference, skinfolds (sum of triceps, biceps, subscapular and suprailiac) and her daily energy intake (kilocalories), paternal height, weight and birth weight, grandmaternal and grandpaternal height and weight, and the Townsend Deprivation Index; missing values for social class of the mother, the mother's father and the mother's partner have been replaced with zeros and a binary indicator for missing is included; missing values for maternal birth weight and head circumference, for paternal height, weight and birth weight, for grandmaternal weight and grandpaternal height and weight are replaced with the sample means of the non-missing observations and binary indicators for missing are included. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table A11: Conditional Associations between Measures of Fetal and Neonatal Health Capital: Birth Weight, Length and Head Circumference. SEM Results

	First measure	**Second measure**	**Third measure**	**Birth Weight**	**Birth Length**	**Birth Head C.**
			Panel A: Second Trimester			
	(1)	(2)	(3)	(4)	(5)	(6)
AC 19 weeks	1.000	1.012***	1.009***	0.284***	0.143***	0.114***
	(0.000)	(0.010)	(0.010)	(0.034)	(0.032)	(0.034)
HC 19 weeks	1.000	1.000***	1.002***	0.069**	0.062*	0.379***
	(0.000)	(0.008)	(0.008)	(0.034)	(0.032)	(0.034)
FL 19 weeks	1.000	1.024***	1.031***	0.105***	0.238***	-0.037
	(0.000)	(0.014)	(0.013)	(0.033)	(0.031)	(0.033)
			Panel B: Third Trimester			
	(1)	(2)	(3)	(4)	(5)	(6)
AC 34 weeks	1.000	1.012***	1.007***	0.528***	0.260***	0.213***
	(0.000)	(0.008)	(0.008)	(0.021)	(0.021)	(0.020)
HC 34 weeks	1.000	1.027***	1.019***	0.130***	0.131***	0.592***
	(0.000)	(0.009)	(0.010)	(0.021)	(0.021)	(0.020)
FL 34 weeks	1.000	1.015***	1.020***	0.170***	0.362***	0.011
	(0.000)	(0.011)	(0.011)	(0.019)	(0.019)	(0.018)
N	*1,982*	*1,982*	*1,982*	*1,982*	*1,975*	*1,975*

Notes: This table shows structural equation modelling results on the associations between three measures of health at birth (birth weight, length and head circumference) and three measures of fetal size in middle and end of gestation (abdominal and head circumference, and femur length). Estimation method is maximum likelihood. Columns (1)-(3) present the results for the measurement system: each fetal anthropometric in each trimester is proxied by three different indicators, the first of which is normalized to 1 for identification. These indicators are the residuals from a regression of the fetal measurement (in mm) on gestational age, and on binary indicators for white ethnicity, male, being a first born and year and month of birth. Columns (4)-(6) present the loadings of each measure of health at birth on the corresponding fetal factor. The birth measures z-scores have been computed using the Child Growth Foundation standards. The fetal size z-scores have been computed according to the Royston [1995] method. AC=Abdominal Circumference; HC=Head Circumference; FL=Femur Length. *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses.

Table A12: Replication of Table 2 on the Birthright Data

	Birth Weight (kg)			
	19 weeks		28 weeks	
Fetal Measure	(1a)	(1b)	(2a)	(2b)
Abdominal Circumference (z)	0.064***	0.090*	0.178***	0.167***
	(0.022)	(0.051)	(0.021)	(0.030)
	[0.017]	[0.015]	[0.148]	[0.147]
	406	*406*	*399*	*399*
Head Circumference (z)	0.055***	0.027	0.144***	0.043
	(0.021)	(0.054)	(0.023)	(0.034)
	[0.012]	[0.015]	[0.096]	[0.147]
	406	*406*	*399*	*399*
Femur Length (z)	0.042**	-0.058	0.106***	-0.030
	(0.021)	(0.049)	(0.023)	(0.032)
	[0.006]	[0.015]	[0.051]	[0.147]
	406	*406*	*399*	*399*

Notes: This table presents the replication of Table 2 in the paper on the Birthright data. The estimates reported in columns (1a) and (2a) are from separate regressions of birth weight on each fetal measure separately; those reported in columns (1b) and (2b) are from regressions of birth weight on all three fetal measures at 19 and 28 weeks of gestation, respectively. All analyses are restricted to term babies (at least 37 weeks of gestation); they also exclude babies with major congenital abnormalities, stillbirths, neonatal deaths, those delivered in other maternity hospitals, those whose scan dates differ from their last menstrual period dates by more than 21 days, and those not fulfilling the study criteria. The measures of fetal size are z-scores, adjusted for gestational age at measurement. *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. In square brackets we report the adjusted R^2. In italics we report the sample size.

Table A13: Replication of Table 3 on the Birthright Data

	BW (z)	BHC (z)	BL (z)	APG1
Fetal Measure (34 weeks)	(1)	(2)	(3)	(4)
Abdominal Circumference (z)	0.437***	0.088	0.245***	-0.198*
	(0.060)	(0.062)	(0.064)	(0.106)
Head Circumference (z)	0.090	0.666***	0.138*	0.169
	(0.067)	(0.067)	(0.070)	(0.104)
Femur Length (z)	0.047	-0.170***	0.223***	-0.040
	(0.066)	(0.060)	(0.066)	(0.091)
	399	*390*	*384*	*399*

Notes: This table presents the replication of Table 3 in the paper on the Birthright data. The estimates reported are from regressions of the birth measures listed in the first row on all three fetal measures in the third trimester of gestation (34 weeks). All analyses are restricted to term babies (at least 37 weeks of gestation); they also exclude babies with major congenital abnormalities, stillbirths, neonatal deaths, those delivered in other maternity hospitals, those whose scan dates differ from their last menstrual period dates by more than 21 days, and those not fulfilling the study criteria. All measures of fetal and birth size are z-scores, adjusted for gestational age at measurement. *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. In italics we report the sample size. APG1=Apgar at 1 minute. BHC=Birth Head Circumference. BL=Birth Length. BW=Birth Weight.

Table A14: Factor analysis and structural equation model for the fetal, birth and postnatal anthropometric measures

	TR1	**TR2**	**TR3**	**Birth**	**Year 1**	**Year 6**
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: Factor analysis (method of principal factors)					
Variance 1^{st} factor	79%	69%	43%	66%	48%	55%
	Panel B: Structural equation model with independent errors					
Size	1	1	1	1	1	1
Head	0.965***	1.053***	0.853***	0.784***	0.549***	0.567***
	(0.020)	(0.023)	(0.045)	(0.022)	(0.033)	(0.034)
Length	0.920***	0.960***	0.652***	0.754***	0.681***	0.726***
	(0.022)	(0.023)	(0.036)	(0.020)	(0.035)	(0.034)
Var(H^*_{it})	0.819***	0.710***	0.691***	0.814***	1.055***	0.986***
	(0.042)	(0.031)	(0.045)	(0.033)	(0.061)	(0.056)
	Panel C: Uniqueness					
Size	0.168	0.252	0.328	0.076	0.060	0.001
Head	0.148	0.221	0.499	0.437	0.733	0.718
Length	0.243	0.347	0.705	0.381	0.533	0.444
	Panel D: Structural equation model with correlated errors					
$Cov(e_{i,size}, e_{i,head})$	0.000	0.000	0.000	0.000	0.000	0.000
	(0.037)	(0.028)	(0.027)	(0.026)	(0.032)	(0.033)
$Cov(e_{i,size}, e_{i,length})$	0.000	0.000	0.000	0.000	0.000	0.000
	(0.036)	(0.027)	(0.026)	(0.024)	(0.032)	(0.034)
$Cov(e_{i,head}, e_{i,length})$	0.000	0.000	0.000	0.000	0.000	0.000
	(0.035)	(0.028)	(0.025)	(0.022)	(0.029)	(0.031)

Notes: All measurements are standardized. The measures of size are abdominal circumference in TR1, TR2 and TR3; and weight at birth, year 1 and year 6. The measures of length are crown-rump length in TR1 (given the lower number of observations for femur length, due to the difficulties of measuring it early in gestation), femur length in TR2 and TR3; and (crown-heel) length at birth, year 1 and year 6. The measures of head are head circumference at all timepoints. Panel A displays the variance explained by the first factor at each timepoint. Panels B and C show results from structural equation models which assume a single factor and constrain the factor loading for size to be 1. The uniquenesses in Panel C are computed as $\frac{Var(e_{imt})}{\beta_m^2 Var(H^*_{it})+Var(e_{imt})}$, given the model $H_{imt} = \beta_m H^*_{it} + e_{imt}$ and $e_{imt} = \upsilon_{imt} + \varepsilon_{imt}$. TR1=11 weeks; TR2=19 weeks; TR3=34 weeks. *** p<0.01, ** p<0.05, * p<0.1.

Table A15: Correlations between fetal, birth and postnatal anthropometric measures

	AC11	HC11	CRL11	AC19	HC19	FL19	AC34	HC34	FL34	BW	BHC	BL	WT1Y	HC1Y	HT1Y	BW6Y	HC6Y	HT6Y
AC11	1																	
HC11	0.8377	1																
CRL11	0.7807	0.7939	1															
AC19	0.6906	0.6875	0.6666	1														
HC19	0.7296	0.779	0.7228	0.729	1													
FL19	0.6803	0.6791	0.6463	0.6914	0.6634	1												
AC34	0.395	0.3607	0.3827	0.5344	0.44	0.3563	1											
HC34	0.3413	0.37	0.3526	0.4208	0.5351	0.3183	0.5628	1										
FL34	0.3334	0.3203	0.3149	0.3916	0.3316	0.4918	0.4433	0.359	1									
BW	0.313	0.3017	0.3398	0.3967	0.357	0.3304	0.6794	0.5156	0.4496	1								
BHC	0.3048	0.2992	0.3314	0.36	0.4432	0.2977	0.5551	0.7222	0.3163	0.7134	1							
BL	0.2645	0.266	0.2825	0.3385	0.3165	0.3407	0.5405	0.4254	0.5464	0.7626	0.5685	1						
WT1Y	0.0876	0.0735	0.066	0.2011	0.1295	0.1357	0.321	0.2017	0.2854	0.3541	0.2739	0.4141	1					
HC1Y	0.0425	0.0565	0.0505	0.1225	0.202	-0.0011	0.2238	0.4502	0.0918	0.2702	0.5553	0.2782	0.474	1				
HT1Y	0.0693	0.0828	0.0647	0.1324	0.119	0.1573	0.1841	0.1423	0.3904	0.3191	0.2191	0.5497	0.6718	0.3242	1			
WT6Y	0.0991	0.0843	0.0841	0.1704	0.1306	0.1612	0.2619	0.1863	0.2314	0.3312	0.234	0.3498	0.5985	0.3085	0.4926	1		
HC6Y	0.0326	0.0543	0.0395	0.0982	0.1743	0.0054	0.2137	0.4195	0.0971	0.2551	0.5306	0.2813	0.3899	0.8162	0.292	0.4875	1	
HT6Y	0.0811	0.0825	0.0606	0.1547	0.128	0.1934	0.1772	0.1506	0.347	0.2825	0.1816	0.4743	0.5403	0.2561	0.7099	0.7482	0.3739	1

Notes: AC11: Abdominal Circumference at 11 weeks (1^{st} trimester). HC11: Head Circumference at 11 weeks (1^{st} trimester). CRL11: Crown-Rump Length at 11 weeks (1^{st} trimester). AC19: Abdominal Circumference at 19 weeks (2^{nd} trimester). HC19: Head Circumference at 19 weeks (2^{nd} trimester). FL19: Femur Length at 19 weeks (2^{nd} trimester). AC34: Abdominal Circumference at 34 weeks (3^{rd} trimester). HC34: Head Circumference at 34 weeks (3^{rd} trimester). FL34: Femur Length at 34 weeks (3^{rd} trimester). BW: Birth Weight. BHC: Birth Head Circumference. BL: Birth Length. WT1Y: Weight at 1 Year. HC1Y: Head Circumference at 1 Year. HT1Y: Height at 1 Year. WT6Y: Weight at 6 Years. HC6Y: Head Circumference at 6 Years. HT6Y: Height at 6 Years.

Table A16: In Utero Growth Patterns and Birth Outcomes, Full Results

	LBW (1)	SGA (2)	HBW (3)	LGA (4)	Preterm (5)
AC Stable Low Trajectory	0.047***	0.142***	-0.167***	-	0.021*
	(0.009)	(0.014)	(0.040)	(-)	(0.012)
AC Declining Trajectory	0.030***	0.070***	-0.066***	-0.026	0.021*
	(0.009)	(0.014)	(0.024)	(0.021)	(0.011)
AC Increasing Trajectory	0.009	0.010	0.089***	0.076***	0.022*
	(0.011)	(0.017)	(0.017)	(0.016)	(0.012)
AC Stable High Trajectory	-0.017	-0.117***	0.154***	0.180***	0.041***
	(0.017)	(0.043)	(0.018)	(0.016)	(0.012)
HC Declining Trajectory	0.016**	-0.001	-0.039*	0.011	0.019*
	(0.007)	(0.014)	(0.021)	(0.018)	(0.010)
HC Increasing Trajectory	-0.016	-0.032*	0.030*	0.007	-0.010
	(0.010)	(0.016)	(0.018)	(0.017)	(0.013)
FL Declining Trajectory	0.021***	0.016	-0.037*	-0.014	0.007
	(0.007)	(0.014)	(0.021)	(0.019)	(0.010)
FL Increasing Trajectory	0.004	0.001	0.033*	0.040**	-0.002
	(0.008)	(0.016)	(0.017)	(0.016)	(0.012)
AUC_X	0.676	0.632	0.630	0.645	0.573
	(0.042)	(0.024)	(0.018)	(0.022)	(0.037)
$AUC_X + fetal$	0.906	0.817	0.799	0.817	0.704
	(0.017)	(0.017)	(0.014)	(0.017)	(0.033)
p	*0.000*	*0.000*	*0.000*	*0.000*	*0.002*
N	*1,781*	*1,781*	*1,781*	*1,553*	*1,792*

Notes: This table shows average marginal effects from probit models of five measures of health at birth (as reported in the top row) on patterns of fetal growth between the second and the third trimester. All models include binary indicators for white ethnicity, gender, being a first born and year and season of birth. LBW=Low Birth Weight: binary indicator for birth weight <2,500g. SGA=Small-for-Gestational Age: binary indicator for birth weight $<10^{th}$ percentile; HBW=High Birth Weight: binary indicator for birth weight >4,000g; LGA=Large-for-Gestational Age: binary indicator for birth weight $>90^{th}$ percentile; Preterm: binary indicator for gestational age at birth <37 weeks. "AC Stable Low Trajectory" is a binary indicator which takes value 1 if the fetus is in the lower quartile of the Abdominal Circumference distribution both in the second and in the third trimester. "AC/FL/HC Declining Trajectory" is a binary indicator which takes value 1 if the fetus is in the lower quartile of the distribution of the difference between the third and the second trimester Abdominal Circumference/Femur Length/Head Circumference. "AC/FL/HC Increasing Trajectory" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the distribution of the difference between the third and the second trimester Abdominal Circumference/Femur Length/Head Circumference. "AC Stable High Trajectory" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the Abdominal Circumference distribution both in the second and in the third trimester. The binary indicators for Head Circumference and Femur Length trajectories are defined in a similar way. *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. AUC_X=Area under the ROC curve for a model which does not include the fetal measures. $AUC_X + fetal$=Area under the ROC curve for a model which also includes the fetal measures. The AUC standard errors are bootstrapped (1,000 replications). *p*=*p*-value for the Null Hypothesis that both models have equal AUC values.

Table A17: In Utero Growth Patterns and Birth Outcomes, Extended Set of Covariates

	LBW (1)	SGA (2)	HBW (3)	LGA (4)	Preterm (5)
AC Stable Low Trajectory	0.054***	0.123***	-0.142***	-	0.020
	(0.010)	(0.014)	(0.039)	(-)	(0.012)
AC Declining Trajectory	0.031***	0.069***	-0.076***	-0.032	0.020*
	(0.008)	(0.014)	(0.024)	(0.021)	(0.010)
AC Increasing Trajectory	0.007	0.001	0.082***	0.071***	0.025**
	(0.011)	(0.016)	(0.017)	(0.017)	(0.011)
AC Stable High Trajectory	-0.010	-0.116***	0.137***	0.163***	0.038***
	(0.016)	(0.038)	(0.018)	(0.015)	(0.012)
HC Declining Trajectory	0.019***	-0.004	-0.033	0.017	0.023**
	(0.007)	(0.014)	(0.021)	(0.017)	(0.009)
HC Increasing Trajectory	-0.010	-0.014	0.031*	0.006	-0.011
	(0.009)	(0.016)	(0.017)	(0.017)	(0.012)
FL Declining Trajectory	0.022***	0.009	-0.026	-0.020	0.004
	(0.007)	(0.014)	(0.020)	(0.019)	(0.009)
FL Increasing Trajectory	-0.001	-0.001	0.011	0.017	-0.006
	(0.008)	(0.015)	(0.017)	(0.017)	(0.012)
AUC_X	0.692	0.776	0.755	0.748	0.668
	(0.041)	(0.020)	(0.017)	(0.022)	(0.035)
$AUC_X + fetal$	0.930	0.868	0.848	0.853	0.792
	(0.013)	(0.013)	(0.012)	(0.016)	(0.027)
p	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
N	*1,671*	*1,671*	*1,671*	*1,458*	*1,681*

Notes: This table shows average marginal effects from probit models of five measures of health at birth (as reported in the top row) on patterns of fetal growth between the second and the third trimester. All models include binary indicators for white ethnicity, male, and being a first born, and controls for year and season of birth, number of children and mother's age at birth, and the following controls measured at baseline (before conception): whether the mother has a degree-level education, belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), owns the house, is single, separated, divorced or widowed, receives welfare benefits, is in fair, bad or very bad health, has been under stress in the last four weeks, was working last week, is a current smoker, drinks more than 4 units of alcohol per week, does any strenuous exercise in the week, does any moderate exercise in the week, whether the mother's partner belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), whether the mother's father belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled); continuous variables for mother's birth weight, pre-pregnancy weight, height, BMI, head circumference, leg length, waist circumference, skinfolds (sum of triceps, biceps, subscapular and suprailiac) and her daily energy intake (kilocalories), paternal height, weight and birth weight, grandmaternal and grandpaternal height and weight, and the Townsend Deprivation Index; missing values for social class of the mother, the mother's father and the mother's partner have been replaced with zeros and a binary indicator for missing is included; missing values for maternal birth weight and head circumference, for paternal height, weight and birth weight, for grandmaternal weight and grandpaternal height and weight are replaced with the sample means of the non-missing observations and binary indicators for missing are included. LBW=Low Birth Weight: binary indicator for birth weight <2,500g. SGA=Small-for-Gestational Age: binary indicator for birth weight $<10^{th}$ percentile; HBW=High Birth Weight: binary indicator for birth weight >4,000g; LGA=Large-for-Gestational Age: binary indicator for birth weight $>90^{th}$ percentile; Preterm: binary indicator for gestational age at birth <37 weeks. "AC Stable Low Trajectory" is a binary indicator which takes value 1 if the fetus is in the lower quartile of the Abdominal Circumference distribution both in the second and in the third trimester. "AC/FL/HC Declining Trajectory" is a binary indicator which takes value 1 if the fetus is in the lower quartile of the distribution of the difference between the third and the second trimester Abdominal Circumference/Femur Length/Head Circumference. "AC/FL/HC Increasing Trajectory" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the distribution of the difference between the third and the second trimester Abdominal Circumference/Femur Length/Head Circumference. "AC Stable High Trajectory" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the Abdominal Circumference distribution both in the second and in the third trimester. *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. AUC_X=Area under the ROC curve for a model which does not include the fetal measures. $AUC_X + fetal$=Area under the ROC curve for a model which also includes the fetal measures. The AUC standard errors are bootstrapped (1,000 replications). *p*=*p*-value for the Null Hypothesis that both models have equal AUC values.

Table A18: Estimated Effects of Fetal and Neonatal Health Capital on Height, BMI and Weight in Early Childhood (6 Years), Full Results with Extended Set of Controls

	Panel A: Height (z-score)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Birth Weight (z)	0.175***			-0.135***		-0.114**	-0.068
	(0.030)			(0.049)		(0.054)	(0.047)
Birth Length (z)		0.361***		0.466***		0.406***	0.098***
		(0.031)		(0.047)		(0.051)	(0.046)
Birth Head Circumference (z)			0.135***	0.006		0.069	0.036
			(0.029)	(0.038)		(0.049)	(0.048)
Fetal Abdominal Circumference TR3 (z)					-0.004	-0.065*	-0.058*
					(0.034)	(0.037)	(0.033)
Fetal Femur Length TR3 (z)					0.231***	0.125***	0.062**
					(0.031)	(0.032)	(0.028)
Fetal Head Circumference TR3 (z)					0.001	-0.070*	-0.058*
					(0.032)	(0.041)	(0.035)
Postnatal Weight 1Y (z)							0.138***
							(0.032)
Postnatal Height 1Y (z)							0.435***
							(0.033)
Postnatal Head Circumference 1Y (z)							0.009
							(0.027)
	Panel B: BMI (z-score)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Birth Weight (z)	0.222***			0.296***		0.233***	0.172***
	(0.034)			(0.053)		(0.059)	(0.055)
Birth Length (z)		0.085**		-0.206***		-0.198***	-0.168***
		(0.039)		(0.052)		(0.055)	(0.057)
Birth Head Circumference (z)			0.185***	0.087**		0.093*	-0.004
			(0.032)	(0.042)		(0.056)	(0.056)
Fetal Abdominal Circumference TR3 (z)					0.188***	0.112**	0.055
					(0.037)	(0.044)	(0.042)
Fetal Femur Length TR3 (z)					-0.059	-0.031	-0.049
					(0.037)	(0.038)	(0.035)
Fetal Head Circumference TR3 (z)					0.042	-0.027	-0.011
					(0.037)	(0.048)	(0.045)
Postnatal Weight 1Y (z)							0.508***
							(0.038)
Postnatal Height 1Y (z)							-0.193***
							(0.039)
Postnatal Head Circumference 1Y (z)							0.054
							(0.036)
	Panel C: Weight (z-score)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Birth Weight (z)	0.260***			0.129**		0.101*	0.087*
	(0.032)			(0.052)		(0.058)	(0.052)
Birth Length (z)		0.274***		0.132***		0.106*	-0.051
		(0.035)		(0.051)		(0.054)	(0.052)
Birth Head Circumference (z)			0.209***	0.063		0.108**	0.025
			(0.031)	(0.041)		(0.054)	(0.051)
Fetal Abdominal Circumference TR3 (z)					0.127***	0.034	-0.004
					(0.037)	(0.043)	(0.039)
Fetal Femur Length TR3 (z)					0.092***	0.046	-0.003
					(0.035)	(0.037)	(0.033)
Fetal Head Circumference TR3 (z)					0.029	-0.064	-0.046
					(0.037)	(0.047)	(0.042)
Postnatal Weight 1Y (z)							0.430***
							(0.036)
Postnatal Height 1Y (z)							0.118***
							(0.037)
Postnatal Head Circumference 1Y (z)							0.043
							(0.034)

Notes: The table shows the estimated coefficients from ordinary least squares regressions of height and BMI at 6 years on birth and fetal measures in the third trimester of gestation (34 weeks) based on the SWS data. Height, BMI and the birth measures have been standardized using the Child Growth Foundation (CGF) standards; the fetal measures have been standardized using the Royston [1995] method. Each column comes from a separate regression. The measures of postnatal conditional growth in column (7) are obtained as the residual of a regression of height and weight at 1 year on birth length and weight, respectively. All models include binary indicators for white ethnicity, gender, being a first born, year and month of birth and mother's age at birth, and the following controls measured at baseline (before conception): binary indicators for the number of children, whether the mother has a degree-level education, belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), owns the house, is single, separated, divorced or widowed, receives welfare benefits, is in fair, bad or very bad health, has been under stress in the last four weeks, was working last week, is a current smoker, drinks more than 4 units of alcohol per week, does any strenuous exercise in the week, does any moderate exercise in the week, whether the mother's partner belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), whether the mother's father belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled); continuous variables for mother's birth weight, pre-pregnancy weight, height, BMI, head circumference, leg length, waist circumference, skinfolds (sum of triceps, biceps, subscapular and suprailiac) and her daily energy intake (kilocalories), paternal height, weight and birth weight, grandmaternal and grandpaternal height and weight, and the Townsend Deprivation Index; missing values for social class of the mother, the mother's father and the mother's partner have been replaced with zeros and a binary indicator for missing is included; missing values for maternal birth weight and head circumference, for paternal height, weight and birth weight, for grandmaternal weight and grandpaternal height and weight are replaced with the sample means of the non-missing observations and binary indicators for missing are included. Robust standard errors in parentheses. All models are estimated on a balanced sample of 1,067 observations, with the exception of the one including postnatal outcomes, which is based on 978 observations. *** p<0.01, ** p<0.05, * p<0.1.

Table A19: Estimated Effects of Fetal and Neonatal Health Capital on IQ in Early Childhood (4 Years)

	WPPSI: Verbal					
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)
Conditional HC Growth TR1-2 (z-score)	4.673***	7.981***	3.756**	8.237***	4.219**	8.766***
	(1.701)	(2.710)	(1.848)	(2.640)	(2.069)	(2.895)
Conditional HC Growth TR2-3 (z-score)	0.213	1.708	0.993	-0.135	1.391	-0.274
	(2.406)	(2.341)	(2.569)	(3.240)	(2.679)	(3.340)
Birth Head Circumference (z-score)			1.271	1.910	0.591	2.833
			(2.602)	(3.026)	(2.711)	(3.189)
Conditional Head Growth 0-1Y					-1.773	-3.899
					(1.997)	(3.582)
Full Controls		✓		✓		✓
R^2	[0.124]	[0.628]	[0.129]	[0.668]	[0.142]	[0.683]
N	*98*	*93*	*96*	*92*	*94*	*90*
	WPPSI: General language					
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)
Conditional HC Growth TR1-2 (z-score)	3.038**	7.346***	2.528*	7.507***	2.333*	7.435***
	(1.393)	(1.549)	(1.324)	(1.618)	(1.387)	(1.753)
Conditional HC Growth TR2-3 (z-score)	2.349	7.279***	3.635**	7.479***	3.980***	7.752***
	(1.758)	(1.348)	(1.402)	(2.297)	(1.447)	(2.418)
Birth Head Circumference (z-score)			0.208	-0.504	0.199	-0.425
			(1.593)	(2.524)	(1.670)	(2.655)
Conditional Head Growth 0-1Y					-0.690	-0.974
					(1.263)	(1.835)
Full Controls		✓		✓		✓
R^2	[0.110]	[0.742]	[0.162]	[0.742]	[0.170]	[0.744]
N	*98*	*93*	*96*	*92*	*94*	*90*
	NEPSY: Sentence repetition					
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)
Conditional HC Growth TR1-2 (z-score)	0.374	0.900***	0.306	0.847***	0.191	0.817**
	(0.336)	(0.308)	(0.344)	(0.300)	(0.375)	(0.339)
Conditional HC Growth TR2-3 (z-score)	0.526*	0.397	0.416	-0.037	0.501	0.048
	(0.303)	(0.281)	(0.402)	(0.391)	(0.369)	(0.409)
Birth Head Circumference (z-score)			0.187	0.632	0.152	0.644
			(0.387)	(0.445)	(0.374)	(0.492)
Conditional Head Growth 0-1Y					0.080	-0.247
					(0.311)	(0.539)
Full Controls		✓		✓		✓
R^2	[0.075]	[0.792]	[0.081]	[0.809]	[0.102]	[0.802]
N	*94*	*90*	*93*	*89*	*91*	*87*

Notes: The table shows the estimated coefficients from ordinary least squares regressions of different measures of verbal IQ at 4 years on measures of head circumference since early gestation until the first year of life based on the SWS data. WPPSI: Wechsler Preschool and Primary Scale of Intelligence; NEPSY: NEuroPSYchological Assessment. The fetal conditional growth z-scores have been computed according to the Royston [1995] method. The birth measures have been standardized using the Child Growth Foundation (CGF) standards. The measures of postnatal conditional growth are obtained as the residual of a regression of head circumference at 1 year on birth head circumference. Each column comes from a separate regression. Models in (1a), (2a) and (3a) include binary indicators for white ethnicity, gender, being a first born and year and season of birth. Models in (1b), (2b) and (3b) include binary indicators for white ethnicity, male, and being a first born, and controls for year and season of birth, number of children and mother's age at birth, and the following controls measured at baseline (before conception): whether the mother has a degree-level education, belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), owns the house, is single, separated, divorced or widowed, receives welfare benefits, is in fair, bad or very bad health, has been under stress in the last four weeks, was working last week, is a current smoker, drinks more than 4 units of alcohol per week, does any strenuous exercise in the week, does any moderate exercise in the week, whether the mother's partner belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), whether the mother's father belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled); continuous variables for mother's birth weight, pre-pregnancy weight, height, BMI, head circumference, leg length, waist circumference, skinfolds (sum of triceps, biceps, subscapular and suprailiac) and her daily energy intake (kilocalories), paternal height, weight and birth weight, grandmaternal and grandpaternal height and weight, and the Townsend Deprivation Index; missing values for social class of the mother, the mother's father and the mother's partner have been replaced with zeros and a binary indicator for missing is included; missing values for maternal birth weight and head circumference, for paternal height, weight and birth weight, for grandmaternal weight and grandpaternal height and weight are replaced with the sample means of the non-missing observations and binary indicators for missing are included. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table A20: Estimated Effects of Birth Health on Anthropometrics and Cognition in Childhood

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
				Panel A: Height (*z*-score)			
Birth Weight (*z*)	0.246***	0.183***			0.173***	0.125***	0.118***
	(0.023)	(0.037)			(0.026)	(0.041)	(0.041)
Birth Length (*z*)			0.189***	0.136***	0.116***	0.101***	0.119***
			(0.018)	(0.026)	(0.021)	(0.029)	(0.030)
Mother FE		✓		✓		✓	✓
N	*7,237*	*7,237*	*7,237*	*7,237*	*7,237*	*7,237*	*7,065*
# mothers		1,738		1,738		1,738	1,720
				Panel B: BMI (*z*-score)			
Birth Weight (*z*)	0.174***	0.194***			0.203***	0.215***	0.212***
	(0.023)	(0.039)			(0.026)	(0.042)	(0.043)
Birth Length (*z*)			0.041**	0.025	-0.045**	-0.036	-0.047
			(0.019)	(0.027)	(0.021)	(0.028)	(0.029)
Mother FE		✓		✓		✓	✓
N	*7,218*	*7,218*	*7,218*	*7,218*	*7,218*	*7,218*	*7,048*
# mothers		1,736		1,736		1,736	1,702
				Panel C: PPVT			
Birth Weight (*z*)	1.304***	0.397			1.170***	-0.151	0.161
	(0.372)	(0.607)			(0.425)	(0.642)	(0.653)
Birth Length (*z*)			0.702**	0.822**	0.210	0.864**	0.699*
			(0.300)	(0.375)	(0.343)	(0.402)	(0.423)
			(0.300)	(0.372)	(0.343)	(0.401)	(0.416)
Mother FE		✓		✓		✓	✓
N	*3,585*	*3,585*	*3,585*	*3,585*	*3,585*	*3,585*	*3,451*
# mothers		1,534		1,534		1,534	1,513
				Panel D: WISC Memory for Digit Span			
Birth Weight (*z*)	0.142**	0.151			0.143**	0.065	0.070
	(0.061)	(0.102)			(0.069)	(0.116)	(0.116)
Birth Length (*z*)			0.057	0.164**	-0.002	0.146*	0.172**
			(0.048)	(0.071)	(0.055)	(0.081)	(0.083)
Mother FE		✓		✓		✓	✓
N	*5,613*	*5,613*	*5,613*	*5,613*	*5,613*	*5,613*	*5,488*
# mothers		1,655		1,655		1,655	1,637
				Panel E: PIAT Math			
Birth Weight (*z*)	0.840***	0.745**			0.678**	0.265	0.300
	(0.245)	(0.377)			(0.276)	(0.405)	(0.413)
Birth Length (*z*)			0.541***	0.897***	0.254	0.823***	0.902***
			(0.205)	(0.266)	(0.231)	(0.287)	(0.297)
Mother FE		✓		✓		✓	✓
N	*7,130*	*7,130*	*7,130*	*7,130*	*7,130*	*7,130*	*6,967*
# mothers		1,691		1,691		1,691	1,671
				Panel F: PIAT Reading Recognition			
Birth Weight (*z*)	0.815***	1.159***			0.865***	0.838**	1.024**
	(0.270)	(0.381)			(0.311)	(0.409)	(0.425)
Birth Length (*z*)			0.283	0.784***	-0.080	0.550*	0.512
			(0.222)	(0.283)	(0.255)	(0.305)	(0.321)
Mother FE		✓		✓		✓	✓
N	*7,124*	*7,124*	*7,124*	*7,124*	*7,124*	*7,124*	*6,962*
# mothers		1,691		1,691		1,691	1,671

Notes: This table displays ordinary least squares estimates of two anthropometric and three cognitive outcomes in childhood (ages 7-11) on birth weight and birth length based on the CNLSY data. Both birth measures have been standardized using the growth chart developed by Olsen et al. [2010] for the United States. Only those cases reporting that birth length is not an estimate have been included. Values lying outside three times the interquartile range from the first or third quartile of the birth weight and birth length distribution have been removed as extreme outliers (Tukey's method). Additionally, values of the Olsen *z*-scores smaller than -4 or greater than 4 have been removed. Controls included in all the estimated specifications not shown in the tables are: gestational age and indicators for the child being male, for birth order, for the mother being 20 years old or younger, and for being older than 35 years, for age at measurement (in years), and for year-of-birth-specific bi-monthly dummies. The specifications in column (7) also include the following prenatal variables: pre-pregnancy weight and gestational weight gain, and binary indicators for whether the first prenatal care visit took place in the first trimester, for whether the mother was drinking in pregnancy 1 day per week or more, and for whether she was smoking <1 pack per day or 1 pack or more per day. The sample only includes children of white ethnicity. The standard errors (in parentheses) are clustered at the level of the mother. *** p<0.01, ** p<0.05, * p<0.1. †: the coefficients on birth weight and birth length are statistically significantly different (two-sided tests).

Table A21: Estimated Effects of Birth Health on Anthropometric and Cognitive Outcomes in Childhood (PtA)

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Height						
Birth Weight (*z*)	1.457***	0.146			0.917***	-0.343
	(0.152)	(0.401)			(0.223)	(0.480)
Birth Length (*z*)			1.509***	0.913**	0.830***	1.089**†
			(0.161)	(0.394)	(0.233)	(0.495)
Mother FE		✓		✓		✓
N	*1,349*	*1,349*	*1,349*	*1,349*	*1,349*	*1,349*
# mothers		1,208		1,208		1,208
Panel B: BMI						
Birth Weight (*z*)	0.208***	0.228**			0.284***†	0.224**
	(0.044)	(0.107)			(0.057)	(0.109)
Birth Length (*z*)			0.093**	0.123	-0.118**	0.008
			(0.045)	(0.122)	(0.059)	(0.125)
Mother FE		✓		✓		✓
N	*1,291*	*1,291*	*1,291*	*1,291*	*1,291*	*1,291*
# mothers		1,153		1,153		1,153
Panel C: PPVT						
Birth Weight (*z*)	0.449**	0.262			0.366	-0.312
	(0.228)	(0.554)			(0.289)	(0.690)
Birth Length (*z*)			0.395*	1.098	0.128	1.259
			(0.237)	(0.813)	(0.300)	(0.985)
Mother FE		✓		✓		✓
N	*1,372*	*1,372*	*1,372*	*1,372*	*1,372*	*1,372*
# mothers		1,231		1,231		1,231
Panel D: WRAT Math Scale						
Birth Weight (*z*)	0.432***	0.437			0.444***†	0.007
	(0.119)	(0.394)			(0.154)	(0.398)
Birth Length (*z*)			0.305**	1.065***	-0.019	1.062***†
			(0.129)	(0.359)	(0.168)	(0.367)
Mother FE		✓		✓		✓
N	*1,328*	*1,328*	*1,328*	*1,328*	*1,328*	*1,328*
# mothers		1,199		1,199		1,199
Panel E: WRAT Reading Scale						
Birth Weight (*z*)	0.794***	-0.399			0.769**	-1.013
	(0.284)	(0.731)			(0.363)	(0.772)
Birth Length (*z*)			0.598**	0.998	0.038	1.494*†
			(0.298)	(0.728)	(0.381)	(0.790)
Mother FE		✓		✓		✓
N	*1,326*	*1,326*	*1,326*	*1,326*	*1,326*	*1,326*
# mothers		1,198		1,198		1,198
Panel F: WISC Verbal Digit Scale						
Birth Weight (*z*)	0.305***	0.470*			0.366***†	0.095
	(0.085)	(0.245)			(0.116)	(0.257)
Birth Length (*z*)			0.174*	0.895***	-0.094	0.846***†
			(0.090)	(0.257)	(0.122)	(0.282)
Mother FE		✓		✓		✓
N	*1,342*	*1,342*	*1,342*	*1,342*	*1,342*	*1,342*
# mothers		1,210		1,210		1,210
Panel G: WISC Verbal Comprehension Scale						
Birth Weight (*z*)	0.186***	0.082			0.209**†	-0.247
	(0.070)	(0.243)			(0.095)	(0.285)
Birth Length (*z*)			0.117	0.614**	-0.036	0.741**†
			(0.074)	(0.247)	(0.101)	(0.303)
Mother FE		✓		✓		✓
N	*1,341*	*1,341*	*1,341*	*1,341*	*1,341*	*1,341*
# mothers		1,209		1,209		1,209

Notes: This table displays ordinary least squares estimates of anthropometric and cognitive outcomes in childhood (age 7) on birth weight and birth length. Both birth measures have been standardized using the growth chart developed by Olsen et al. [2010] for the United States. Values lying outside three times the interquartile range from the first or third quartile of the birth weight and birth length distribution have been removed as extreme outliers (Tukey's method). Controls included in all the estimated specifications not shown in the tables are: gestational age and indicators for the child being male, of white ethnicity, for being a first born, for number of previous births, for the mother being 20 years old or younger, and for being older than 35 years, for age at measurement (in years for the anthropometric outcomes and also in months for the cognitive outcomes), and for year of birth. The standard errors (in parentheses) are clustered at the level of the mother. *** p<0.01, ** p<0.05, * p<0.1. †: the coefficients on birth weight and birth length are statistically significantly different (two-sided tests).

Table A22: Prenatal, Birth, Postnatal Health Capital and Childhood Overweight at 6 Years

	Overweight							
	(1a)	(2a)	(3a)	(1b)	(2b)	(3b)	(4a)	(4b)
Fetal Abdominal Circumference TR2 (z)	0.033***	0.030***			0.025	0.018		0.012
	(0.012)	(0.012)			(0.015)	(0.015)		(0.015)
Fetal Abdominal Circumference Growth TR2-TR3 (z)	0.060***	0.045***			0.043**	0.027		0.013
	(0.014)	(0.013)			(0.018)	(0.017)		(0.017)
Fetal Abdominal Circumference Growth TR3-Birth	0.036***	0.022*			0.020	0.004		0.001
	(0.014)	(0.013)			(0.018)	(0.017)		(0.017)
Fetal Abdominal Circumference Slow Growth TR2-Birth	0.151***	0.126**			0.133**	0.115**		0.126**
	(0.056)	(0.054)			(0.056)	(0.055)		(0.050)
Fetal Abdominal Circumference Fast Growth TR2-Birth	-0.117**	-0.134***			-0.114**	-0.129**		-0.151***
	(0.054)	(0.052)			(0.055)	(0.053)		(0.053)
Fetal Femur Length Slow Growth TR2-Birth	0.052	0.028			0.026	0.015		0.013
	(0.054)	(0.051)			(0.057)	(0.054)		(0.057)
Fetal Femur Length Fast Growth TR2-Birth	-0.085*	-0.082			-0.083	-0.084		-0.068
	(0.051)	(0.050)			(0.054)	(0.052)		(0.052)
Fetal Femur Length Accelerated Growth TR2-Birth	0.022	0.031			0.028	0.033		0.038
	(0.025)	(0.024)			(0.025)	(0.025)		(0.024)
Fetal Head Circumference Growth TR3-Birth	0.022*	0.029**			0.018	0.024*		0.013
	(0.013)	(0.012)			(0.014)	(0.013)		(0.013)
Fetal Head Circumference Fast Growth TR2-Birth	0.039	0.024			0.022	0.010		0.022
	(0.048)	(0.047)			(0.049)	(0.048)		(0.043)
Fetal Asymmetric AC/HC Growth TR2-TR3	0.038	0.028			0.037	0.030		0.026
	(0.027)	(0.026)			(0.027)	(0.026)		(0.026)
Birth Weight (z)			0.081***	0.069***	0.038	0.043*	0.077***	0.069***
			(0.020)	(0.020)	(0.028)	(0.025)	(0.020)	(0.026)
Birth Length (z)			-0.043**	-0.029	-0.031	-0.020	-0.044**	-0.034
			(0.020)	(0.020)	(0.022)	(0.022)	(0.020)	(0.023)
High Birth Weight			0.039	0.006	0.042	0.021	0.005	0.017
			(0.036)	(0.034)	(0.037)	(0.036)	(0.035)	(0.036)
Low Apgar 1M			0.038	0.024	0.030	0.022	0.009	0.011
			(0.031)	(0.031)	(0.031)	(0.030)	(0.032)	(0.033)
Low Apgar 5M			0.087	0.066	0.094	0.068	0.110*	0.107
			(0.069)	(0.065)	(0.069)	(0.066)	(0.065)	(0.066)
Postnatal Weight Growth 0-1Y (z)							0.116***	0.109***
							(0.015)	(0.015)
Postnatal Height Growth 0-1Y (z)							-0.039***	-0.033**
							(0.014)	(0.014)
Full Controls		✓		✓		✓	✓	✓
Postnatal Growth							✓	✓
p-value joint significance Fetal	*0.000*	*0.000*			*0.007*	*0.006*		*0.015*
p-value joint significance Birth			*0.000*	*0.001*	*0.128*	*0.262*	*0.000*	*0.029*
p-value joint significance Postnatal							*0.000*	*0.000*
AUC	0.686	0.794	0.666	0.773	0.696	0.795	0.821	0.836
p-value AUC					0.020	0.011		0.019
N	*1,097*	*1,035*	*1,097*	*1,035*	*1,097*	*1,035*	*956*	*956*

Notes: This table shows average marginal effects from probit models for the probability of being overweight (BMI-for-age >85^{th} percentile according to the Child Growth Foundation standards) at 6 years on patterns of fetal growth starting in the second trimester and birth outcomes, chosen using the lasso among 34 measures (see footnote 45 in the paper). Models in (1a), (2a) and (3a) include binary indicators for white ethnicity, gender, being a first born and year and season of birth. Models in (1b), (2b), (3b), (4a) and (4b) include binary indicators for white ethnicity, male, and being a first born, and controls for year and season of birth, number of children and mother's age at birth, and the following controls measured at baseline (before conception): whether the mother has a degree-level education, belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), owns the house, is single, separated, divorced or widowed, receives welfare benefits, is in fair, bad or very bad health, has been under stress in the last four weeks, was working last week, is a current smoker, drinks more than 4 units of alcohol per week, does any strenuous exercise in the week, does any moderate exercise in the week, whether the mother's partner belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), whether the mother's father belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled); continuous variables for mother's birth weight, pre-pregnancy weight, height, BMI, head circumference, leg length, waist circumference, skinfolds (sum of triceps, biceps, subscapular and suprailiac) and her daily energy intake (kilocalories), paternal height, weight and birth weight, grandmaternal and grandpaternal height and weight, and the Townsend Deprivation Index; missing values for social class of the mother, the mother's father and the mother's partner have been replaced with zeros and a binary indicator for missing is included; missing values for maternal birth weight and head circumference, for paternal height, weight and birth weight, for grandmaternal weight and grandpaternal height and weight are replaced with the sample means of the non-missing observations and binary indicators for missing are included. "Fetal Abdominal Circumference Growth TR2-TR3 (z)" is a measure of conditional growth between weeks 19 and 34, computed according to the Royston [1995] method. "Fetal Abdominal Circumference Growth TR3-Birth (z)" is a measure of conditional growth between weeks 34 and birth. "Fetal Abdominal Circumference Slow Growth TR2-Birth" is a binary indicator which takes value 1 if the fetus is in the lower quartile of the Abdominal Circumference growth distribution both between weeks 19-34 and between week 34 and birth. "Fetal Abdominal Circumference Fast Growth TR2-Birth" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the Abdominal Circumference growth distribution both between weeks 19-34 and between week 34 and birth. "Fetal Femur Length Slow Growth TR2-Birth" is a binary indicator which takes value 1 if the fetus is in the lower quartile of the Femur Length growth distribution both between weeks 19-34 and between week 34 and birth. "Fetal Femur Length Fast Growth TR2-Birth" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the Femur Length growth distribution both between weeks 19-34 and between week 34 and birth. "Fetal Femur Length Accelerated Growth TR2-Birth" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the distribution of the difference between the Femur Length growth between week 34 and birth and between weeks 19-34. "Fetal Head Circumference Growth TR3-Birth (z)" is a measure of conditional growth between weeks 34 and birth. "Fetal Head Circumference Fast Growth TR2-Birth" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the Head Circumference growth distribution both between weeks 19-34 and between week 34 and birth. "Fetal Asymmetric AC/HC Growth TR2-TR3" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the distribution of the difference between the Abdominal Circumference growth and the Head Circumference growth between weeks 19 and 34. The birth outcomes z-scores have been computed using the Child Growth Foundation standards. The fetal and birth measures included in the regression have been selected using lasso (see text for details). The measures of postnatal conditional growth are standardized residuals of regressions of weight and height at one year on their respective birth measures. *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. AUC=Area under the ROC curve. The AUC standard errors are bootstrapped (1,000 replications). p=p-value for the Null Hypothesis that the models in (2a) and (3a), in (2b) and (3b), and in (4a) and (4b), respectively, have equal AUC values.

Table A23: Prenatal and Birth Health Capital and Childhood Respiratory Health at 6 Years

	Asthma (GP-Diagnosed) or Wheezing							
	(1a)	(1b)	(2a)	(2b)	(3a)	(3b)	(4a)	(4b)
Fetal Abdominal Circumference Fast Growth TR2-Birth	-0.168**	-0.190***			-0.127*	-0.144**		-0.199***
	(0.069)	(0.070)			(0.072)	(0.072)		(0.073)
Fetal Head Circumference Accelerated Growth TR2-Birth	-0.073**	-0.069**			-0.080**	-0.075**		-0.087***
	(0.033)	(0.032)			(0.032)	(0.032)		(0.032)
Fetal Asymmetric HC/AC Growth TR2-TR3	0.016	0.042			0.010	0.035		0.033
	(0.035)	(0.035)			(0.036)	(0.036)		(0.037)
Fetal Symmetric AC/HC Growth TR2-TR3	-0.064**	-0.054*			-0.073**	-0.063**		-0.061*
	(0.031)	(0.031)			(0.031)	(0.031)		(0.032)
Birth Head Circumference			0.044**	0.048***	0.045**	0.047***	0.049***	0.047***
			(0.017)	(0.017)	(0.018)	(0.017)	(0.018)	(0.018)
Low Birth Weight			0.234**	0.206**	0.233**	0.212**	0.178**	0.190**
			(0.092)	(0.086)	(0.093)	(0.087)	(0.091)	(0.091)
High Birth Weight			-0.083**	-0.106**	-0.066	-0.076*	-0.100**	-0.059
			(0.040)	(0.042)	(0.042)	(0.044)	(0.044)	(0.045)
Low Apgar 1M			0.073**	0.076**	0.080**	0.083**	0.077**	0.086**
			(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)
Low Apgar 5M			0.061	0.009	0.054	0.004	0.032	0.018
			(0.080)	(0.073)	(0.078)	(0.073)	(0.076)	(0.077)
Small Birth Head Circumference			0.076**	0.076**	0.080**	0.078**	0.087**	0.088**
			(0.035)	(0.035)	(0.035)	(0.035)	(0.036)	(0.036)
Short Birth Length			-0.095	-0.069	-0.099	-0.078	-0.068	-0.077
			(0.064)	(0.062)	(0.064)	(0.062)	(0.063)	(0.063)
Asymmetric SGA			0.040	0.039	0.034	0.030	0.024	0.016
			(0.059)	(0.057)	(0.058)	(0.056)	(0.060)	(0.059)
Preterm			0.061	0.035	0.059	0.038	0.044	0.044
			(0.068)	(0.069)	(0.068)	(0.069)	(0.072)	(0.070)
Postnatal Weight Growth 0-1Y (*z*)							0.013	0.015
							(0.015)	(0.015)
Postnatal Head Growth 0-1Y (*z*)							-0.001	-0.007
							(0.015)	(0.015)
Full Controls		✓		✓		✓	✓	✓
Postnatal Growth							✓	✓
p-value joint significance Fetal	*0.000*	*0.000*			*0.000*	*0.000*		*0.000*
p-value joint significance Birth			*0.001*	*0.001*	*0.000*	*0.002*	*0.002*	*0.004*
p-value joint significance Postnatal							*0.644*	*0.619*
AUC	0.619	0.695	0.631	0.691	0.662	0.714	0.694	0.719
p-value AUC					0.018	0.015		0.010
N	*1,115*	*1,051*	*1,115*	*1,051*	*1,115*	*1,051*	*996*	*996*

Notes: This table shows average marginal effects from probit models for the probability of having asthma or wheezing at 6 years on patterns of fetal growth starting in the second trimester and birth outcomes, chosen using the lasso among 34 measures (see footnote 45 in the paper). Models in (1a), (2a) and (3a) include binary indicators for white ethnicity, gender, being a first born and year and season of birth. Models in (1b), (2b), (3b), (4a) and (4b) include binary indicators for white ethnicity, male, and being a first born, and controls for year and season of birth, number of children and mother's age at birth, and the following controls measured at baseline (before conception): whether the mother has a degree-level education, belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), owns the house, is single, separated, divorced or widowed, receives welfare benefits, is in fair, bad or very bad health, has been under stress in the last four weeks, was working last week, is a current smoker, drinks more than 4 units of alcohol per week, does any strenuous exercise in the week, does any moderate exercise in the week, whether the mother's partner belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), whether the mother's father belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled); continuous variables for mother's birth weight, pre-pregnancy weight, height, BMI, head circumference, leg length, waist circumference, skinfolds (sum of triceps, biceps, subscapular and suprailiac) and her daily energy intake (kilocalories), paternal height, weight and birth weight, grandmaternal and grandpaternal height and weight, and the Townsend Deprivation Index; missing values for social class of the mother, the mother's father and the mother's partner have been replaced with zeros and a binary indicator for missing is included; missing values for maternal birth weight and head circumference, for paternal height, weight and birth weight, for grandmaternal weight and grandpaternal height and weight are replaced with the sample means of the non-missing observations and binary indicators for missing are included. "Fetal Abdominal Circumference Fast Growth TR2-Birth" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the Abdominal Circumference growth distribution both between weeks 19-34 and between week 34 and birth. "Fetal Head Circumference Accelerated Growth TR2-Birth" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the distribution of the difference between the Head Circumference growth between week 34 and birth and between weeks 19-34. "Fetal Asymmetric HC/AC Growth TR2-TR3" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the distribution of the difference between the Head Circumference growth and the Abdominal Circumference growth between weeks 19 and 34. "Fetal Symmetric Abdominal/Head Circumference Growth TR2-TR3" is a binary indicator which takes value 1 if the fetus is above the lower quartile and below the upper quartile of the distribution of the difference between the Abdominal Circumference growth and the Head Circumference growth between weeks 19 and 34. "Low Birth Weight" is a binary indicator which takes value 1 if birth weight <2,500g. "High Birth Weight" is a binary indicator which takes value 1 if birth weight >4,000g. "Low Apgar 1(5) Minute" is a binary indicator which takes value 1 if the Apgar score is less than 8. "Small Birth Head Circumference" is a binary indicator which takes value 1 if the head circumference at birth is <35.36cm (Barker et al. [1993]). "Short Birth Length" is a binary indicator which takes value 1 if the length at birth is <47cm (Tuvemo et al. [1999]). "Asymmetric SGA" is a binary indicator which takes value 1 if birth weight-for-gestational age $<10^{th}$ percentile and head circumference-for-gestational age $\geq 10^{th}$ percentile. "Preterm" is a binary indicator which takes value 1 if the gestational age at birth is less than 37 weeks. The fetal and birth measures included in the regression have been selected using lasso (see text for details). The measures of postnatal conditional growth are standardized residuals of regressions of weight and height at one year on their respective birth measures. *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. AUC=Area under the ROC curve. The AUC standard errors are bootstrapped (1,000 replications). *p*=*p*-value for the Null Hypothesis that the models in (2a) and (3a), in (2b) and (3b), and in (4a) and (4b), respectively, have equal AUC values.

Table A24: Prenatal, Birth, Postnatal Health Capital and Childhood Hyperactivity Problems at 3 Years

	Hyperactivity Problems (SDQ)							
	(1a)	(2a)	(3a)	(1b)	(2b)	(3b)	(4a)	(4b)
Fetal Abdominal Circumference Slow Growth TR2-Birth	0.075*	0.089**			0.065	0.084*		0.097**
	(0.042)	(0.043)			(0.044)	(0.045)		(0.045)
Fetal Femur Length Slow Growth TR2-Birth	0.062	0.098**			0.047	0.089*		0.097**
	(0.046)	(0.045)			(0.048)	(0.047)		(0.047)
Fetal Femur Length Accelerated Growth TR2-Birth	-0.039	-0.037			-0.038	-0.037		-0.035
	(0.024)	(0.024)			(0.024)	(0.024)		(0.025)
Fetal Head Circumference Slow Growth TR2-Birth	0.069*	0.004			0.068	0.007		-0.017
	(0.042)	(0.044)			(0.044)	(0.045)		(0.045)
Fetal Head Circumference Fast Growth TR2-Birth	-0.081*	-0.105**			-0.079	-0.108**		-0.126**
	(0.048)	(0.051)			(0.050)	(0.054)		(0.054)
Fetal Head Circumference Accelerated Growth TR2-Birth	-0.053**	-0.062**			-0.054**	-0.062**		-0.064**
	(0.026)	(0.025)			(0.026)	(0.026)		(0.026)
Fetal Asymmetric HC/AC Growth TR2-TR3	0.021	0.030			0.018	0.028		0.036
	(0.024)	(0.024)			(0.025)	(0.025)		(0.025)
Fetal Symmetric HC/FL Growth TR2-TR3	-0.035*	-0.044**			-0.034*	-0.043**		-0.043**
	(0.020)	(0.020)			(0.020)	(0.020)		(0.020)
Birth Head Circumference (*z*)			-0.016	-0.011	0.003	0.006	-0.015	0.000
			(0.012)	(0.012)	(0.013)	(0.013)	(0.012)	(0.014)
Short Birth Length			0.065*	0.066*	0.033	0.031	0.074*	0.035
			(0.038)	(0.038)	(0.040)	(0.039)	(0.039)	(0.041)
Asymmetric SGA			0.043	0.046	0.023	0.013	0.068	0.025
			(0.047)	(0.046)	(0.049)	(0.047)	(0.046)	(0.047)
Large-for-Gestational Age			-0.028	-0.025	-0.024	-0.016	-0.030	-0.019
			(0.042)	(0.041)	(0.041)	(0.040)	(0.041)	(0.041)
Postnatal Weight Growth 0-1Y (*z*)							0.019	0.024*
							(0.012)	(0.012)
Postnatal Head Growth 0-1Y (*z*)							-0.030**	-0.035***
							(0.012)	(0.012)
Full Controls		✓		✓		✓	✓	✓
Postnatal Growth							✓	✓
p-value joint significance Fetal	*0.000*	*0.000*			*0.011*	*0.001*		*0.000*
p-value joint significance Birth			*0.061*	*0.140*	*0.863*	*0.914*	*0.035*	*0.866*
p-value joint significance Postnatal							*0.049*	*0.013*
AUC	0.629	0.705	0.594	0.683	0.629	0.705	0.697	0.722
p-value AUC					0.008	0.022		0.012
N	*1,428*	*1,336*	*1,428*	*1,336*	*1,428*	*1,336*	*1,267*	*1,267*

Notes: This table shows average marginal effects from probit models for the probability of having ADHD (a score greater than 5 on the Strength and Difficulties Questionnaire Hyperactivity scale) at 3 years on patterns of fetal growth starting in the second trimester and birth outcomes, chosen using the lasso among 34 measures (see footnote 45 in the paper). Models in (1a), (2a) and (3a) include binary indicators for white ethnicity, gender, being a first born and year and season of birth. Models in (1b), (2b), (3b), (4a) and (4b) include binary indicators for white ethnicity, male, and being a first born, and controls for year and season of birth, number of children and mother's age at birth, and the following controls measured at baseline (before conception): whether the mother has a degree-level education, belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), owns the house, is single, separated, divorced or widowed, receives welfare benefits, is in fair, bad or very bad health, has been under stress in the last four weeks, was working last week, is a current smoker, drinks more than 4 units of alcohol per week, does any strenuous exercise in the week, does any moderate exercise in the week, whether the mother's partner belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled), whether the mother's father belongs to high social class (I: professional or II: management and technical), or to low social class (IIIM: skilled manual, IV: partly skilled or V: unskilled); continuous variables for mother's birth weight, pre-pregnancy weight, height, BMI, head circumference, leg length, waist circumference, skinfolds (sum of triceps, biceps, subscapular and suprailiac) and her daily energy intake (kilocalories), paternal height, weight and birth weight, grandmaternal and grandpaternal height and weight, and the Townsend Deprivation Index; missing values for social class of the mother, the mother's father and the mother's partner have been replaced with zeros and a binary indicator for missing is included; missing values for maternal birth weight and head circumference, for paternal height, weight and birth weight, for grandmaternal weight and grandpaternal height and weight are replaced with the sample means of the non-missing observations and binary indicators for missing are included. "Fetal Abdominal Circumference Slow Growth TR2-Birth" is a binary indicator which takes value 1 if the fetus is in the lower quartile of the Abdominal Circumference growth distribution both between weeks 19-34 and between week 34 and birth. "Fetal Femur Length Slow Growth TR2-Birth" is a binary indicator which takes value 1 if the fetus is in the lower quartile of the Femur Length growth distribution both between weeks 19-34 and between week 34 and birth. "Fetal Femur Length Accelerated Growth TR2-Birth" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the distribution of the difference between the Femur Length growth between week 34 and birth and between weeks 19-34. "Fetal Head Circumference Slow Growth TR2-Birth" is a binary indicator which takes value 1 if the fetus is in the lower quartile of the Head Circumference growth distribution both between weeks 19-34 and between week 34 and birth. "Fetal Head Circumference Fast Growth TR2-Birth" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the Head Circumference growth distribution both between weeks 19-34 and between week 34 and birth. "Fetal Head Circumference Accelerated Growth TR2-Birth" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the distribution of the difference between the Head Circumference growth between week 34 and birth and between weeks 19-34. "Fetal Asymmetric HC/AC Growth TR2-TR3" is a binary indicator which takes value 1 if the fetus is in the upper quartile of the distribution of the difference between the Head Circumference growth and the Abdominal Circumference growth between weeks 19 and 34. "Fetal Symmetric HC/FL Growth TR2-TR3" is a binary indicator which takes value 1 if the fetus is above the lower quartile and below the upper quartile of the distribution of the difference between the Head Circumference growth and the Femur Length growth between weeks 19 and 34. "Short Birth Length" is a binary indicator which takes value 1 if the length at birth is <47cm (Tuvemo et al. [1999]). "Asymmetric SGA" is a binary indicator which takes value 1 if birth weight-for-gestational age $<10^{th}$ percentile and head circumference-for-gestational age $\geq 10^{th}$ percentile. "Large for Gestational Age" is a binary indicator which takes value 1 if birth weight-for-gestational age $>90^{th}$ percentile. The fetal and birth measures included in the regression have been selected using lasso (see text for details). The measures of postnatal conditional growth are standardized residuals of regressions of weight and height at one year on their respective birth measures. *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. AUC=Area under the ROC curve. The AUC standard errors are bootstrapped (1,000 replications). *p*=*p*-value for the Null Hypothesis that the models in (2a) and (3a), in (2b) and (3b), and in (4a) and (4b), respectively, have equal AUC values.