Prenatal Economic Shocks and Birth Outcomes in UK Cohort Data*

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Abstract

We consider the effects of major prenatal economic shocks experienced by mothers on two indicators of newborn-infant health, birth weight and head circumference, using detailed microdata from the UK ALSPAC survey. Controlling for physiological and socioeconomic factors, an economic shock in the first 18 weeks of gestation lowers birth weight by 40-70 grams and head circumference by 2-3mm. We find evidence of transmission via poorer maternal health due to absolute material deprivation and tobacco and alcohol consumption, but not for the endocrinological effects of increased psychosocial anxiety. The fragile-male hypothesis holds for birth weight but not for head circumference, as predicted by recent theories on gender differences in prenatal development.

Key Words: ALSPAC, Birth Weight, Economic Shocks, Head Circumference, Infant Health

JEL Classification: I1, J1

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1 Introduction

Economic shocks are known to affect individual health and wellbeing. Over the last two decades a vast empirical literature has documented the epidemiological implications of economic contractions (Barr and Taylor-Robinson, 2016; Currie *et al.*, 2015 Frasquilho *et al.*, 2016; Ruhm, 2000; 2015), involuntary job losses (Gallo *et al.*, 2000; Schaller and Stevens, 2014; Strully, 2009) and other related factors such as sharp declines in household-level income (Adda *et al.*, 2009, Prause *et al.*, 2009). While the impacts identified vary substantially depending on the type of shock experienced, how it is measured, and the outcome considered, the weight of evidence suggests that adverse economic events are usually harmful for health.[1] Furthermore, these effects appear to be fairly pervasive. Economic shocks (or their latent threat) can be linked to a variety of poor physical outcomes, such as mortality (Eliason and Storrie, 2009), obesity (Barnes *et al.*, 2013) and cardiovascular disease (Gallo *et al.*, 2006), mental outcomes such as depression and suicide (Burgard *et al.*, 2007; Blakely *et al.*, 2003), and unhealthy behaviours such as smoking and other forms of substance abuse (Hammer, 1992).[2]

We here ask whether the health effects of negative economic shocks may be transmitted across generations, from expectant mothers to their unborn children. This is a plausible hypothesis, as the physical condition of pregnant mothers is known to be an important determinant of newborn infant health (Wadhwa *et al.*, 1993). As such, any external factor that affects maternal wellbeing may feed through to prenatal development. The relationship between maternal and foetal health is also important, as the latter is believed to exert a strong causal influence on wellbeing over the life cycle (Currie and Lin, 2007; McGovern, 2013).[3] The survey by Almond and Currie (2011) suggests that in-utero shocks can have more severe and longer-lasting effects than those occurring during early childhood, so that investments targeting the health and wellbeing of expectant mothers may yield substantial social returns.

In this paper we examine the effects of economic shocks on two related proxy measures of newborn infant health - birth weight and head circumference. Birth weight is useful in this respect as it is systematically measured for newborns, and predicts a wide variety of negative physiological and

[1] An overview in Currie *et al.* (2015) provides details on some conflicting empirical findings in this literature. For instance, considering employment shocks, some work based upon aggregate data has shown *positive* health impacts (e.g. Ruhm, 2000) while those using microdata tend to find negative impacts (e.g. Offer *et al.*, 2010; Sullivan and von Wachter, 2009). A related literature also finds negative impacts for other types of adverse shocks - e.g. intimate partner violence (Boy and Salihu, 2004), parental bereavement (Black *et al.*, 2016) and exposure to radiation (Black *et al.*, 2019).

[2] Catalano *et al.* (2011) provide a survey of this literature.

[3] See also Almond (2006), who shows that the onset of the 1918 Spanish Flu predicted disability, lower incomes and an increased reliance upon governmental transfer payments for children gestating during this period. Similarly Scholte *et al.* (2015) find that the unexpected 1944-1945 Dutch famine had measurable ill-effects on the health and employment outcomes of the affected births half a Century later. In both cases the plausible exogeneity and sharp timing of these events suggest that the estimated impacts are causal.

socioeconomic outcomes.[4] These include infant mortality (McCormick, 1985), a range of physical and psychological conditions in childhood and beyond (Hack *et al.*, 1995; Orchinik *et al.*, 2011) and adulthood economic characteristics such as education, earnings and employment (Almond *et al.*, 2005; Black *et al.*, 2007; Currie and Hyson, 1999; Figlio *et al.*, 2014). Head circumference is less-frequently measured and hence less widely-used, but still acts as a useful indicator of foetal brain development, and is correlated in particular with cognitive outcomes in later life (Gale *et al.*, 2006; Hagenaars *et al.*, 2016). Notably there are some biological differences in the way these two birth outcomes are determined in the womb (especially related to gender) and in the types of health issues and cognitive skills they predict (Ashwal *et al.*, 2009; Heinonen *et al.*, 2008; Veena *et al.*, 2010; Yajnik, 2004).

There is a growing body of research on the links between prenatal economic shocks and birth weight, although we are unaware of any papers that focus on head circumference.[5] Most existing research exploits large administrative data sets on birth outcomes and uses quasi-experimental approaches based on timing or location to match mothers to economic shocks (Bozzoli and Quintana-Domeque, 2014; Burlando, 2014; Carlson, 2015; Catalano, 1991). One benefit of this approach is that *ecological* or aggregate-level economic shocks are plausibly exogenous to individual-level foetal health, so that the effects estimated in these papers are likely to be causal (although endogenous sorting into groups may affect the estimates). However aggregate data typically offer only limited scope for the control of mediating variables, which prevents researchers from investigating the estimated relationships in detail. As a result, any unobserved factors that are jointly determined with these shocks may also play an important transmission role (Margerison-Zilko, 2010).

On the contrary, micro-level analyses of the type presented here (where the key independent variable is measured at the individual level) provide greater scope for disentangling the effects of various contributing factors, and therefore can offer a more in-depth picture of the underlying mechanisms. Nonetheless these studies are rarer (Dooley and Prause, 2005; Margerison-Zilko *et al.*, 2011), as they require data sets with rich lists of potential covariates, which are typically too small to provide statistically-meaningful estimates. Further, inferring causal effects from correlations in micro-data is more challenging, as idiosyncratic economic shocks are more likely to be determined by unobservables that are also related to maternal health. As a result, micro-level studies such as ours make less definitive causal claims than those in other contributions, but can shed light on certain aspects of these relationships that are often otherwise inaccessible.

Our key independent variable refers to a major economic shock experienced by the mother when

[4] Conti *et al.* (2018) note however that this indicator misses a number of important dimensions of infant health.

[5] Note that there is a related literature that examines factors such as paternal unemployment (e.g. Cole *et al.*, 1983; De Cao *et al.*, 2019).

pregnant. While a great deal of the existing literature has focussed on movements in income, this on its own may not suffice to describe the relationship between family economic resources and the demands that are made on them. In particular, an economic shock can involve greater expenses.[6]

Using a subjectively-measured covariate of interest also comes with some costs and benefits for identifying impacts upon foetal health. For instance, our variable will capture certain aspects of financial shocks that are neglected by objective indices. Adverse economic events can take a multitude of forms (e.g. unemployment, income loss through familial breakup, large unexpected expenses) and are sensitive to mitigating factors such as risk preferences and the presence of safety nets. Therefore, self-assessed measures allow for broader definitions of economic shocks, and can provide better control for important unobserved phenomena. However, self-assessed variables may also be unduly influenced by other factors, including intangible characteristics that are unrelated to adverse economic events, but correlated with the error terms from regression equations.[7]

Despite the ambiguity arising from this second issue, we have several strategies for mitigating endogeneity concerns in our models. By taking advantage of the survey design (which eliminates, at least in part, both reverse causality and bias from selection into pregnancy), and by subjecting our models to a battery of identifying diagnostics (covariate balance, parameter stability to assess unobservables, placebo regressions), we produce results that appear to capture a true causal flow.

Our research here has three primary objectives. The first (Obj 1) is simply to establish an empirical relationship between adverse economic events during pregnancy and birth outcomes in UK data. Using regression models that control for a variety of physiological and socioeconomic determinants, we estimate that major economic shocks experienced in the first 18 weeks of gestation predict lower average birth weight of around 40-70 grams, and smaller head circumference of 2-3mm. These effect sizes are large enough for prenatal economic shocks to be considered a substantial threat to infant health. Subject to our assumptions of exogeneity, a back-of-the-envelope calculation suggests protecting mothers from severe financial shocks early in the gestational period would have about 5-10% of the impact of eliminating maternal smoking.

Our second objective (Obj 2) is to understand how the correlations we observe come about. Collecting evidence on the transmission mechanism is important as (i) not all sources of fluctuations

[6]Some supportive evidence comes from Waves 1 to 18 (1991-2008) of the British Household Panel Survey (BHPS) data, where respondents are asked "Would you say that you yourself are better off or worse off financially than you were a year ago?". Around one quarter say better-off, one quarter worse-off and almost exactly one half about the same. Starting in Wave 3 of the BHPS, respondents who reported being better or worse off were then asked "Why is that?", with the answers to this open-ended question being reported verbatim. In the overall sample, three response categories dominate for those whose financial position has worsened: a rise in expenses for almost exactly 50% of respondents, followed by a fall in income (28%) and "Other" (11%).

[7]For example, it is possible that mothers who perceive an economic shock to be more severe may have poorer mental or physical health relative to other mothers.

in aggregate birth sizes are necessarily harmful, and (ii) understanding how harmful effects come about is useful to tailor more effective policy. For example, if economic shocks cause smaller birth size only via selection/composition effects, a policy response may not be required. This could be the case if economically-induced stress affects sex ratios with a preference for girls (who are typically smaller and lighter), or if healthier mothers disproportionately avoid reproducing in poor economic conditions, creating a temporary increase in the relative birth rate of less-healthy infants. Both of these hypotheses have received some support in the literature, e.g. see Catalano (2003), Navara (2014) and Margerison-Zilko (2010).

Conversely, if the effect of economic shocks is to directly reduce the birth size, then the consequences for health could be considerable. We here examine three of the most plausible non-compositional pathways that have been identified in the literature. The first works via absolute constraints on resources: financial problems might limit mothers' nutritional intake or prevent access to appropriate healthcare, both of which could affect intrauterine growth (Lechtig *et al.*, 1975; Rogers, 1998). Empirical evidence for this effect comes from Almond *et al.* (2011), who use US data to show that exogenous variations in the introduction of food-stamp programmes were associated with sharp improvements in newborn-infant health. Bozzoli and Quintana-Domeque (2014) also examine birth outcomes, and show that Argentina's 2001 economic crisis led to lower birth weights. These declines were in addition largest for mothers with little formal education, who were the most likely to have experienced direct material hardship while pregnant.

The next channel we explore is a direct physiological one, where an adverse economic event leads to emotional distress. This distress is known to increase hypertension and raise cortisol levels, both of which have been flagged in the medical literature as inhibitors of foetal development (Bolten *et al.*, 2011; Wadhwa *et al.*, 2011). Stress may also induce pre-term delivery (Copper *et al.*, 1996) or disrupt the normal functioning of the immune system (Segerstrom and Miller, 2004), raising the probability of infections that retard growth. Notably it has been suggested that these mechanisms may not necessarily reflect a malfunctioning of the mother's reproductive system, but rather could be evolutionary adaptations designed to prevent biological over-investments in unfavourable conditions (Pike, 2005).

Our final channel is behavioural, where stress or anxiety do not directly affect intrauterine development, but rather provoke unhealthy coping strategies that do. Typical responses to psychosocial stress include smoking (Baker *et al.*, 2004), alcohol consumption (Sinha, 2012) and drug abuse, (McFarlane *et al.*, 1996) all of which have been identified as determinants of foetal development. Given the strong links between these behaviours and socioeconomic conditions this hypothesis appears to be very plausible, although the empirical analysis in Margerison-Zilko (2014) finds little support for it in US data.

The data we use allow for some of these mechanisms to be explored. We for example show that financial shocks experienced during the first 18 weeks of pregnancy are a significant and robust predictor of smaller births, even when controlling for the mother's direct level of material wellbeing. However by interacting our shocks with markers of socioeconomic disadvantage we find much larger effect sizes for poorer mothers, suggesting that even in a developed country, absolute material deprivation plays an important role. We also show that economic shocks are associated with greater maternal depression and anxiety, and higher rates of tobacco and alcohol consumption. We then add these variables to our regressions to consider their role as mediators. Including maternal alcohol and tobacco consumption substantially reduces the economic-shock coefficients, while adding the mental-health measures does not. Financial shocks are seemingly then more likely to be transmitted in-utero through a mother's behaviour than via changes in her mental health.

The third objective of the paper (Obj 3), after estimating the baseline models and examining the above transmission channels, is to see whether these correlations are larger for male births. The motivation for doing so comes from relatively recent medical research showing that, due to subtle gestational differences, boys are less well-equipped than girls to deal with adverse intrauterine conditions (Eriksson *et al.*, 2010; Kraemer, 2000). This *fragile male* hypothesis is supported empirically in terms of birth weights (Hanson *et al.*, 1999; Currie and Schwandt, 2016), and the mechanisms are well-understood physiologically. For example, at a given gestational age males are larger (implying greater intrauterine growth rates) which is thought to make them more dependent upon a steady nutritional flow. And greater rates of placental uptake mean that male births are also more affected by factors such as toxicity due to smoking and pollution (Fukuda *et al.*, 2002). Stratifying our analysis by sex, we find evidence that male foetuses are indeed more affected by economic shocks when the outcome is birth weights; however, we also find the reverse result (i.e. increased female vulnerability) for head circumference. Although seemingly contradictory, the findings are consistent with theories of prenatal development, where male growth processes favour the head at the expense of the body and placenta but female growth processes do not (Eriksson *et al.*, 2010; Roland *et al.*, 2013).

The remainder of the paper is structured as follows. Section 2 introduces the data and presents the descriptive statistics of our key variables, as well as some later-life cognitive and health outcomes for children with smaller birth sizes. Section 3 uses regression analysis to establish our baseline result that prenatal economic shocks have harmful physiological implications (Obj 1) and conducts some informal diagnostics on identification. Section 4 explores the transmission channel focussing on the role of economic deprivation and potential mediating effects (Obj 2). Section 5 then turns to sex differences in effect sizes (Obj 3) and considers some sample-selection issues that may affect our results. Last, Section 6 summarizes and concludes.

2 Data

The data come from the Avon Longitudinal Study of Parents and Children (ALSPAC), which is a large survey conducted by the University of Bristol starting in the early 1990s.[8] This cohort study recruited over 14,000 pregnant women who were due to give birth between April 1991 and December 1992 in Bristol and the surrounding Avon area.[9] The geographic region is located in the South West of the United Kingdom and is a little more affluent and better-educated than the rest of the country. The sample we obtain has slightly higher socioeconomic status than that of the targeted population, and is somewhat less ethnically diverse.[10]

The ALSPAC survey was designed to study the effects of environmental, genetic and socioeconomic influences on children's health and development. Mothers and their children are followed from 4 weeks gestation until adulthood, with a vast array of questions asked over numerous waves spanning more than 25 years. Initially the survey was only completed by the mother, and collected detailed information on her life, background, education, health, employment, opinions, life events and relationships. Later, mothers answered questions about the development of their children, and finally the children themselves also completed surveys.[11] Data collection was more frequent during pregnancy and early infancy, and in this paper we are able to make use of information from four separate survey waves obtained prior to birth. This survey structure is a key advantage of the ALSPAC data as it allows us to deal in part with timing issues that would otherwise create endogeneity problems in cross-sectional analyses. In all cases the economic shocks we observe *precede* birth, which mitigates concerns about biases arising from reverse causality. While reverse-causal flows from early pregnancy are still possible, those associated with birth are not. Since births are likely to be much more economically disruptive than pregnancies, we argue that this accounts for the bulk of any reverse-causal effect.

Also our sample only considers financial events experienced *after* conception, which prevents endogenous selection due to women making fertility decisions based on their prevailing economic

[8]See Boyd *et al.* (2013) and Fraser *et al.* (2013) for details of the ALSPAC survey.

[9]In 1996 the County of Avon was abolished and the area split between four new unitary authorities: Bath and North East Somerset, Bristol, North Somerset and South Gloucestershire.

[10]The representativeness of the data is addressed in Tables 10 and 11 (in the Appendix), which compare the stratified averages of demographic and socioeconomic markers and birth outcomes in ALSPAC with those from Avon and the UK as a whole.

[11]Please note that the study website contains details of all the data that is available through a fully searchable data dictionary and variable search tool: see the following webpage: http://www.bristol.ac.uk/alspac/researchers/our-data/. Informed consent for the use of data collected via questionnaires and clinics was obtained from participants following the recommendations of the ALSPAC Ethics and Law Committee at the time.

conditions (Aparicio *et al.*, 2020; Neugart and Ohlsson, 2013).[12] As we do not have access to an explicit identification strategy (such as in the form of a natural experiment) these characteristics are crucial and underpin our assumptions of exogeneity throughout. Additional information on the different variables and the times at which they are measured appears in Table 12 in the Appendix.

Our dependent variables are the standard birth-weight and head-circumference measures in ALSPAC, with the former in grams and the latter in centimetres: both of these are measured at birth or shortly after. Having both of these measures is one of the key motivations for our use of ALSPAC (most cohort studies do not record head circumference) as it allows us to simultaneously explore two different aspects of newborn-infant health. While these variables are positively correlated, they are by no means perfectly collinear.[13] In terms of observations, our estimation sample retains outcomes from twin births but excludes further multiple births (triplets and quadruplets).[14] We further drop observations on births that are more than four weeks premature in order to distinguish between low weight due to pre-term delivery and that from intrauterine growth restriction.[15] We do so as the latter is a little more readily predicted by both physiological and socioeconomic factors (Kramer, 1987). Consequently all analysis is conditional upon gestational age (as well as survey response). As a result, our estimation sub-sample average birth weights are slightly higher and rates of Low Birth Weight (LBW) somewhat lower (5.3% vs 7%) than the UK national averages.

As noted in the introduction, our indicator of an adverse economic event is defined at the individual level and is obtained from a self-assessed question on the onset of a major financial problem since pregnancy.[16] This variable is measured at 18 weeks gestation. As the variable is explicitly defined as occurring after conception we treat it as an exogenous shock, but note that in some instances these events may be anticipated.[17] Five ordinal responses on occurrence/intensity are recorded with options (i) *Yes & it affected a lot*, (ii) *Yes, fairly affected*, (iii) *Yes, mildly affected*, (iv) *Yes, but did not affect me at all*, and (v) *No did not happen.* From these we generate a dummy to identify mothers who had financial problems that they regarded as severe (i.e. response (i)).[18] As such, we do not distinguish between no economic shocks and less-severe shocks. By limiting our focus to economic events that occur in the first 18 weeks of pregnancy, changes in intrauterine

[12]It is still possible for pregnancy to be a fundamental source of economic problems (which would represent a reverse-causal effect). However as our sample consists only of pregnant mothers this should not affect our parameter estimates.

[13]The correlation of 0.71 is fairly strong, as depicted in Figure 3 in the Appendix.

[14]Results based only on singleton births are available from the authors upon request. Since approximately 98% of out sample are single-birth outcomes the results are very similar to those reported below.

[15]Excluding these observations results (as expected) in slightly lower parameter estimates on our covariate of interest.

[16]The question is worded as *Since becoming pregnant: You had a major financial problem.* The ordinal response categories are as reproduced in the text.

[17]This financial-problems variable continues to be asked to the mother regularly following birth. In a related study Clark *et al.* (2017) use information on mothers' financial problems up to childhood age 11 to predict cognitive, behavioural and emotional-health outcomes at age around 16.

[18]As a robustness check we also used a coding where the occurrence of any shock (i.e. outcomes i-iv) was set equal to one. This specification yielded smaller effect sizes and was less often statistically significant when predicting head circumferences. For the sake of brevity we have not reported these results but they are available from the authors upon request

growth have enough time to affect child outcomes.[19] Approximately 4% of mothers experience such shocks in a given year, which gives us an intuitive guide to their magnitude - they can be regarded as one-in-twenty-five person-year occurrences.[20] Last, as the variable is subjective it picks up idiosyncratic phenomena such as personality, support structures and risk preferences, which may affect interpersonal comparability. However we do not regard this problem as too severe for two reasons. First, we emphasise that the variable is systematically correlated with other more objectively-defined socioeconomic indicators. Second, by stratifying our sample into relatively-homogeneous population subgroups based upon these indicators, we can remove heterogeneity in responses that occur across the groups.

ALSPAC also contains a large number of potential covariates, and our choice here is largely motivated by the exogeneity concerns highlighted in Angrist and Pischke (2009). Two basic sets of controls are used: a physiological set, which we regard as part of a critical core, and a set of economic and demographic variables that are useful for unravelling the effects of other social phenomena. We also look at the roles played by psychological factors (anxiety and depression scores) and behavioural factors (smoking and alcohol consumption). The physiological variables include the mother's age, height, and pre-pregnancy weight and Body Mass Index (BMI). The number of previous pregnancies and previous miscarriages are also included, alongside indicators of multiple births and whether the child is female. We also consider data on the father's height and weight in order to capture paternal genetic factors that may also influence the size of births.

Last, the socioeconomic controls include dummies for various educational attainments, home-ownership status and an index of absolute economic deprivation, which is a 0-15 aggregate of indicators of financial strain.[21] Given that our fundamental objective is to estimate the effect of a specific economic phenomenon on health outcomes, the way we control for these socioeconomic factors is important. Ideally, in certain models we would like to have available direct measures of economic circumstances, such as household income and the wealth and consumption of the mother. However as these do not appear in the early waves of ALSPAC we infer mothers' financial wellbeing by noting that education is a good predictor of lifelong income, home ownership serves as a proxy for wealth, and material deprivation is a measure of poverty.

[19] Our data set also contains another economic shock indicator that covers the latter half of the pregnancy from 18-32 weeks. Since shocks experienced in this interval are unlikely to have much of an effect on the size of the birth, we later use this indicator as a "placebo" treatment to test for appropriate identification in our models.

[20] Further intuition can be gained by expressing such a shock purely in terms of income. In BHPS data from 1991-1992, a one-in-twenty-five year shock involves a year-to-year reduction (in household post-fiscal equivalised terms) of around 52% - a figure that is relatively stable throughout the decade. Such a shock results in an average rank mobility transition (down the income distribution) of 34%.

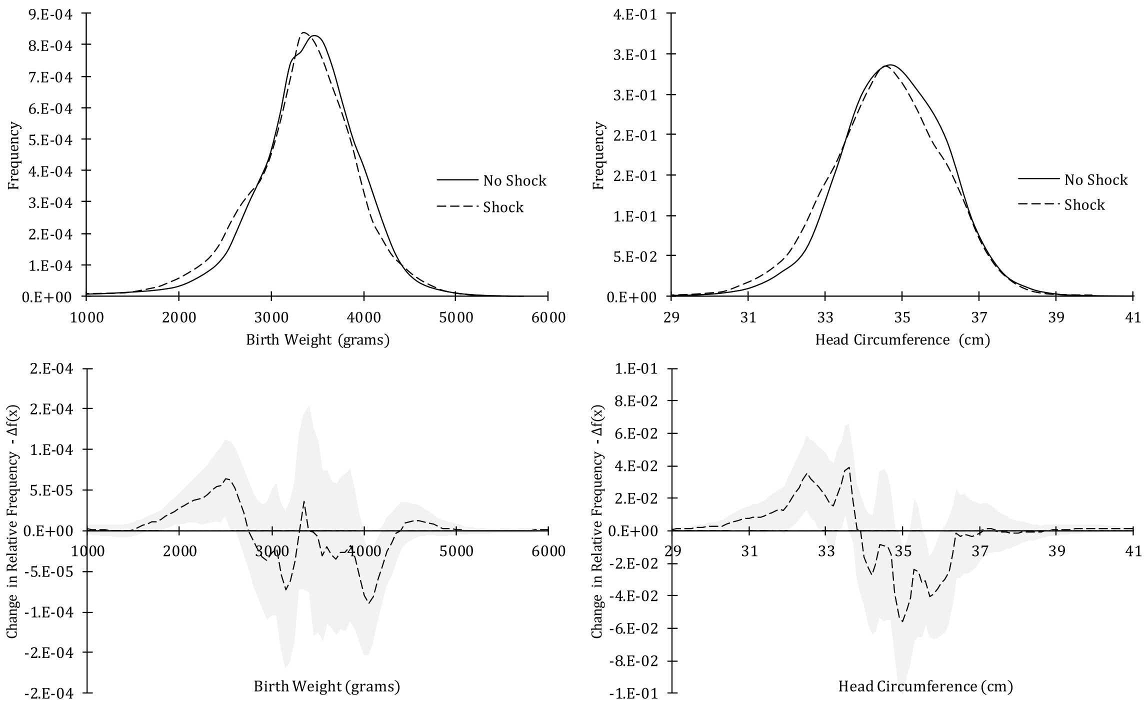
[21] This variable is obtained from five questions on the ease of which various household items can be purchased. The question is phrased *How difficult at the moment do you find it to afford these items: Food; Clothing; Heating; Rent or Mortgage; Things you will.* The four ordinal responses are: *(i) Very Difficult; (ii) Fairly Difficult; (iii) Slightly Difficult; and (iv) Not Difficult.* The responses are coded from 0-3 and aggregated such that higher values indicate greater levels of absolute deprivation.

2.1 Descriptive Analysis

We begin by depicting the data. Figure 1 presents estimates of the distributions of both birth weight and head circumference by the presence of a financial shock. These come from Gaussian Kernel Density Estimators (KDEs) using an adaptive bandwidth.[22] The left panel shows the density for birth weight and the right panel that for head circumference, where the solid lines depict outcomes for mothers who did not experience shocks and the dotted lines those who did. The bottom two panels show the differences in the densities between the two groups with 90% bootstrap confidence intervals in grey. The birth-weight data on the left show that mothers who experienced a prenatal economic shock had slightly but significantly lower probabilities of moderately heavy children (4000-4500 grams) and a higher probability of slightly underweight children (2000-2500 grams). However, the tails appear similar, suggesting that economic shocks may be unrelated to the more extreme outcomes at either end of the distribution. The results for head circumference in the right panels are approximately the same. The modal head circumference is almost identical for the two groups, and the tail outcomes also appear similar. However, there are differences in the number of slightly larger and slightly smaller than average outcomes. Again these changes are statistically significant, but only over some segments of the support range.

[22]This two-stage variable-bandwidth estimator is known to outperform fixed-bandwidth approaches in terms of Mean Integrated Squared Error (MISE). The first stage is a regular Gaussian KDE and is used to adjust the bandwidth of a second-stage estimator. This ensures that higher bandwidths are used in the tails where observations are scarce and lower bandwidths in the centre, which allows subtle distributional features to be captured.

Figure 1: Birth Weights and Head Circumferences by Gestational Financial Shocks



Note: The top two panels give adaptive kernel density estimates of birth weights and head circumferences for infants whose mothers did and did not experience economic shocks while pregnant. The dashed line depicts the former case and the solid line gives the latter. The lower two panels show the differences in these estimates with the 90% bootstrap confidence interval being depicted in grey.

Table 1: Descriptive Statistics: Key Variables

	Major Economic Shock			No Economic Shock			Full Sample		
	$\bar{x}$	$\hat{\sigma}_x$	n	$\bar{x}$	$\hat{\sigma}_x$	n	$\bar{x}$	$\hat{\sigma}_x$	n
Economic Shock	-	-	445	-	-	10108	0.042	0.201	10553
Birth Weight (gm)	3347	620.8	445	3403	568.8	10108	3399	571.3	11573
Head Circumference (cm)	34.52	1.917	335	34.78	1.574	7810	34.77	1.584	8938
Age	27.05	5.365	445	27.94	4.760	10108	27.87	4.861	11573
Height (m)	1.643	0.065	370	1.641	0.065	8917	1.641	0.065	10043
Pre-Pregnancy Weight (kg)	62.39	12.03	373	61.71	10.87	9014	61.72	10.95	10154
Pre-Pregnancy BMI	23.14	4.206	370	22.93	3.820	8917	22.93	3.839	10043
No. of miscarriages	0.335	0.699	445	0.286	0.667	10108	0.293	0.677	11573
1 Previous Pregnancy	0.330	0.471	445	0.325	0.468	10108	0.323	0.467	11573
2 Previous Pregnancies	0.220	0.415	445	0.184	0.388	10108	0.184	0.387	11573
3 Previous Pregnancies	0.117	0.322	445	0.091	0.288	10108	0.093	0.291	11573
4 Previous Pregnancies	0.045	0.207	445	0.034	0.180	10108	0.035	0.183	11573
>5 Previous Pregnancies	0.054	0.226	445	0.030	0.170	10108	0.033	0.178	11573
Twins	0.014	0.118	353	0.023	0.151	8815	0.022	0.147	9952
Infant Female	0.517	0.500	445	0.479	0.500	10108	0.481	0.500	11573
Partner Weight (kg)	79.34	13.81	218	78.09	11.43	6714	78.11	11.53	7407
Partner Height (cm)	1.759	0.071	217	176.0	6.969	6723	176.0	6.984	7415
Married	0.638	0.481	434	0.773	0.419	10030	0.758	0.428	11475
Single	0.265	0.442	434	0.175	0.380	10030	0.187	0.390	11475
Education - O/A Level	0.598	0.491	405	0.584	0.493	9519	0.578	0.494	10798
Education - Degree	0.091	0.288	405	0.133	0.340	9519	0.133	0.340	10798
Home Owned	0.577	0.495	442	0.768	0.422	10018	0.744	0.437	11472
Home Rented	0.387	0.488	442	0.203	0.403	10018	0.223	0.416	11472
Material Deprivation Score	7.057	4.225	404	2.637	3.327	9499	2.856	3.500	10551

Note: The table presents descriptive statistics on the key variables used in the analysis. The first three rows give the outcome variables and the economic shock indicator. The rest of the table refers to the control variables. The treated sub-sample is on the left, the untreated subsample in the centre and the results for the full sample are on the right.

The descriptive statistics for our key variables appear in Table 1. Average birth weight in the full sample is almost 3,400 grams with an average head circumference of close to 34.5cm. As expected from Figure 1, mothers who experienced economic shocks in the first 18 weeks had smaller infants on average. The gap in birth weight in our data is 44 grams and the differential in head circumference is around 2.5mm, although these differences partially reflect the effect of missing data. If assessed only across non-missing observations, we obtain gaps of 56 grams and 2.6mm respectively, both of which are statistically significant at the 10% level. To appreciate the size of these differences we note they correspond to about 10% of a standard deviation for weights and about 16% of a standard deviation for circumferences. The variation in outcomes is also higher for mothers who experienced these shocks, and we again can reject the null of no differences between the groups at the 5% significance level.[23] In terms of the other covariates, we note that the distributions are slightly different for the affected and unaffected mothers. Regarding

[23]We do not use observations where there are missing observations on economic shocks. Robust inference is used for differences in means while differences in variances are evaluated using Breusch-Pagan heteroskedasticity tests.

the physiological variables, affected mothers are slightly younger and have greater histories of miscarriage and fewer previous pregnancies. The socioeconomic differences between the two groups are more substantial, with the affected mothers having poorer socioeconomic outcomes in terms of education, home ownership and material-deprivation scores.

2.2 Birth Size and Teenage Health/Education Outcomes

To check that small birth size is linked to lower adolescent wellbeing in our data, Table 2 replicates some standard results in terms of cognitive/educational performance and general health (e.g. Bundervoet and Fransen, 2018).[24] We begin by stratifying the samples by size, using the standard definition of LBW as being under 2500gm, and by defining Low Head Circumference (LHC) as below 32.5cm. Both the LBW and LHC thresholds correspond to approximately the smallest 5% of births, and we note that the indicators are quite strongly correlated - 41% of infants classified as LBW or LHC were also small according to the other measure. These two variables are then matched to child health and educational performances at ages 15-16. The educational outcomes come from standardized High School test scores in English, Mathematics and Science, while the health indicators are BMI, a generic five-point self-rated health score, and outcomes from the 26-point Short-form Mood and Feelings Questionnaire (SMFQ). All variables are assumed to be cardinal (where higher values indicate better outcomes) and we calculate averages across groups. The top panel in Table 2 shows standardised (i.e. z-score) differences in means for LBW and LHC infants over the full sample, while the middle and bottom panels show the scores stratified by child gender.

Table 2: Differences in Cognitive and Health Outcomes for LBW and LHC Children at ages 15-16

Cognitive (Full Sample)	Birth Weight	Head Circ	Health (Full Sample)	Birth Weight	Head Circ
English Point Score	-0.1213**	-0.0380	Self Rated Health	0.0555	-0.0960
Math Point Score	-0.1560***	-0.0983**	Body Mass Index	-0.2287***	-0.1559**
Science Point Score	-0.1183**	-0.0351	Mood and Feelings	0.0096	-0.1251
Cognitive (Male)	Birth Weight	Head Circ	Health (Male)	Birth Weight	Head Circ
English Point Score	-0.1969***	-0.1745**	Self Rated Health	0.2913***	0.2101
Math Point Score	-0.0892	-0.0952	Body Mass Index	-0.4031***	-0.4248***
Science Point Score	-0.0573	-0.0440	Mood and Feelings	0.3855***	0.3046**
Cognitive (Female)	Birth Weight	Head Circ	Health (Female)	Birth Weight	Head Circ
English Point Score	-0.0473	0.0474	Self Rated Health	-0.0965	-0.2117**
Math Point Score	-0.2215***	-0.1002*	Body Mass Index	-0.0669	0.0168
Science Point Score	-0.1777**	-0.0295	Mood and Feelings	-0.1805	-0.2824**

Note: Each column gives the differential in standard deviations for health and educational outcomes between LBW and LHC births and the rest of the sample. *, ** and *** denote significance at 10%, 5% and 1% respectively.

[24]We also ran regressions examining whether these outcome variables are also predicted by prenatal economic shocks. While our parameter estimates are of the expected signs (affected mothers had children with poorer health and educational outcomes) the correlations were not significant at standard levels.

The first column shows that LBW children perform substantially below their peers in terms of cognitive outcomes, with average scores that are 0.12-0.16 standard deviations below the sample means. This gap is largest for Mathematics as compared to English or Science, although the relative magnitudes are similar. LHC children also underperformed across all the three subjects, although the differentials are smaller and less often statistically significant. Stratifying by gender we see that male LBW/LHC births were most disadvantaged in English, while for girls the biggest differential was in Mathematics. Nonetheless, the aggregate figure over all cognitive indicators suggests the disadvantage associated with small birth size is probably slightly larger for males. The results for the health indicators are ambiguous - there are no significant differences in the self-rated overall and psychological health scores between either LBW or LHC births and the others, although there are some significant differences by gender.[25] Conversely there are meaningful gaps for BMI with smaller births corresponding to significantly lower teenage BMI figures. This partly reflects a left-tail phenomenon: LBW and LHC children were 5-6% more likely to be underweight (BMI<18.5) than the rest of the sample.[26]

2.3 Missing Values and Imputation

Finally, an inspection of the other covariates in Table 1 reveals that missing data may well affect our analysis. This is to be expected given the construction of the survey - the subjects are all expecting mothers and the instrument requires repeated follow-ups involving a range of very personal questions. We restrict ourselves to an estimation sample with 11,573 observations on birth weights and 8,938 on head measurements obtained from the full data set outlined above (note that we have additional missing values on head circumferences due to this variable being less frequently recorded). At first glance this looks like a large data set - around ten times the size of the sample in Dooley and Prause (2005) and almost twice that in Margerison-Zilko *et al.* (2011). However, considering data points without missing information these sample sizes fall to 8,021 and 6,339. In other words, around 30% of our observations have missing values on at least one covariate.

A relatively high proportion of missing data can pose problems for the econometric analysis in two ways. First, the pattern of missing data may be systematic, where the failure to respond is a function of the mother's observed or unobserved attributes. Selection on this basis will produce a sub-sample that is not representative of the underlying population. Second, ignoring observations with missing values wastes valuable information, which is important when looking for potentially subtle phenomena in what is (by some microeconometric standards) a reasonably small sample. We

[25] Other work has however found associations between small birth size and diminished mental health (Mathewson et al. 2017).
[26] Correlations have also been found between birth weight and obesity later in life, see the review by Yu et al. (2011) for details.

tackle this problem by producing estimates based on case-wise deletion (i.e. taking the standard approach of ignoring missing data), multiple imputation, and the missing-indicator method (where missing values are replaced by the variable mean and a dummy variable indicating that the value for that variable in that observation is missing). For the sake of brevity we here only report the results from multiple imputation, but note that those from the other two approaches are generally similar.[27]

3 Baseline Estimations

We here estimate the effects of economic shocks during pregnancy on child birth outcomes, controlling for the presence of a number of potential confounding factors. The basic equation is given below, where H is a health outcome (normalised so that all coefficients are interpreted as standard-deviation changes), X a $n \times k$ matrix of assumedly exogenous control variables, s a dummy for having experienced an economic shock and ε an error term.

$$H = \alpha + X\beta + \phi s + \varepsilon. \tag{1}$$

The parameters α, β and ϕ are estimated by OLS with heteroskedasticity-robust standard errors. We omit the standard errors for the sake of brevity (although statistical significance is denoted in the usual way) but have made the full models available upon request.

We have six different specifications - three with birth weight as the health outcome and three with head circumferences. The first estimation in each set excludes the controls and measures the bivariate association between H and s. The second then includes biological control variables, such as mother's age, height, weight and birth history, while the third adds markers of socioeconomic welfare (education, marital status, home-ownership of the mother and the material-deprivation score).

[27] The multiple-imputation technique we employ is based on multivariate normal regression, a technique which handles any arbitrary (non-monotone) pattern of missing data. The technique assumes multivariate normality in the distribution of X and hence is more appropriate when all variables are continuous. Other methods such as chained imputation with logit models for binary variables were not used due to perfect prediction problems in some regressions. Estimates based upon alternative missing data approaches are available upon request.

Table 3: Birth Outcomes and Economic Shocks:- Regression Models

	Birth Weight			Head Circumference		
	Model (1)	Model (2)	Model (3)	Model (1)	Model (2)	Model (3)
Prenatal Economic Shock (gm/cm)	-61.67**	-77.09***	-57.67**	-0.268***	-0.266***	-0.215**
Prenatal Economic Shock (SD)	-0.108**	-0.135***	-0.101**	-0.169***	-0.168***	-0.136**
Age		0.049***	0.010		0.014	-0.006
Age-Squared/100		-0.074**	-0.019		0.009	0.017
Height		1.134	0.959		0.087	-0.063
Pre-pregnancy weight (kg)		0.020*	0.021*		0.022*	0.023*
Pre-pregnancy BMI		-0.018	-0.020		-0.032	-0.034
No. of miscarriages		-0.050***	-0.060***		-0.023	-0.030
1 Previous Pregnancy		0.228***	0.244***		0.075**	0.092***
2 Previous Pregnancies		0.289***	0.322***		0.080**	0.111***
3 Previous Pregnancies		0.302***	0.360***		0.081*	0.132***
4 Previous Pregnancies		0.269***	0.354***		-0.011	0.056
>5 Previous Pregnancies		0.153**	0.245***		0.029	0.106
Twins		-1.314***	-1.308***		-0.925***	-0.925***
Infant Female		-0.181***	-0.183***		-0.419***	-0.421***
Partner Weight (kg)		0.003**	0.003**		0.004***	0.004***
Partner Height (m)		0.006***	0.005***		0.002	0.001
Married			0.092**			0.028
Single			0.033			0.030
Education - O/A Level			0.057**			0.050*
Education - Degree			0.134***			0.131**
Home Owned			0.110**			0.063
Home Rented			0.031			0.008
Material Deprivation Score			-0.004			-0.005
Constant	0.005	-4.773***	-3.918***	0.007	-1.521	-0.922
Pseudo R^2	0.034%	9.923%	10.26%	0.185%	9.181%	9.320%
F	4.40	82.27	59.75	6.93	51.97	38.07
N	11573	11573	11573	8938	8938	8938

Note: The table contains estimates of the determinants of birth weight and head circumference as per EQ (1). The first three columns present results for birth weight while head circumference is given in the latter three. Model (1) only includes the treatment dummy while Model (2) uses a variety of physiological controls. Model (3) employs both socioeconomic and physiological controls. Dummy variables are defined relative to a reference individual who has not experienced an economic shock, has had no previous pregnancies and gives birth to a single male child. This individual is without O/A levels and is mortgaging their home. Standard errors are based upon White (1980) robust covariance and the symbols *, ** and *** denote significance at 10%, 5% and 1% respectively.

The estimates in Table 3 provide baseline evidence for a negative relationship between individual economic shocks and foetal health. The key estimates appear in the first two rows, which show the effect sizes in (i) natural units and (ii) standard deviations. The estimates in the first columns (Model 1) replicate the raw differential in birth weights between mothers who experienced a shock and those who did not,[28] while the second column (Model 2) presents the same estimates while controlling for the physiological details of both the mother and the pregnancy. The second column of Table 3 shows that, within physiologically-similar mothers/pregnancies, those who experienced prenatal shocks had children who weighed around 77 grams less at birth (14% of a standard deviation) with head circumferences that were 2.7 millimetres (17% of a standard deviation) smaller

[28]Note that the small difference in estimates here is due to the imputation process we use for these regressions.

than the rest of the sample.

The third column (Model 3) shows how these estimated coefficients change when we introduce controls for socioeconomic indicators. The estimated coefficients here are a little smaller than those in column (2), but not strikingly so and remain significant. Economic shocks then translate into lower birth weights of around 60-70gms and smaller head circumferences of 2-3mm.[29] To put these results into context, we later estimate the respective effects of maternal smoking to be around 220gms and 4mm. Multiplying each parameter estimate by the incidence of the variable reveals that the aggregate reduction in birth weight due to economic shocks is approximately 5% of that due to cigarette consumption, with an analogous figure for head circumference of around 10%. Our economic shock indicator is therefore less important for birth outcomes than smoking, but the estimates remain large enough to be economically meaningful. If all mothers were exposed to economic shocks within the first 18 weeks of gestation, we predict that the incidence of LBW children would rise by almost 18 percentage points.

Turning to the other estimates, we see that the coefficients on the other variables are broadly similar for the two outcomes. The standardized impact of economic shocks is a little larger for head circumference, but the size and significance of most of the other variables are sharper for birth weight. Maternal age is correlated with birth weight but not head circumference, and only matters through its correlation with social factors. Previous birth histories (the number of prior miscarriages and pregnancies) are stronger determinants of birth weight, as is the case for the socioeconomic indicators. As such, birth weights seem to be more sensitive to both biological variations and changes in the mother's economic environment, which can also be seen in the slightly higher pseudo-R^2 figures (the squared correlations between the predicted and actual values averaged over all imputation rounds) between the models.

3.1 Identification Diagnostics

Finally, in order to be useful for policy-making it is important that the estimates above reflect an underlying causal relationship. We emphasise again that, by design, the regressions control for reverse-causality associated with childbirth (although not early pregnancy) and some types of endogenous selection. However, there are other threats to appropriate identification, such as unobserved heterogeneity correlated with our shock variable. In this section we consider (i) covariate balance, (ii) employ placebo regressions, and (iii) study the likely influence of unobservables, as diagnostics for our regression models.

[29]Some estimates for birth weights presented later in the paper produce slightly smaller effect sizes, which is why we report our main result to be a range from 40-70gms.

Covariate Balance

One major identification issue is the possibility that the mothers who experienced economic shocks might simply differ systematically (especially along biological lines) from those who did not. Such differences may invalidate our treatment-control interpretation of the estimates in Table 3 (Pei *et al.*, 2019). However, as apparent in Table 1, there is little evidence that affected and unaffected mothers vary substantially along observable lines. This is consistent with the treatment-assignment being only weakly determined by factors that may otherwise impact upon birth weight or head circumference. To investigate in more detail, Table 15 (in the Appendix) estimates models of the form $s = X\theta + v$ (i.e. linear-probability models for the presence of a shock, where X represents the covariates in EQ (1)). Figures 5-7 (also in the Appendix) also shows the densities depicting the balance in our key variables.

In our full model there is no evidence of systematic differences between affected and unaffected mothers along our pre-treatment biological dimensions. None of our biometric variables are significantly related to experiencing a shock, and from the reduced model (which only contains biological variables), our R-Squared terms indicate that less than 1% of the variation in occurrence of shocks is explained by these factors. Some significant correlations do exist for our socioeconomic variables, most notably the measure of maternal financial deprivation. Mothers that were poorer to start with were more likely to experience a shock (there were also correlations that were significant at 10% for our education variables), and the distribution of this control variable is notably different (see Figure 6). It is thus possible that these mothers were economically disadvantaged in unobservable ways prior to pregnancy, which may also feed into pre-natal health. Nonetheless (as we outline below), controlling for the observable facets of socioeconomic status, which may only partially capture true material wellbeing, has very little influence over our estimates, which suggests that this channel is not meaningfully affecting our results.

Unobservable Factors

While there is little evidence of covariate imbalance between mothers who were affected/unaffected by prenatal shocks, there is always the possibility that there are meaningful unobservable differences between the groups. If uncontrolled, these factors could plausibly bias the parameter estimates in Table 3. However, informal evidence from this table also suggests that unobservables are unlikely to play a major role in determining outcomes. Our assessment method here comes from Altojoni *et al.* (2005) and Nunn and Wantchekon (2011), who examine the stability of regression coefficients once observable factors are added to the model. The intuition is that if our coefficient of interest is stable after adjusting for confounders that we do observe (and if these factors also improve the model fit), then it is unlikely that unobservable confounders would be sufficient to reverse these effects. To proceed, we take the ϕ coefficients from Table 3 estimated in the presence of full controls, limited controls, and no controls, and determine the ratios $\hat{\phi}^F / \left(\hat{\phi}^R - \hat{\phi}^F\right)$, where $\hat{\phi}^F$ denotes the estimate from the full model and $\hat{\phi}^R$ that from the restricted model. This quantity therefore calculates how important unobservable factors must be (relative to observables) in order to explain away our effect sizes. Our estimates for both birth weight and head circumference are stable, producing ratios of {14.42; 2.97} for birth weight and {4.06; 4.22} for head circumference. All are greater than one, and generally exceed the benchmark value of three, indicating that unobservable factors would have to have an influence that is many times larger (and in an offsetting direction) in order to undo our results.

A similar method proposed by Oster (2019) evaluates the influence of unobservables required to reduce effect sizes to zero, scaled by the relative change in fit according to the R^2 term. Under two scenarios (where $R^2_{max} = 1$ and $R^2_{max} = 1.3R^2$) we estimate (using our full models) these terms to be {1.98, 32.94} for birth weight and {0.468 and 12.20} for head circumference. Again these indicate that unobservables are unlikely to be sufficient to explain away our estimates, bar the initial estimate for head circumference.

Placebo Regressions

As a final informal diagnostic, we repeat the estimations from Table 3 but also include an alternative economic-shock indicator which only considers experiences from the second half (i.e. from 18-32 weeks) of the pregnancy. The idea here is to reinforce the above findings via a set of "placebo" regressions, where if operating as expected, our assumed causal mechanism should produce smaller effect sizes. As we have excluded premature births, economic shocks must operate via intrauterine growth restrictions, which is why shocks during the later stages of pregnancy should have smaller effects.[30] While it is possible that latter shocks do not offer much time for a foetus to recover (which would predict smaller birth sizes), we argue that the slow nature of infant growth makes this unlikely relative to the former effect. Therefore if we observe that the ϕ coefficients either rise or do not fall in size for shocks closer to birth, this would suggest that some other unobserved factor(s) correlated with our economic-shock variables may be behind the results.

[30] As major economic shocks are typically slowly resolved, this approach effectively assumes that a shock restricts growth for the remainder of the pregnancy.

Table 4: Birth Outcomes and Economic Shocks:- 0-18 Weeks vs 18-32 Weeks

	Birth Weight			Head Circumference		
	Model (1)	Model (2)	Model (3)	Model (1)	Model (2)	Model (3)
Shock 0-18 Weeks (gm/cm)	-55.01*	-63.51**	-49.88*	-0.243**	-0.227**	-0.192*
Shock 0-18 Weeks (SD)	-0.096*	-0.111**	-0.087*	-0.154**	-0.143**	-0.121*
Shock 18-32 Weeks (gm/cm)	-26.84	-55.21*	-40.32	-0.097	-0.151*	-0.115
Shock 18-32 Weeks (SD)	-0.047	-0.097*	-0.071	-0.061	-0.095*	-0.072

Note: The table contains estimates of the effects of economic shocks occurring from (i) 0-18 weeks and (ii) 18-32 weeks. The model specifications (1-3) are as above. The first two rows give estimates on the earlier shocks (in gm/cm and then standard deviations) and the bottom two rows present results for the latter shocks. Standard errors are based upon White (1980) robust covariance and symbols *, ** and *** denote significance at 10%, 5% and 1% respectively.

The key estimates from these regressions are presented in Table 4. Across all three models for both birth indicators, we see smaller effect sizes (i.e. estimates that are closer to zero) for shocks occurring nearer to birth. This is therefore consistent with our assumed process where our economic events negatively affect foetal growth rates. Notably the estimates for the second half of the pregnancy are on average around 40% smaller, and much less statistically significant than those in the first half. As infant growth tends to rise with gestational time (Kiserud *et al.*, 2018) we expect to see a greater fraction of total growth in the latter period, and therefore if our estimates are causal and act uniformly over the pregnancy, they should be reduced in magnitude. Given that(i) our results line up closely with expectations, and (ii) are also broadly consistent in size to those found in the quasi-experimental literature (Almond *et al.*, 2011; Bozzoli and Quintana-Domeque, 2014; Burlando, 2014; Carlson, 2015) this leads us to suggest that the estimates reflect a causal relationship.

3.2 Quantile Regressions

The above models produce singular scalar estimates over the distributions of our outcome variables. We now consider the possibility of varying effect sizes, and estimate quantile regressions with the same sets of covariates as in Table 3. Parameters may vary naturally with the size of the birth as reductions are likely to have greater health impacts when they occur at the lower tails of the distributions. Further, from the plots in Figure 1, it appears that the affected and unaffected densities diverge in ways that vary across the outcome distributions. To study this phenomenon, we use the conditional quantile estimator (as opposed to the unconditional estimator of Firpo *et al.*, 2009), as we need to define smaller births with respect to certain factors such as child gender.

Figure 4 in the Appendix shows the estimated effect sizes in standardised units, where each horizontal axis shows the quantile of interest and the vertical axis the impact of the shock for births at that point. A number of stylised facts emerge. First, the point estimates are negative for all regressions for virtually all quantiles (marginally positive values are obtained for quantiles near

100) and it thus seems likely that economic shocks reduce birth size throughout the size distribution. Second, these estimates are stronger for smaller weights and circumferences, and become closer to zero for higher quantiles. Third, the estimates are normally only significantly different from zero for births from around the 10th to the 50th percentile in terms of weight, and the 10th to the 40th percentile for circumferences (note that these values vary somewhat according to the model). We thus identify meaningful impacts for births that were already fairly small, which is somewhat in line with the diminished probability density for these outcomes in Figure 1 above. The increased effect-sizes at the low end are also likely to be meaningful for the frequency of very small outcomes. If we recalculate the increase in LBW infants subject to all mothers being affected, the rate is expected to rise by 25%, rather than by 18% as indicated by the linear model above.[31]

4 Potential Transmission Channels

4.1 Absolute Deprivation

One notable feature of Table 3 is that the socioeconomic controls in Model (3) partially capture the economic wellbeing of mothers, which will itself be at least temporarily affected by major economic shocks. The estimates of ϕ in these models do not then reflect low material wellbeing *per se*, but rather the impact of major economic events conditional on the mother's level of socioeconomic resources. Since the estimated ϕ parameters for both weight and circumference remain significant and are only a little smaller than those in Model (2), we may then be capturing some form of *stress* effect along the lines raised in the introduction, rather than a *deprivation* effect. This idea is further reinforced by the fact that our shocks are only moderately associated with our other indicators of socioeconomic status.[32]

However, as our measures of absolute material wellbeing are imperfect, the estimates from Model (3) could still reflect short-term absolute economic hardship. This deprivation hypothesis is supported by previous empirical research on socioeconomic status and newborn health (Currie, 2003; 2009; Currie and Moretti, 2008; Spencer *et al.*, 1999), and in our models we do find that absolute material wellbeing predicts better birth outcomes. That is, both birth weight and head circumference rise with education and home ownership, and decline with material deprivation. Since more financially-comfortable mothers have larger births, it is therefore possible that shocks that lower material wellbeing might still operate directly by limiting consumption.

[31] These values are obtained by determining the fraction of our sample that were born within the interval between 2,500gm and the estimated effect sizes. For the quantile estimates the conditional quantile is obtained for each individual via their residual term.

[32] The correlations between shocks and having a degree, owning a home and our material-deprivation count are -0.019, -0.078 and 0.240 respectively.

To distinguish between these channels, we ask whether the shock effects are larger for mothers towards the bottom of the socioeconomic scale. If shocks reduce health through consumption constraints, we would expect to see larger effects for mothers who are less well-off, and therefore more likely to experience absolute economic hardship (i.e. we assume that infant health is a concave function of access to resources). If the effect is not larger for economically-disadvantaged mothers, absolute material deprivation would not seem to be an important factor in the transmission of these shocks.[33]

We proceed by stratifying our sample into two groups using the resource variables in Table 1: (i) the material-deprivation score, (ii) home-ownership dummies and (iii) education. As these variables can all be thought of as indicators of a latent socioeconomic scale we also carry out a factor analysis of (i)-(iii) to create a fourth summary indicator. We then define a series of dummy variables m_j for the mother being in the higher material-wellbeing group for indicator j. As our variables are ordinal and take on only a limited number of integer values, 50/50 splits are generally not possible here: our high-status groups typically contain about three-quarters of our sample, and we hence estimate whether economic shocks have a greater impact on the bottom 25% of mothers.

The general equation below is again estimated by OLS using robust covariance for inference

$$H = \alpha + X\beta + \phi s + \gamma m_j \times s + \varepsilon. \tag{2}$$

The parameter ϕ now captures the effect of the economic shock for mothers in the disadvantaged groups, while γ is the interaction term which measures the degree of protection provided by belonging to the higher-status group according to j. Tables 5 and 6 below present the results.

[33] While finding stronger effects at the bottom of the socioeconomic scale is consistent with a deprivation effect, other channels may also be at work. For example, shocks might be more stressful or may provoke different responses for poorer mothers. However, the existing literature suggests that economic shocks are only slightly more harmful for the poorer (Rohde *et al.*, 2016), likely due to the importance of adaptive or peer-group comparison effects (Clark *et al.*, 2008). A second potential explanation here is that there might be some heterogeneity in what defines shocks over different population subsections. Poorer mothers might have different interpretations of the term than richer mothers, and it may hence be the type of shock (one that occurs more readily at the lower end of the socioeconomic scale) that matters. If this is the case then a stratified approach can be seen as picking up this type of response heterogeneity.

Table 5: Interaction Effects:- Economic Shocks and Birth Weight by Socioeconomic Status

	Model (1)	Model (2)	Model (3)	Model (4)
Economic Shock (ES)	-0.219***	-0.292***	-0.243***	-0.275***
ES×Low Economic Deprivation	0.178*			
ES×Home Ownership		0.274***		
ES×High Education			0.159	
ES×Factor V1-V3				0.233**
Physiological Controls	Y	Y	Y	Y
Socioeconomic Controls	N	N	N	N
Economic Shock (ES)	-0.171**	-0.218**	-0.167	-0.195**
ES×Low Economic Deprivation	0.140			
ES×Home Ownership		0.202*		
ES×High Education			0.097	
ES×Factor V1-V3				0.152
Physiological Controls	Y	Y	Y	Y
Socioeconomic Controls	Y	Y	Y	Y

Note: The table presents results based upon EQ (1) where birth weight is regressed against economic shocks and interaction terms. Models (1)-(4) employ indicators of high status on the basis of (i) a low material deprivation score, (ii) home ownership, (iii) a high educational attainment, and (iv) the first factor from a correspondence analysis of indicators (i)-(iii). Physiological controls are used in the top panel and both physiological and socioeconomic controls are used in the bottom panel. Standard errors are based upon White (1980) robust covariance and symbols *, ** and *** denote significance at 10%, 5% and 1% respectively.

In Table 5 the effect of shocks on birth weight is much smaller for mothers with higher education (either having completed some tertiary education or with a degree) or who are wealthy enough to either have bought or be buying their homes. The effect sizes for less-advantaged women range from -0.17 to -0.29 standard deviations per shock (95-165 grams) depending on the regression controls. Conversely, the estimated effect sizes for higher-status women are effectively zero: in most cases $\hat{\gamma} \approx -\hat{\phi}$ so that higher status almost completely protects against negative shocks. The estimates of γ are routinely positive and generally significant across the models.

The estimates in Table 6 tell a similar story for head circumference, with the effect size rising to -0.18 to -0.34 of a standard deviation (2.8 to 5.4mm) for low-status groups but dropping to zero for the higher-status groups. Again, mothers who are wealthy enough to be buying their own homes or who do not face high levels of material deprivation are almost entirely protected, a result also echoed in the summary indicator. The estimates for education are along the same lines, although the result falls just short of significance at standard levels. Overall, the general robustness of these estimates across birth outcomes, model specifications and status indicators appears to confirm that higher socioeconomic status moderates the effect of negative financial shocks.

The underlying relationship between material wellbeing and birth outcomes identified here is of substantial interest. Other research has uncovered this relationship in poorer and middle-income

Table 6: Interaction Effects:- Economic Shocks and Head Circumference by Socioeconomic Status

	Model (1)	Model (2)	Model (3)	Model (4)
Economic Shock (ES)	-0.293***	-0.324***	-0.250**	-0.342***
ES×Low Economic Deprivation	0.264*			
ES×Home Ownership		0.276**		
ES×High Education			0.124	
ES×Factor V1-V3				0.296**
Physiological Controls	Y	Y	Y	Y
Socioeconomic Controls	N	N	N	N
Economic Shock (ES)	-0.251**	-0.274**	-0.183	-0.281**
ES×Low Economic Deprivation	0.229			
ES×Home Ownership		0.241*		
ES×High Education			0.071	
ES×Factor V1-V3				0.240*
Physiological Controls	Y	Y	Y	Y
Socioeconomic Controls	Y	Y	Y	Y

Note: The table presents results based upon EQ (1) where birth weight is regressed against economic shocks and interaction terms. Models (1)-(4) employ indicators of high status on the basis of (i) a low material deprivation score, (ii) home ownership, (iii) a high educational attainment, and (iv) the first factor from a correspondence analysis of indicators (i)-(iii). Physiological controls are used in the top panel and both physiological and socioeconomic controls are used in the bottom panel. Standard errors are based upon White (1980) robust covariance and symbols *, ** and *** denote significance at 10%, 5% and 1% respectively.

countries (e.g. Bozzoli and Quintana-Domeque, 2014), with the proposed mechanism focusing on maternal nutrition. As our data refer to a high-income country and our sample is richer than the UK average, we do not expect malnutrition to be an important channel. However, variations on this theme may well apply in higher-income situations. One possibility is that nutritional quality also matters, with economic shocks shifting dietary composition towards cheaper and less-nourishing foods. The US empirical literature has established links between low income and poor diet, where volume and caloric content are appropriate but the quality or range of foods is reduced (Drewnowski and Specter, 2004; Darmon and Drewnowski, 2008). For this to explain our results, there must also be a link between diet quality and birth outcomes for richer countries, as found by Abu-Saad and Fraser (2010).

A second plausible explanation for this phenomenon in richer countries is unequal access to healthcare services. Although the UK has an extensive public-health system, factors such as uncertainty over out-of-pocket expenses or disproportionate needs due to a lack of preventative care can produce socioeconomic gradients in access rates (Goddard and Smith, 2001). If an economic shock causes expectant mothers to eschew potentially costly healthcare, then preventable physiological conditions that also affect birth weight such as anaemia, intrauterine infection and hypertension may be partially responsible for our results. Notably, however, any such effect is likely to be stronger than our data suggest, due to the observer effect in the collection of the data. As ALSPAC carefully monitored maternal health through the gestational period, these mothers would have been less likely than the UK population as a whole to be affected by avoidable medical conditions.

4.2 Other Potential Transmission Channels

We now turn to the two additional hypotheses that were mentioned in the introduction - that our correlations could operate either via the mental health of the mother (i.e. a stress effect) or through behaviours such as smoking and alcohol use. These are plausible mechanisms - stress is known to have a number of endocrinological effects, and smoking and alcohol consumption are well-established determinants of poor foetal health.

To determine whether the effect of economic shocks is mediated by mental health or maladaptive behaviours, we re-specify our Table 3 models to include these variables as controls. Including post-treatment controls in regression equations thus alters the interpretation of our parameter estimates, as part of our causal affects are diverted through the mediating variable (Angrist and Pischke, 2009). This is undesirable when identifying a singular treatment effect (see the literature on "bad controls"), but suitable for performing path-based decompositions, subject to the assumption of zero covariance between the errors in our full model and that for the treatment assignment. In our cases, if the ϕ coefficients are unaffected by the inclusion of potential mediators, the shocks do not transmit via these channels. Conversely if a ϕ estimate declines to zero then economic shocks only matter in that (i) they produce that mediating factor and (ii) the mediator influences the outcome.

A drawback of this approach however is that it relies upon two-part causal mechanisms that are difficult to estimate in cross-sectional data. That is, we are not able to determine how much the associations between economic shocks and mediating factors reflect the direct responses of the latter to the former. However, the previous literature has shown that causal flows from shocks to our potential intermediates are generally plausible. Links between adverse economic events and diminished mental health have been documented by a variety of authors (e.g. Brand, 2015; Catalano, 1991; Watson and Osberg, 2019) and the relationship appears to be causal. It similarly seems plausible that negative health behaviours be causally induced by economic shocks. For example Currie *et al.* (2015) show that the Great Recession promoted smoking and drinking in US mothers (which go on to harm health (Hadju and Hadju, 2018)), while Adda *et al.* (2009) find similar behavioural results associated with drops in income. Nonetheless this link is not without ambiguity, e.g. Ruhm (2000) observes that recessions in the 1970s and 1980s appeared to improve maternal health behaviour, and Apouey and Clark (2015) find that positive income shocks predicted poorer behaviours in panel data.[34]

[34] Note that the findings of Adda *et al.* (2009) and Apouey and Clark (2015) can be reconciled if it is the disturbance associated with

To examine these potential channels we consider additional variables from the ALSPAC survey. The mental-health measures we use come from the Crown Crisp Experiential Index (CCEI) for anxiety and depression. Formally known as the Middlesex Hospital Questionnaire, the CCEI scales are aggregates from 0-16 of Yes/No and Likert scores designed to measure neurotic psychopathology (Crown and Crisp, 1966). Both the anxiety and depression sub-scales are used, but we omit the somatic variable. Maternal behaviour is measured by dummy variables for alcohol and tobacco consumption - by construction these capture the extensive but not the intensive margins of use. Both of these variables are reported twice - in the first 18 weeks of gestation (from the same survey wave as our shock measure) and afterwards in the last eight weeks.

Table 7 shows the average scores of these variables for mothers who did and did not experience economic shocks, with the raw scores in the first two rows and the standardized averages in the bottom rows. Affected mothers had much higher levels of anxiety and depression on the CCEI scales, with raw scores 60-70% higher than those in the unaffected group, and slightly greater differentials for anxiety. Similarly, around 45% of affected mothers smoked cigarettes in either period compared to about 25% for those who did not experience economic shocks. Just over 50% of mothers consumed alcohol in either period, with only slight (insignificant) differences between the groups. Anxiety, depression and tobacco consumption also increase with gestational time while alcohol consumption fell.

Table 7: Average Behavioural Indicators and Mental Health Aggregates

	CCEI Anxiety		CCEI Depression		Tobacco Consumption		Alcohol Consumption	
	18 weeks	32 Weeks	18 Weeks	32 Weeks	18 Weeks	28 Weeks	18 Weeks	28 Weeks
No Shock	4.720***	4.939***	4.259***	4.848***	0.229***	0.265***	0.542***	0.512
18 Week Shock	8.127***	7.829***	7.080***	7.294***	0.452***	0.465***	0.596***	0.514
No Shock (sd)	-0.041***	-0.038***	-0.041***	-0.040***	-0.030***	-0.037***	-0.006***	0.003
18 Week Shock (sd)	0.924***	0.769***	0.879***	0.714***	0.489***	0.408***	0102***	0.006

Note: Each row gives either the sample average or the normalized average calculated from a z transformation. Hypothesis tests are for significant differences across affected and unaffected groups and are based upon robust covariance. *, ** and *** denote 10%, 5% and 1% significance.

We first consider the mental-health aggregates, which will capture physiological stress responses (Agarwal, *et al.*, 2016). The estimates in the middle three columns of Table 8 reveal that the inclusion of these variables has fairly little impact on our main parameter estimates. The standard-deviation point estimates for our three birth-weight models without the mental-health mediators are {-0.108, -0.135, -0.101}, which with these variables become {-0.085, -0.121, -0.095}. The analogous changes for head circumference are from {-0.169, -0.168, -0.136} to {-0.155, -0.162, -0.137}. Thus across all six models there is little mediation via maternal anxiety or depression -

a shock, rather than the pecuniary effect, that matters for behaviour. Further evidence from more recent economic cycles indicates that these aggregate-level shocks have had no effect (Ruhm, 2015) or have had harmful effects (Currie *et al.*, 2015) on health.

the effect sizes are essentially unchanged. Further, these variables themselves are not predictive of birth outcomes once the biological, economic and demographic factors are taken into account (see Table 13 in the Appendix). Their coefficients are invariably small, only rarely significant and are usually of opposing (offsetting) signs.

The fact that maternal anxiety/depression does not predict foetal health is important, as it means that there is no capacity in our models for flow-on effects via these variables. Therefore, regardless of the causality of economic shocks and mothers' mental health, the relationship must operate through different channels as there is no secondary link from mental health to birth outcomes. Thus while the medical literature on birth-outcome results does suggest that mental health plays a role, our results are more in line with Currie and Rossin-Slater (2013), Black *et al.* (2016) and Persson and Rossin-Slater (2018), who use natural experiments created by hurricanes or unexpected deaths and find relatively little (or even negligible) stress effects on birth weights.[35] Further, while weak bivariate associations between birth sizes and depression/anxiety are found in Field *et al.* (2004) and are also present in our data, these associations evaporate once physical characteristics are controlled for.[36]

Table 8: Transmission Effects and Birth Outcomes

	Original Estimates			MH Factors			Behavioural Factors		
Birth Weight (gm)	-61.67**	-77.09***	-57.67**	-48.56	-69.13**	-54.27*	-11.71	-41.16	-40.96
Birth Weight (sd)	-0.108**	-0.135***	-0.101**	-0.085	-0.121**	-0.095*	-0.021	-0.072	-0.072
Head Circ (cm)	-0.268***	-0.266***	-0.215**	-0.246**	-0.257***	-0.217**	-0.182*	-0.204**	-0.190*
Head Circ (sd)	-0.169***	-0.168***	-0.136**	-0.155**	-0.162***	-0.137**	-0.115*	-0.129**	-0.120*
Biological Controls	N	Y	Y	N	Y	Y	N	Y	Y
Soc/Econ Controls	N	N	Y	N	N	Y	N	N	Y

Note: The first two columns show the original estimates controlling for (i) physiological factors and (ii) both physiological and socioeconomic factors. The estimates in the second two columns include the behavioural variables as additional controls, while the final two columns include mental health controls for anxiety and depression. *, ** and *** denote significance at 10%, 5% and 1%.

The transmission effect of smoking and alcohol consumption appears in the last three columns of Table 8. Here the changes in the effect sizes are larger. The standard-deviation point estimates in the birth-weight models are again {-0.103, -0.128, -0.101} prior to the inclusion of these behavioural factors, but fall to {-0.021, -0.072, -0.072} afterwards. In the first case approximately 80% of the estimated effect size disappears once tobacco and alcohol consumption are included, while in the second and third cases the drops are around 45% and 30%. For head circumference the coefficient changes are a little smaller, with initial point estimates of {-0.169, -0.168, -0.136} and mediated effect sizes of {-0.115, -0.129, -0.120}. Here tobacco and alcohol use accounts for 32%, 25% and 12% of the original estimates. Hence over both outcomes, controlling for these factors implies

[35] Other contributions have found more sizable impacts, e.g. Carlson (2018) and Camacho (2008).

[36] Also see Andersson et al. (2004).

slightly smaller effect sizes, in the vicinity of 40gm and 2mm, rather than the 50-70 and 2-3mm as reported in Table 3.

The interpretation of these results is a little more complex than that of the mental-health variables. From our estimates it appears that maladaptive maternal behaviour partially explains why mothers who experience economic shocks have smaller (and in particular lighter) births, although the degree to which this is causal is unclear. If the flow-on effects from shocks to behaviours are weak then this channel will be relatively unimportant. However it is also possible that the effects are greater than our estimates suggest, as there are many other potentially important behavioural traits that are unobserved and for which we cannot directly control. For example, the potential link between low socioeconomic status and maternal nutrition outlined above may be behavioural, rather than reflecting an inability to afford a high-quality diet. Other behaviours such as drug abuse (Lovallo, 2015), poor sleeping habits (Basta *et al.*, 2007), a lack of exercise (Stephens, 1988), or other forms of personal neglect such as failure to take medication, inadequate care of injury or poor hand washing (Gonzalez *et al.*, 2008) have all been identified as responses to psychosocial stress. While not all these factors are directly linked to birth outcomes, they are all likely to lead to poorer maternal health and therefore may have indirect effects on birth outcomes.

5 Fragile Males

The estimates presented above are averages across our entire sample of births. However, an emerging body of literature underlines meaningful differences in gestational processes between males and females (Melamed *et al.*, 2013), which may create dissimilarities in the ways they respond to external stimuli. One hypothesis that has attracted recent attention is that male foetuses are more vulnerable than those of females to adverse intrauterine shocks. For example recessions, natural disasters, stressful life events, and maternal behaviours such as smoking all appear to affect sex ratios in favour of female births (see Currie and Schwandt (2016) and the references therein). As this comes about via higher rates of male miscarriage it appears that girls are better able to handle suboptimal gestational conditions (Eriksson *et al.*, 2010).

A number of physiological factors may account for this result. As male births are larger and more energy-intensive they tend to have faster rates of intrauterine growth, which places greater demands on nutritional flows and creates vulnerabilities to shortages (Tanner, 1989). Further, placentas for males are smaller (and hence foetal/placental ratios are higher) and have less reserve capacity, which also may increase dependence upon maternal diet (Roland *et al.*, 2013). And male growth patterns also favour head and brain development relative to body growth, while the reverse holds for female foetuses, making males more slender for a fixed gestational weight (Eriksson *et al.*, 2010). Patterns of reduced male birth weights also emerge empirically when foetuses are distressed. For example Jedrychowski *et al.* (2011) show that exposure to pollutants is associated with much larger declines in birth weights for males, while Currie and Schwandt (2016) document similar results from the effects of the dust cloud following the 9/11 terrorist attacks in New York.

To examine whether boys are also more sensitive to economic shocks, we re-estimate the models as in EQ (1) stratifying by gender. This allows all coefficients to differ, reflecting gender-specific heterogeneity in the determination of birth outcomes. We present the key parameter estimates below in Table 9 (descriptive statistics stratified by gender appear in Table 16 in the Appendix).

Table 9: Economic Shock Effect Sizes by Gender

	Males			Females		
Birth Weight (gm)	-74.27*	-90.84**	-72.56*	-41.70	-61.13	-43.42
Birth Weight (sd)	-0.130*	-0.159**	-0.127*	-0.073	-0.107	-0.076
Head Circ (cm)	0.192	0.227	0.196	-0.277**	-0.306**	-0.242*
Head Circ (sd)	-0.121	-0.143	-0.124	-0.175**	-0.193**	-0.153*
Biological Controls	N	Y	Y	N	Y	Y
Soc/Econ Controls	N	N	Y	N	N	Y

Note: The table presents estimates from EQ (1) where data is stratified by the gender of the infant. Results for birth weights are in the first two rows and head circumferences are in the latter rows. Estimates for males are on the left and estimates for females are on the right. Inference is based upon White (1980) covariance. *, ** and *** denote significance at 10%, 5% and 1% respectively.

The estimates provide some qualified support for male birth weights being more responsive to prenatal economic shocks. Across the three models the male coefficients are 50-80% higher than for those for females (the male estimates range from -73 to -91 grams, or -0.127 to -0.159 standard deviations, while the female estimates are from -42 to -61 grams, or -0.073 to -0.107 standard deviations). In all cases the estimates are largest with only the biological controls, and smallest when the socioeconomic covariates are added. The economic-shock parameters are only significantly different from zero in the male equations, and in no cases are the ϕ coefficients significant for females. The reduced significance in these models is unlikely to only reflect smaller effect sizes however (the estimates of ϕ are not too dissimilar from those in Table 3), but rather a function of the smaller sample sizes used. Nonetheless taking these results at face value (i.e. only considering significant estimates), economic shocks do not meaningfully predict female birth sizes while they do so for males.

Conversely the fragile-male hypothesis does not appear to hold for head circumferences. The male effect sizes range from -1.92 to -2.27 mm (-0.121 to -0.143 standard deviations), with analogous female figures of -2.42 to -3.06 mm (-0.153 to -0.193 standard deviations). The female figures are thus systematically a little larger than those for males. Furthermore in a reversal of the case for birth weights, it is only the estimates for girls that are significant - we are not able to establish predictive empirical relationships for boys here. Taken together these findings suggest that the fragile male hypothesis may require some modification. As birth weights have much stronger associations with health and cognitive performances than do head circumferences (as in Table 2) our results suggest that males are more negatively affected. However an important implication of Table 9 is that females are vulnerable too, albeit in a different way. Notably the patterns we observe are consistent with the sex differences in growth strategies outlined above, where females invest more in placental growth (which secures nutrient flows) and body weight while males invest more heavily in head and brain development. Since this channel operates through maternal nutrition the result lines up with the hypothesis in Section 4, whereby economic shocks act by reducing diet composition or quality.

5.1 Gender Sensitive Selectivity

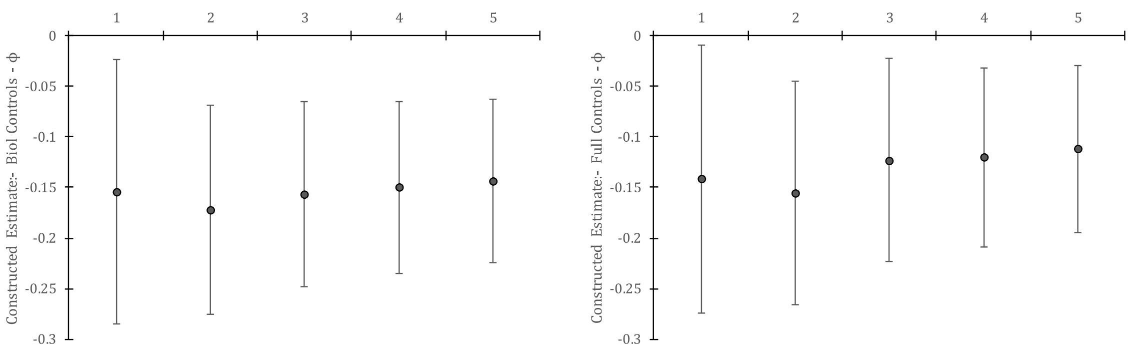
Last, given that suboptimal intrauterine conditions do appear to affect males more, it is possible that the regressions above be affected by gender-sensitive selectivity issues. As our data are conditional on live births, pregnancy outcomes that result in miscarriages will drop out of our sample. If economic shocks are damaging enough to trigger spontaneous abortions disproportionately amongst males, this would result in a higher proportion of female births in the affected subset of our data. As per Table 1 our total female birth rate is 48.1% (slightly below the UK national average of 48.7%)[37] with the figures for the unaffected and affected subsamples being 47.9% and 51.7% respectively. That is, mothers who experienced prenatal economic shocks had female births at a rate almost 4% points higher than those that did not - a difference that is statistically significant at $\alpha = 10\%$. If this relationship is causal it is worth considering the potential impacts upon our results. As the most severe reactions to economic shocks may lead to missing observations on the dependent variable, our estimated ϕ coefficients from Tables 3-6 will be biased towards zero, so that we underestimate the negative effects of economic shocks. Furthermore, as this selection operates by gender, males may be relatively more fragile than our estimates suggest.

To obtain an idea of the potential size of these biases, we perform a calibration exercise using the male and female birth rates above. We take the sex ratios in the affected subsample, and consider the additional male births that would be needed for the sex ratio to match that in the unaffected subsample. As these births did not occur (i.e. the pregnancy resulted in miscarriage) we assume that the birth otherwise would have been relatively small, and attribute an effect obtained from a quantile regression at the qth conditional percentile for this group. We thus assume an equivalency

[37] See https://www.gov.uk/government/uploads/system/uploads/attachment/data/file/200527/Gender/birth/ratio/in/the/UK.pdf.

between these low outcomes and spontaneous abortion. We then reconstruct the estimate as a weighted average of (i) the regular male estimates from Table 3, (ii) the regular female estimates, and (iii) the estimates for fragile males obtained from the qth conditional percentile. The weights across the three groups are chosen to eliminate the discrepancy in the sex ratios for the affected and unaffected sub-samples.[38] Figure 2 below plots these constructed values over $q = 1\% - 5\%$ for birth weights reported in standardised coefficients. As our models for head circumference produce larger estimates for girls but do not predict miscarriage, we do not consider this outcome here.

Figure 2: Reconstructed Parameter Estimates Accounting for Male Miscarriage:- Birth Weights



Note: The figure gives estimates that account for endogenous selection by imputing effect sizes for missing males using quantile regressions. The vertical bars represent 90% confidence intervals and the constructed point estimates are denoted with black circles. Each bar presents a separate estimate based on an imputation derived from the qth quantile. Estimates in the left panel use the biological controls from Table 1 and the right panel uses both biological and socioeconomic controls.

If the missing male births are assigned an effect size associated with the 1%-2% conditional quantiles, then the average effect sizes are somewhat larger than those in the above tables. In these cases, the standardised impacts are around -0.15 to -0.17 standard deviations (from 85 to 100 grams) as opposed to 40-70 grams as obtained in the previous models. If we take higher quantiles (i.e. beyond 5%) this increase is smaller, and the associated standard errors are large enough such that our changes cannot be adequately distinguished from sampling variation. However, since miscarriage is a more severe birth outcome than belonging to the lowest few percentiles of the conditional distribution, it is likely that these estimates understate the true impacts of these shocks. Additionally, the simulation has some implications for the relative effect sizes for males and females. If we hold the female effect sizes constant at the values in Table 9, and consider the ratio of male-to-female estimates, simulating the effects from missing births reveals a more pronounced degree of male vulnerability. Instead of male effect sizes being 50% to almost 80% larger, imputing

[38]This involves a female proportion of 47.9%, an observed male proportion of 44.7% and a constructed (i.e. unobserved) male proportion of 7.4%.

the missing boys using the lowest conditional quantiles increases the male estimates by a further 20-30%.

6 Conclusion

This paper has contributed to the limited body of literature using micro-data to explore the relationship between prenatal income shocks and birth outcomes. Taking highly-detailed data from the UK in the early 1990s, we observe that women who experienced economic shocks during the first 18 weeks of pregnancy had substantially smaller births, a finding that persists when controlling for a wide variety of maternal physiological characteristics and socioeconomic determinants. We show that material wellbeing appears to play a fairly central role in this relationship: not only do indicators of higher socioeconomic status predict healthier outcomes, but shocks that reduce material standing only matter for mothers who are at the lower end of the socioeconomic scale. Absolute deprivation then seems to produce lower birth weights and smaller head circumferences, a result which is notable for a developed country with broad-based health insurance such as the UK. Reductions in maternal diet quality or failures to access healthcare services may plausibly explain this finding.

We also explore the role of other mediating channels, and find that controlling for maternal mental health does not substantially alter the effect sizes. Further, mental health is itself not related to birth outcomes once other factors are controlled for, so that economic shocks do not act directly via this channel. Conversely, alcohol and tobacco consumption are significant predictors of poor infant health, and including these variables in our models does substantially reduce our coefficients. Since these behavioural traits are plausibly causally determined by shocks, this appears to be an important link. Taken together our results thus suggest that the way in which mothers respond to economic shocks ultimately affects infant health. There is a similarity between this channel and that of economic deprivation, as poor diet or failing to medicate or keep appointments may also be behavioural responses to stress. Other factors such as drug abuse or poor self-care likely also fall under this umbrella.

Last, we looked at the role of child gender, as per the fragile-male hypothesis of intrauterine development. Stratifying by gender, we only obtain statistically-significant effects of economic shocks for males with birth weight as the dependent variable, but find the opposite result for head circumference. Although this pattern is surprising (as birth weights and head circumferences are positively correlated), it is consistent with recent theories of gender differences in prenatal development.

Our research has a number of policy implications. Ensuring that mothers have sufficient economic resources to maintain physiological health is clearly important, and therefore social-welfare systems that either prevent economic shocks from occurring or from being translated into absolute deprivation may improve infant health. Policies that discourage maladaptive responses to shocks are also likely to be beneficial, although interventions aimed at reducing anxiety or depression will not yield improvements unless lower stress translates into healthier maternal behaviour. Finally, as female foetuses are a little more resilient, future research could aim to identify ways of protecting the mothers of male infants.

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Appendix

Table 10: Socioeconomic and Demographic Representativeness of Mothers - ALSPAC and Avon to Great Britain

		ALSPAC	Avon	Great Britain
Socioeconomic	Home Owner Occupier	79.1%	68.7%	63.4%
	Household has Car	90.8%	83.7%	75.6%
Demographic	Married Couple	79.4%	71.7%	71.8%
	Non-White Mother	2.2%	4.1%	7.6%

Note: The table contains some socioeconomic and demographic statistics from ALSPAC and compares with Avon and Great Britain. The first two rows give socioeconomic indicators and the latter two give some demographic indicators. See http://www.bristol.ac.uk/alspac/researchers/cohort-profile/.

Table 11: Birth and Infant Representativeness of ALSPAC to Great Britain

		Birth		1 Year Clinical		2 Year Clinical	
		ALSPAC	Great Britain	ALSPAC	Great Britain	ALSPAC	Great Britain
Birth Weight (gm)	Male	3,550	3,550	10,540	10,150	13,030	12,530
	Female	3,420	3,410	9,840	9,730	12,420	12,290
Length (cm)	Male	51.26	51.09	76.53	76.23	87.54	87.82
	Female	50.41	50.21	74.60	74.43	86.13	86.49

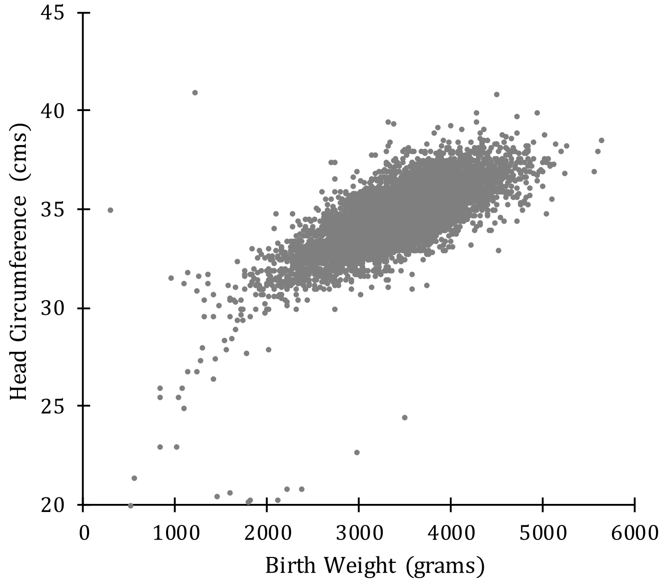
Note: The table compares birth outcomes and infant development in terms of weights and lengths from ALSPAC to Great Britain as a whole. The first two columns give newborn outcomes while the columns on the right give outcomes measured at one and two years of age. See http://www.bristol.ac.uk/alspac/researchers/cohort-profile/.

Table 12: Variable Descriptions and Survey Wave Structure

Variable	Type	Survey Wave
Economic Shock	Dummy - coded from ordinal response	18 Weeks Gestation
Birth Weight (gm)	Continuous	Birth
Head Circumference (cm)	Continuous	Birth
Age	Continuous	8 Weeks Gestation
Height	Continuous	12 Weeks Gestation
Pre-pregnancy weight (kg)	Continuous	12 Weeks Gestation (Retrospective)
Pre-pregnancy BMI	Continuous	8/12 Weeks Gestation (Retrospective)
No. of miscarriages	Count	18 Weeks Gestation
No. of Previous Pregnancy	Count	18 Weeks Gestation
Twins	Dummy	Birth
Infant Female	Dummy	Birth
Partner Weight (kg)	Continuous	18 Weeks Gestation
Partner Height (m)	Continuous	18 Weeks Gestation
Married	Dummy	8 Weeks Gestation
Single	Dummy	8 Weeks Gestation
Education - O/A Level	Dummy	32 Weeks Gestation
Education - Degree	Dummy	32 Weeks Gestation
Home Owned	Dummy	8 Weeks Gestation
Home Rented	Dummy	8 Weeks Gestation
Material Deprivation Score	Count of ordinal responses	32 Weeks Gestation
Tobacco First 18 Weeks	Dummy	18 Weeks Gestation
Tobacco Last 8 Weeks	Dummy	Post Birth (Retrospective)
Alcohol First 18 Weeks	Dummy	18 Weeks Gestation
Alcohol Last 8 Weeks	Dummy	Post Birth (Retrospective)
CCEI Depression 1	Count of ordinal responses	18 Weeks Gestation
CCEI Depression 2	Count of ordinal responses	32 Weeks Gestation
CCEI Anxiety 1	Count of ordinal responses	18 Weeks Gestation
CCEI Anxiety 2	Count of ordinal responses	32 Weeks Gestation

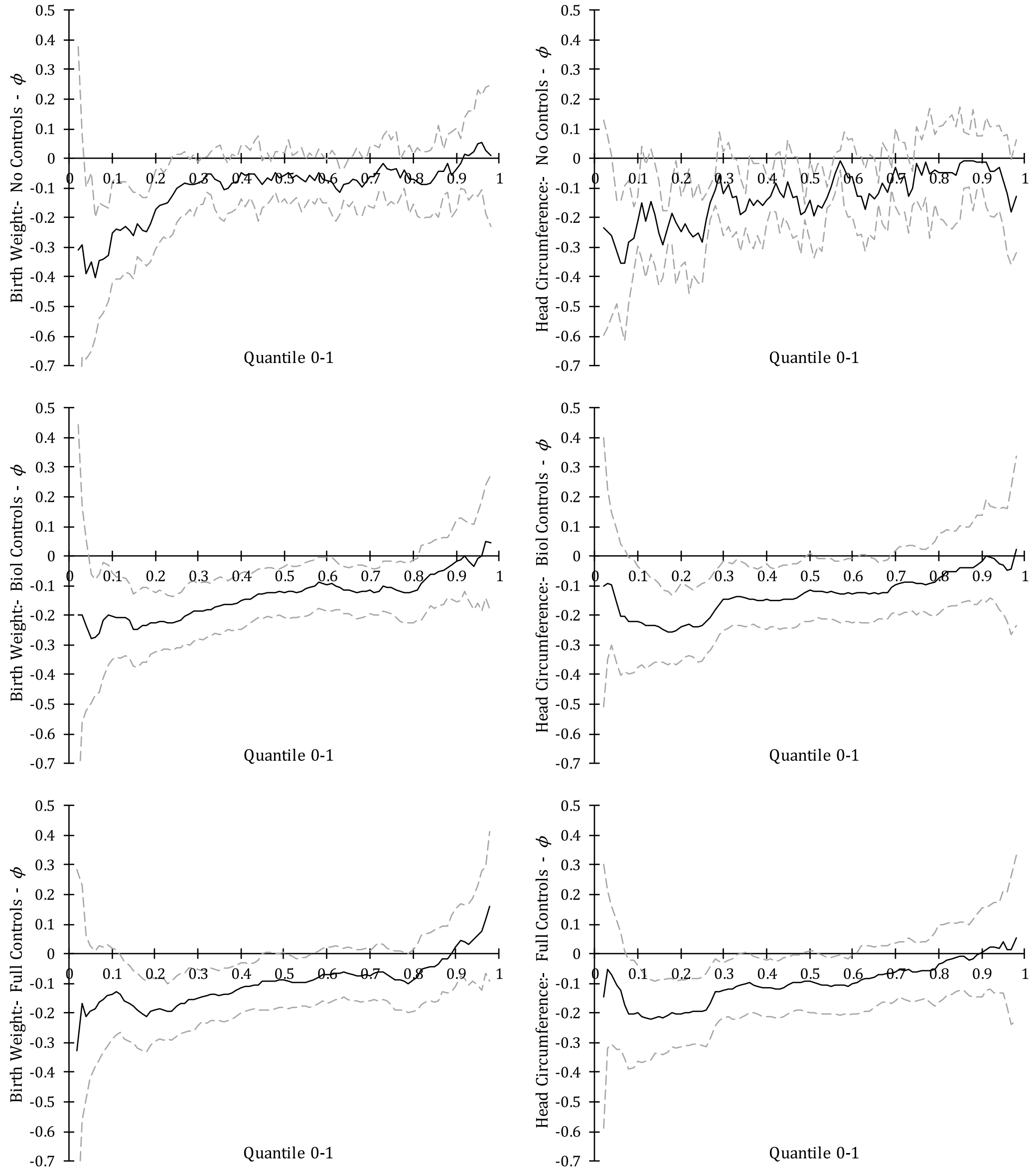
Note: The table describes the structure of the waves used from the ALSPAC survey. Retrospective here refers to a survey question in a particular wave that refers to events or behaviours from earlier time periods.

Figure 3: Scatter Plot of Birth Weights and Head Circumferences:- ALSPAC Data



Note: The figure shows the bivariate association between birth weights (horizontal axis) and head circumferences (vertical axis). The figure is based on the intersect of the two variables and contains 8,938 observations. The correlation between these variables is 0.71.

Figure 4: Quantile Regressions - Standardised Estimates - Birth Weights and Head Circumferences



Note: The figure gives quantile regression estimates of the standardised effects of economic shocks on birth weights (left panels) and head circumferences (right panels). The top row uses no control variables, the middle row employs the biological controls and the bottom row uses both biological and socioeconomic controls. 90% Confidence Intervals are depicted in grey.

Table 13: Mediating Effects - Mental Health Aggregates

	Birth Weight			Head Circumference		
	Model (1)	Model (2)	Model (3)	Model (1)	Model (2)	Model (3)
Prenatal Economic Shock (gm/cm)	-48.56	-69.13**	-54.27*	-0.246**	-0.257***	-0.217**
Prenatal Economic Shock (sd)	-0.085	-0.121**	-0.095*	-0.155**	-0.162***	-0.137**
CCEI Anxiety at18 Weeks	-0.009**	-0.005	-0.005	-0.002	0.001	0.001
CCEI Anxiety at 32 Weeks	-0.002	-0.001	0.000	-0.004	-0.003	-0.002
CCEI Depression at 18 Weeks	-0.002	-0.004	-0.003	0.000	-0.003	-0.001
CCEI Depression at 32 Weeks	0.008	0.007	0.009*	0.002	0.003	0.004
Age		0.047***	0.010		0.013	-0.006
Age-Squared/100		-0.072**	-0.020		-0.008	0.017
Height		1.106	0.920		0.099	-0.061
Pre-pregnancy weight (kg)		0.020*	0.022*		0.022*	0.023*
Pre-pregnancy BMI		-0.019	-0.022		-0.032	-0.034
No. of miscarriages		-0.050***	-0.059***		-0.024	-0.030
1 Previous Pregnancy		0.228***	0.243***		0.076***	0.092***
2 Previous Pregnancies		0.289***	0.321***		0.082**	0.111***
3 Previous Pregnancies		0.303***	0.359***		0.083*	0.132***
4 Previous Pregnancies		0.271***	0.352***		-0.008	0.055
≥5 Previous Pregnancies		0.159**	0.248***		0.033	0.106
Twins		-1.316***	-1.310***		-0.926***	-0.926***
Infant Female		-0.181***	-0.183***		-0.419***	-0.421***
Partner Weight (kg)		0.003**	0.003**		0.004***	0.004***
Partner Height (m)		0.006***	0.005***		0.002	0.001
Married			0.091**			0.030
Single			0.031			0.030
Education - O/A Level			0.059**			0.050*
Education - Degree			0.137***			0.131***
Home Owned			0.109**			0.063
Home Rented			0.031			0.008
Material Deprivation Score			-0.005*			-0.006
Constant	0.028	-4.697***	-3.858**	0.027	-1.516	-0.932
Pseudo R^2	0.242%	9.979%	10.30%	0.222	9.920%	9.931%
F	2.67	65.93	51.06	1.66	41.81	32.63
N	11573	11573	11573	8938	8938	8938

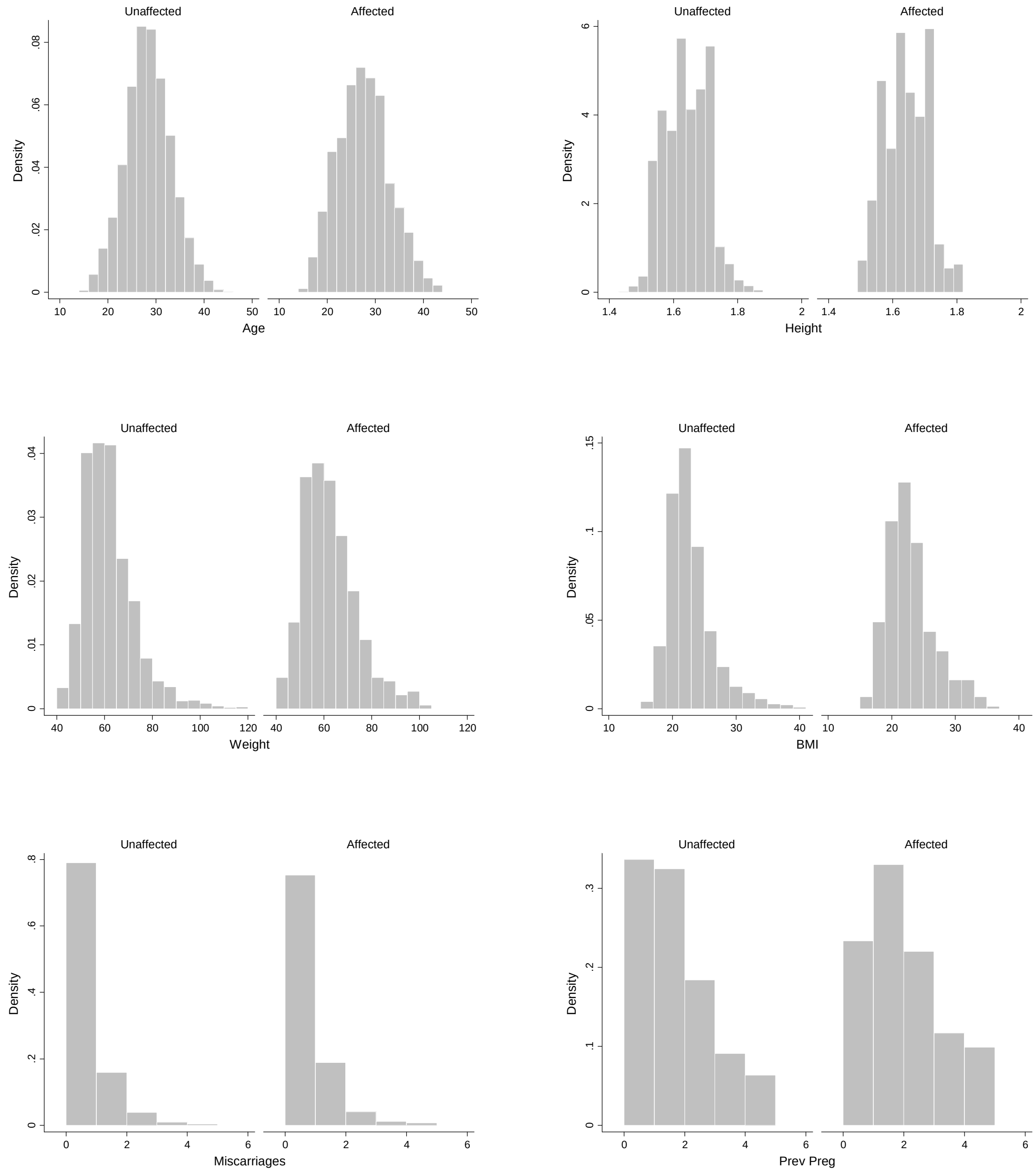
Note: The table contains the full models used to estimate the mediating effects presented in Table 7. Dummy variables are defined relative to a reference individual who has not experienced an economic shock, has had no previous pregnancies and gave birth to a single male child. This individual is without O/A levels and is mortgaging their home. Standard errors are based upon White (1980) robust covariance and the symbols *, ** and *** denote significance at 10%, 5% and 1% respectively.

Table 14: Mediating Effects - Tobacco and Alcohol Consumption

	Birth Weight			Head Circumference		
	Model (1)	Model (2)	Model (3)	Model (1)	Model (2)	Model (3)
Prenatal Economic Shock (gm/cm)	-12.00	-41.13	-41.13	-0.182*	-0.204**	-0.190*
Prenatal Economic Shock (sd)	-0.021	-0.072	-0.072	-0.115*	-0.129**	-0.120*
Tobacco 1st 18 Weeks	-0.057*	-0.033	-0.027	-0.076**	-0.054	-0.050
Tobacco Final 8 Weeks	-0.372***	-0.395***	-0.391***	-0.193***	-0.206***	-0.201***
Alcohol 1st 18 Weeks	-0.014	-0.034*	-0.033*	0.010	-0.003	-0.004
Alcohol Final 8 Weeks	0.085***	0.064***	0.061***	0.054**	0.033	0.028
Age		0.001	-0.005		-0.014	-0.015
Age-Squared/100		-0.009	-0.001		0.0028	0.026
Height		0.709	0.652		-0.251	-0.303
Pre-pregnancy weight (kg)		0.024**	0.024**		0.025**	0.026**
Pre-pregnancy BMI		-0.028	-0.029		-0.041	-0.041
No. of miscarriages		-0.066***	-0.068***		-0.031	-0.034*
1 Previous Pregnancy		0.254***	0.256***		0.091***	0.100***
2 Previous Pregnancies		0.348***	0.353***		0.116***	0.129***
3 Previous Pregnancies		0.397***	0.407***		0.135***	0.157***
4 Previous Pregnancies		0.409***	0.422***		0.070	0.095
$\geq$5 Previous Pregnancies		0.324***	0.339***		0.124	0.154
Twins		-1.315***	-1.317***		-0.923***	-0.927***
Infant Female		-0.188***	-0.188***		-0.424***	-0.425***
Partner Weight (kg)		0.003**	0.003**		0.004***	0.004***
Partner Height (m)		0.005***	0.005***		0.001	0.001
Married			0.022			-0.018
Single			0.016			0.017
Education - O/A Level			0.011			0.026
Education - Degree			0.058			0.091**
Home Owned			0.072			0.044
Home Rented			0.064			0.029
Material Deprivation Score			0.000			-0.002
Constant	0.085***	-3.045**	-2.917**	0.040**	-0.376	-0.257
Pseudo R^2	3.814%	13.17%	13.20%	1.371%	10.11%	10.15%
F	77.64	87.18	64.50	19.92	45.11	34.45
N	11573	11573	11573	8938	8938	8938

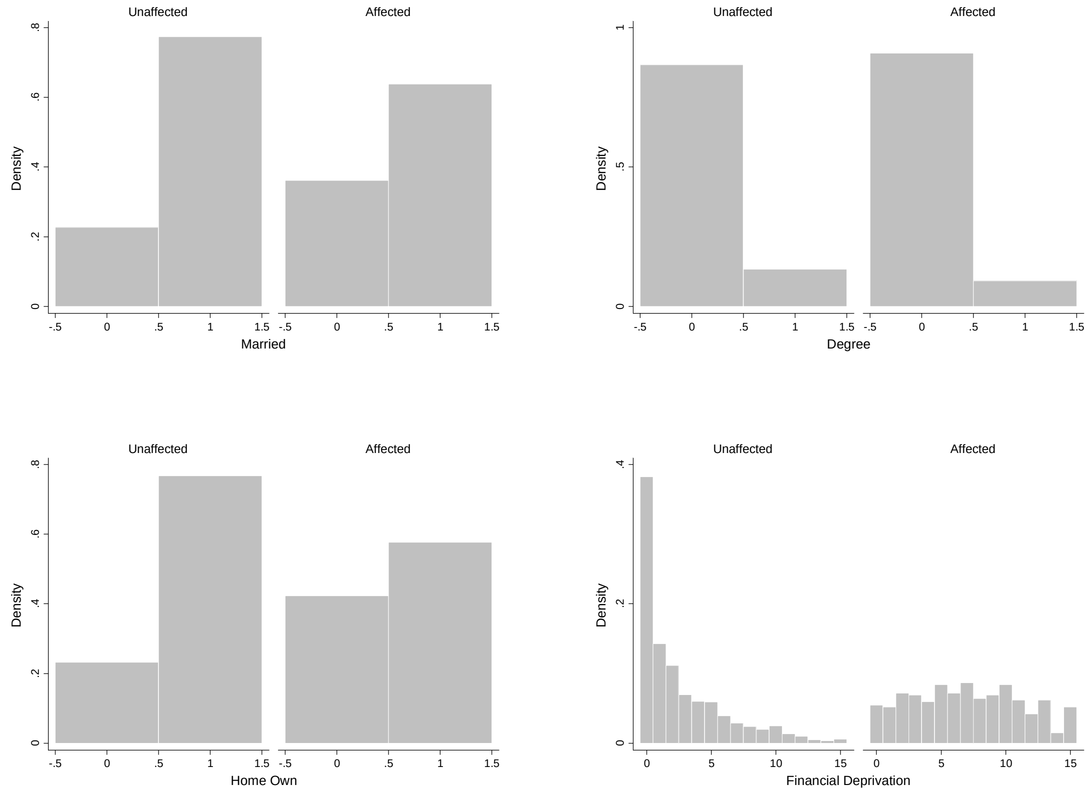
Note: The table contains the full models used to estimate the mediating effects presented in Table 7. Dummy variables are defined relative to a reference individual who has not experienced an economic shock, has had no previous pregnancies and gave birth to a single male child. This individual is without O/A levels and is mortgaging their home. Standard errors are based upon White (1980) robust covariance and the symbols *, ** and *** denote significance at 10%, 5% and 1% respectively.

Figure 5: Covariate Balance: Maternal Biometric



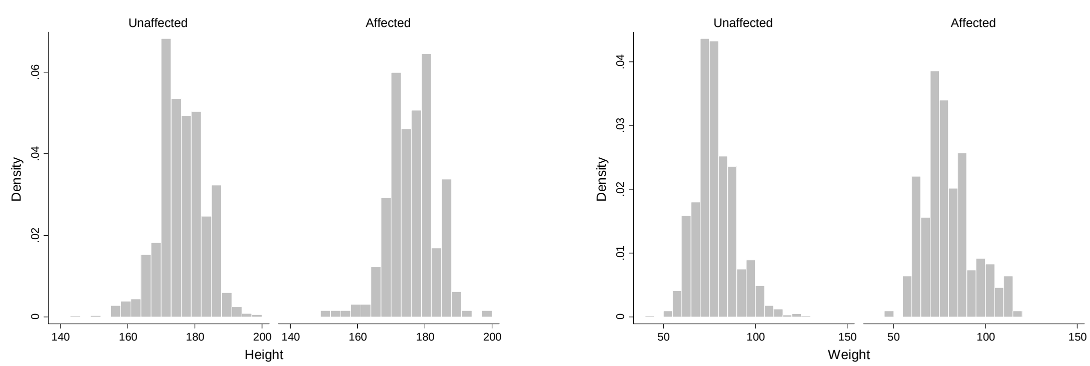
Note: The figures depict covariate distributions for mothers unaffected (left) and affected (right) by economic shocks within the first 18 weeks of pregnancy. Biometric covariates shown are age, height, weight, BMI, miscarriages and previous pregnancies. Note that the final category in the previous-pregnancy count is unbounded.

Figure 6: Covariate Balance: Maternal Socioeconomic



Note: The figures depict covariate distributions for mothers unaffected (left) and affected (right) by economic shocks within the first 18 weeks of pregnancy. Socioeconomic covariates shown are marital status, home ownership (either owned or mortgaged), having a university degree, and our pre-treatment financial deprivation score.

Figure 7: Covariate Balance: Paternal Biometric



Note: The figures depict covariate distributions for partners of mothers unaffected (left) and affected (right) by economic shocks within the first 18 weeks of pregnancy. Biometric covariates shown are height and weight.

Table 15: Economic Shocks: - Linear Probability Models - Selection on Observables

	Model (2)	Model (3)
Age	-0.0091	-0.0023
Age-Squared/100	0.0001	0.0001
Height	-0.1163	-0.0846
Pre-pregnancy weight (kg)	0.0021	0.0016
Pre-pregnancy BMI	-0.0053	-0.0042
No. of miscarriages	-0.0079	-0.0035
1 Previous Pregnancy	0.0117*	-0.0033
2 Previous Pregnancies	0.0281***	0.0109
3 Previous Pregnancies	0.0290**	0.0043
4 Previous Pregnancies	0.0344	-0.0024
≥5 Previous Pregnancies	0.0590*	0.0096
Twins	0.0044	0.0078
Infant Female	0.0013	0.0022
Partner Weight (kg)	0.0003	0.0003
Partner Height (m)	-0.0004	-0.0001
Married		0.0011
Single		0.0001
Education - O/A Level		0.0142*
Education - Degree		0.0158*
Home Owned		-0.0065
Home Rented		0.0111
Material Deprivation Score		0.0130***
Constant	0.3830	0.1276
R^2	0.0059	0.0694
F	2.02	5.83
N	5921	5738

Note: The table presents regressions showing selection into major economic shocks based on observables. The first column employs biological controls while the second uses both biological and socioeconomic controls. Regressions are performed on the pre-imputation sample. *, ** and *** denote significance at 10%, 5% and 1% respectively.

Table 16: Descriptive Statistics: Gender of Child

	Male			Female		
	$\bar{x}$	$\hat{\sigma}_x$	n	$\bar{x}$	$\hat{\sigma}_x$	n
Economic Shock	0.039	0.194	5480	0.045	0.208	5073
Birth Weight (gm)	3449	595.4	6007	3344	539.0	5566
Head Circumference (cm)	35.09	1.609	4610	34.43	1.483	4328
Age	27.97	4.911	6007	27.75	4.805	5566
Height (m)	1.641	0.065	5188	1.640	0.066	4855
Pre-Pregnancy Weight (kg)	61.79	10.87	5256	61.64	11.04	4898
Pre-Pregnancy BMI	22.95	3.811	5188	22.91	3.869	4855
No. of miscarriages	0.291	0.661	6007	0.294	0.693	5566
1 Previous Pregnancy	0.318	0.466	6007	0.327	0.469	5566
2 Previous Pregnancies	0.189	0.391	6007	0.179	0.383	5566
3 Previous Pregnancies	0.098	0.297	6007	0.089	0.284	5566
4 Previous Pregnancies	0.033	0.178	6007	0.037	0.188	5566
>5 Previous Pregnancies	0.034	0.182	6007	0.031	0.174	5566
Twins	0.024	0.152	5164	0.020	0.141	4788
Partner Weight (kg)	78.12	11.46	3794	78.11	11.60	3613
Partner Height (m)	176.0	6.973	3794	176.0	6.997	3621
Married	0.753	0.431	5954	0.763	0.425	5521
Single	0.189	0.392	5954	0.184	0.387	5521
Education - O/A Level	0.576	0.494	5590	0.580	0.494	5208
Education - Degree	0.131	0.338	5590	0.135	0.342	5208
Home Owned	0.744	0.436	5953	0.743	0.437	5519
Home Rented	0.225	0.418	5953	0.220	0.414	5519
Material Deprivation Score	2.863	3.502	5448	2.849	3.499	5103

Note: The table presents descriptive statistics stratified by gender in aid of the analysis in Section 5. Male outcomes are presented on the left and female outcomes on the right.