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Abstract
We examine the effect of alcohol exposure *in utero* on child academic achievement. As well as studying the effect of *any* alcohol exposure, we investigate the effect of the *dose*, *pattern,* and *duration* of exposure. We use a genetic variant in the maternal alcohol-metabolism gene *ADH1B* as an instrument for alcohol exposure, whilst controlling for the child's genotype on the same variant. We show that the instrument is unrelated to an extensive range of maternal and paternal characteristics and behaviours. OLS regressions suggest an ambiguous association between alcohol exposure *in utero* and children's academic attainment, but there is a strong social gradient in maternal drinking, with mothers in higher socio-economic groups more likely to drink. In stark contrast to the OLS, the IV estimates show negative effects of prenatal alcohol exposure on child educational attainment. These results are very robust to an extensive set of model specifications. In addition, we show that that the effects are solely driven by the maternal genotype, with no impact of the child's genotype.

Key words: Academic achievement; prenatal alcohol exposure; Mendelian randomization; ALSPAC
JEL-code: I12, J24

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1. Introduction and Literature

The first scientific study that examined the effects of excessive alcohol intake during pregnancy was published by a Liverpool prison physician in 1899 (Sullivan, 1899). He argued that alcohol consumption caused the higher rates of stillbirth observed among female alcoholic prisoners compared to their sober counterparts. The detrimental effects of excessive drinking during pregnancy are currently well-known. The effects of low-to-moderate drinking, however, are less conclusive. Indeed, there are conflicting recommendations regarding the 'threshold' for maternal prenatal alcohol consumption, ranging from total abstinence in most countries including the US to restricted consumption in the UK. Only in 1995 did the UK Department of Health issue guidelines for women who were (planning to become) pregnant, stating that "women should not drink more than 1 or 2 units of alcohol once or twice a week, and should avoid episodes of intoxication" (DH, 1995). Their most recent guidelines are very similar: despite advising pregnant women not to drink *in the first three months* of pregnancy, they mention that, if women choose to drink, they should not exceed 1 to 2 units once or twice a week, as "at this low level, there is no evidence of any harm to the unborn baby" (NICE, 2008).

These conflicting recommendations arise from inconsistent findings in observational studies of the correlation between low-to-moderate alcohol consumption and child development (including physical and mental health, cognitive and behavioural outcomes). Some find negative effects on child development, some do not find evidence of developmental differences, and others argue it improves child outcomes (for reviews of this literature, see e.g. Gray and Henderson, 2006; Polygenis et al., 1998; Abel and Hannigan, 1995). One of the major problems in estimating the causal effects of prenatal alcohol consumption is that it is a choice; as such, it may be related to other unobserved characteristics that also affect the outcome of interest, biasing the estimates.

This paper examines the impact of alcohol exposure *in utero*, as proxied by whether the mother consumed any alcohol during pregnancy, on child academic achievement. We also investigate the effect of the *dose*, *pattern*, and *duration* of exposure. We deal with unobserved residual confounding using 'Mendelian randomization', referring to the random allocation of an individual's genotype at conception (Davey Smith and Ebrahim, 2003). Although this allocation is random at the family trio level (i.e. from parents to children), at a population level it has been shown that genetic variants are largely unrelated to the many socioeconomic and behavioural characteristics that are closely linked with each other and that confound conventional observational studies. This has been shown using a wide range of genetic variants[1], different

[1] Including, for example, *LAC1* (rs4988235), *CETP* (rs708272), *TNF-α* (rs1800629), *GPX4* (rs1007), *MTHFR* (rs1801133), *FTO* (rs9939609), as well as the variant used here (*ADH1B*, rs1229984).

data sources[2], and for an extensive set of background characteristics[3] (see e.g. Bhatti et al., 2005; WTCCC, 2007; Davey Smith et al., 2008; Kivimäki et al., 2008; von Hinke Kessler Scholder et al., 2011; Lawlor et al., 2013).[4] Hence, we employ a carefully validated genetic variant that is associated with decreased alcohol exposure as an instrumental variable (IV) for exposure to alcohol *in utero* (Zuccolo et al., 2009). Under assumptions discussed in detail below, genetic variants are independent of unobservable confounders, including those that occur *in utero*. As such, Mendelian randomization can be exploited to make causal inferences about the effects of behavioural or health conditions that have (at least partly) a genetic aetiology on certain outcomes of interest. For a brief introduction to some of the genetic terms referred to in this study, see Appendix A.

Our contribution to the literature is, first, to examine the causal effects of prenatal alcohol exposure on child development. As suggested by the relatively few studies attempting to investigate the causal effects (see below), it is particularly difficult to estimate these due to unobserved residual confounding. Second, as it is obviously unethical to design a randomized controlled trial, we show that quasi-experimental designs, such as Mendelian randomization, may provide a powerful and useful alternative for causal inference. We also present a thorough discussion of the assumptions required in Mendelian randomization experiments, and provide additional evidence on the validity of genetic variants as instrumental variables by testing its correlation with an unusually wide range of maternal and paternal characteristics and behaviours. Third, we add to the literature on the long-term effects of the early environment on later child outcomes (for a recent overview, see Almond and Currie, 2011), on potential differential investments by parents in response to child development (Almond and Mazumder, 2013), as well as on identifying important periods of parental investments *per se* (Cunha and Heckman, 2007). Finally, we provide advice to policy makers, distinguishing between the effects

[2] Such as the British Women Heart and Health Study, the Young Finns Study, the Copenhagen General Population Study, the Avon Longitudinal Study of Parents and Children, as well as different case-control samples.

[3] These include more 'medical' characteristics (e.g. pulse, lung function, vitamin levels, haemoglobin, fasting insulin, fasting glucose, fibrinogen, C-reactive protein, plasma viscosity, etc.) as well as socioeconomic or behavioural characteristics (e.g. area deprivation, SES, types of foods/drinks consumed, time use, walking speed, educational level, age when parents died, housing characteristics, nurse estimation of life expectancy, etc.)

[4] For example, Bhatti et al. (2005) explores differences in polymorphism frequencies by willingness to participate in studies. They examine three studies with different recruitment designs and different participation incentives. Conditional on having provided blood or saliva samples, they investigate whether genotype frequencies differ by the timing of non-response to questionnaires (early, late and never responders), finding no systematic correlations. Davey Smith et al. (2008) estimate pairwise correlations between non-genetic and genetic variables and compare the number of correlations that are statistically significant with the number expected by chance if all variables were uncorrelated. They show significant correlations between behavioural, socioeconomic and physiological factors, with 45% of the 4,560 pairwise correlations being significant at the 1% level. In contrast, genetic variants show no greater association with each other, nor with the behavioural, socioeconomic and physiological factors than what would be expected by chance. Consistent with these findings, the allele frequencies in British blood donors have been shown to be virtually identical to those in the British 1958 cohort study (WTCCC, 2007). The former are clearly a highly selected sample in the population, whereas the latter includes a nationally representative sample of all children born in one week in Britain. Taken together, this suggests that genetic variants are generally unrelated to potential confounders.

of low-to-moderate versus excessive alcohol exposure *in utero*.

We start by presenting some simple descriptive statistics about the prevalence of maternal prenatal alcohol consumption, as these are not well documented in the economics literature. We show that 63% of pregnant women drink at some point during pregnancy, with 17% reporting that they binged (defined as drinking four units of alcohol in a day). On average, women drink 1.5 units of alcohol per week. OLS regressions show an ambiguous association between alcohol exposure *in utero* and children's educational attainment, with exposure to wine having a positive association, but exposure to beer being negative. Binge drinking is bad for the child, but a longer exposure to alcohol (in terms of the number of trimesters) is positively associated with the child's outcomes.

We then present evidence of a strong social gradient in alcohol exposure, with older mothers, and those of higher socio-economic position being more likely to drink during pregnancy, and particularly drink wine. Beer consumption on the other hand, is associated with smoking, lower education, and worse mental health. We use a genetic variant in the maternal Alcohol Dehydrogenase 1B gene, an alcohol-metabolizing gene, as an instrument for prenatal alcohol exposure. We show that the SNP is associated with alcohol exposure *in utero*. In addition, we demonstrate that it is not related to any of the background characteristics that we show to be associated with prenatal drinking. To provide additional evidence on the validity of our IV approach, we exploit the richness of our data and correlate the SNP to an unusually extensive range of maternal and paternal prenatal characteristics and behaviours; we find no evidence of any systematic associations that would suggest the instrument is invalid. In stark contrast to the OLS, our IV estimates show strong negative effects of alcohol exposure *in utero* on child educational achievement, which are robust to a large set of model specifications. In addition, the reduced form regressions show that the effects are solely driven by the maternal SNP, with no impact of the child's SNP on the child's academic attainment. The results also suggest that low-to-moderate (as opposed to excessive) exposure may have similar negative effects on child outcomes. Yet, despite the large negative effects, we find little evidence of differential parental responsive investments to child development, exploring an unusually wide range of parental postnatal responses and behaviours.

The relatively few studies in the economics literature that have attempted to deal with unobserved confounding related to prenatal alcohol exposure generally find large negative effects on child development.[5] Exploiting a Swedish alcohol policy experiment from the 1960s that increased alcohol availability in two Swedish counties by allowing grocery stores to sell strong beer, Nilsson (2008) investigates the effects of prenatal alcohol exposure on a set of adult

[5] Other studies in the epidemiology literature include Lewis et al. (2012) and Zuccolo et al. (2013).

outcomes. The policy experiment led to a sharp increase in alcohol consumption in the experimental regions, particularly among youths, causing the experiment to be discontinued prematurely. Using a difference-in-difference-in-differences design, he finds that children born to mothers under age 21, who have the longest prenatal exposure to the experiment at delivery, have a lower human capital attainment later in life: total years of schooling are reduced by 0.27 on average, with males being more affected (0.47 years) than females (0.10 years). Children exposed prenatally to alcohol are four percentage points less likely to have completed high school, and 2.5 percentage points less likely to have graduated. Their earnings at age 32 are 24 percent lower compared to those not exposed, and the proportion on welfare increased by five percentage points.

Wüst (2010) uses Danish survey and register data to examine the effect of maternal inputs on child birth outcomes (birth weight, foetal growth, and preterm birth). OLS analyses suggest an ambiguous association between prenatal alcohol consumption and birth outcomes. The sibling fixed effects however, shows clear negative effects, suggesting that each daily unit of alcohol decreases birth weight by 147 grams (4%), and increases the probability of a preterm birth by 7.8 percentage points.[6] Exploiting changes in the minimum legal drinking age over time across US states, similar adverse effects on birth outcomes are reported by Fertig and Watson (2009), whilst Barreca and Page (2012) find no effects. Finally, Zhang (2010) examines the relationship between state-level alcohol taxes, prenatal drinking, and infant health using the US Natality Files and the Behavioural Risk Surveillance System. The results suggest that an increase in taxes on beer relates to a decrease in the incidence of low birth weight.

Our paper is structured as follows: the next section reviews the mechanisms through which alcohol can affect the foetus, and discusses the metabolism of alcohol. Sections three presents the methodological framework and discusses the validity of the instrument. The data is introduced in section four, followed by the results in section five. We conclude with a discussion of our findings.

2. Mechanisms

2.1 In utero alcohol exposure and child development

Excessive drinking during pregnancy is well-known to be detrimental to the foetus, potentially leading to Foetal Alcohol Spectrum Disorder (FASD, a pattern of mental and physical defects). The effects of low-to-moderate drinking are less clear, and there is no consensus as to what

[6] Although not the main research question in their study, Rosenzweig and Wolpin (1994) also do not find any effects of maternal prenatal alcohol consumption on child test scores in their GLS estimation, but the estimates become negative when using a within-mother specification.

level of exposure is toxic to the foetus.

Numerous mechanisms have been suggested to contribute to alcohol-induced foetal damage. Its effects on the developing brain are particularly complex, as – depending on the developmental stage of the cells – alcohol can affect cell division, the survival of migrating cells, the establishment of mature cell structures/functions, as well as interfere with the brain's cellular functions. For example, after multiplication through cell division, nerve cells in the foetal brain migrate to an appropriate location where they mature to their full form and function. Alcohol exposure during cell division may decrease the cell division rate, whilst exposure during later stages may deplete cells due to alcohol-induced cell death (Goodlett and Horn, 2001). Hence, the timing of alcohol exposure may be important for different aspects of brain development. However, because the brain is one of the first organs to begin and the last to complete development, it is susceptible to damage throughout pregnancy (Guerri, 2002). Furthermore, as it is the blood alcohol level, rather than the amount of alcohol consumed, that can cause foetal damage, binge drinking is generally regarded as more damaging than drinking the same amount of alcohol over a longer period (Guerri, 2002).

Any damage due to prenatal alcohol exposure however, does not necessarily show at birth or in infancy, but may only manifest later in childhood, adolescence or even adulthood. Hence, affected children may go undetected until problems arise in the academic environment (Coles et al., 1991), with neurodevelopmental problems potentially persisting into adult life (Gray and Henderson, 2006). The most prominent dysfunctions include deficits in verbal learning and in integrating visual information, alterations in spatial memory and in reaction time, impaired attention, reduced academic achievement and other cognitive and motor skills (Guerri, 2002; Russell, 1991).

2.2 The metabolism of alcohol

Figure 1 graphically presents the first two steps in the metabolism of ethanol.[7] The alcohol dehydrogenase (ADH) family of enzymes, which includes ADH1B, catalyses its first step: oxidizing ethanol to acetaldehyde, a mutagenic and carcinogenic metabolite. With that, the ADH1B enzyme plays a major role in the breakdown of ethanol. The rare variant of rs1229984, a single nucleotide polymorphism, or SNP, in the ADH1B gene, greatly increases ADH1B enzymatic activity, resulting in a quicker reduction of blood alcohol levels, and sharper rises of acetaldehyde in blood and organs (see Appendix A for a brief introduction to some of the genetic terms used here). The latter in turn leads to symptoms such as increased heart rate and

[7] Ethanol is also known as pure alcohol or drinking alcohol. It is the type of alcohol found in alcoholic beverages.

nausea. Individuals with the rare variant of *ADH1B* therefore consume *less* alcohol, as found in numerous studies across many populations (see below). Hence, foetuses of mothers who carry the rare variant of *ADH1B* have a reduced exposure to alcohol compared to foetuses of mothers who carry the common variant. Note that the effects of *ADH1B* on alcohol consumption are subtle: it does *not* make an individual an alcoholic or in other ways alcohol-dependent. Instead, it only reduces alcohol intake by a small amount.[8]

3. Methodological framework

We use a SNP in the alcohol dehydrogenase 1B (*ADH1B*) gene rs1229984 to explain variation in alcohol exposure *in utero*. The vast majority of individuals of European ancestry are homozygous for the common allele. In fact, there are very few individuals who are homozygous for the rare allele (<1%). We therefore specify a binary instrument, equalling 1 when the individual carries either one or two copies of the rare allele (A), assuming a dominant genetic model (as in Zuccolo et al., 2009, 2010); i.e. we compare individuals with genotype GA or AA to those with genotype GG.

3.1 Potential outcomes framework

Let Z denote this binary genetic variant, with $Z_i = 1$ indicating that the mother of child i carries the rare variant, and $Z_i = 0$ implying that the mother of child i does not carry the rare variant. Let A and S denote random variables representing, respectively, alcohol intake and the educational outcome. Let $A_i(z)$ be the potential alcohol exposure for child i when the instrument is set to z. Similarly, let $S_i(z, a)$ be the potential outcome for child i that would be obtained if the instrument was set to z, and alcohol exposure, the treatment variable, was set to a. Only one of the two potential exposures or treatments ($A_i(0)$ and $A_i(1)$), and only one of the two potential outcomes $\big(S_i\big(0, A_i(0)\big)$ and $S_i\big(1, A_i(1)\big)\big)$ are ever observed for any one child.

As implicit in our notation, we assume that there is no interference between units (the Stable Unit Treatment Value Assumption, see Rubin, 1980). Given the set of potential outcomes, we can define the causal effect for child i of Z on A as $\big(A_i(1) - A_i(0)\big)$, and the causal effect for child i of

[8] The second step in the metabolism of ethanol is mainly driven by aldehyde dehydrogenase enzymes. Some individuals carry a polymorphism in the *ALDH2* gene which encodes an enzyme that is unable to clear acetaldehyde, leading to severe symptoms of facial flushing, increased heart rate, and nausea, causing these individuals to abstain from alcohol or drink very little. This *ALDH2* variant has been used in Mendelian randomization studies to explore the causal effects of alcohol consumption on blood pressure (Chen et al., 2008), drug use and anti-social behavior (Irons et al., 2007), and upper aerodigestive and stomach cancers (Hashibe et al., 2008; Zhang et al., 2007). However, its relevance is limited to East-Asian populations as the variant is absent in populations of European ancestry.

Z on S as $\left(S_i\left(1, A_i(1)\right) - S_i\left(0, A_i(0)\right)\right)$. These are also known as the intention-to-treat effects. Our framework follows the work by, among others, Imbens and Angrist (1994) and Angrist, Imbens and Rubin (1996). We briefly lay out our structural assumptions, and discuss more specifically how these apply to our research question.

Assumption 1: (Conditional) Independence

$$Z_i \perp \{S_i(z, a), A_i(z)\}_{z,a}$$

Independence assumes that the instrument is as good as randomly assigned. *Conditional* independence implies that independence holds conditional on some (vector of) covariate(s) X_i, which would be denoted by $Z_i \perp \{S_i(z, a), A_i(z)\}_{z,a} | X_i$.

Although genetic variants are randomly assigned at conception, the independence assumption can be violated when a systematic relationship exists between the allele frequency and the outcome of interest in different sub-populations; this is also known as population stratification. The most common example, and one that is important in the case of *ADH1B*, is ancestry. The *ADH1B* variant is one of the most ethnically stratified: the Minor Allele Frequency (MAF; the frequency with which the rare allele occurs in the population) ranges from 2-5% in Western European populations to 60-70% in North-East Asia (Borinskaya et al., 2009). However, population stratification is likely to be less important in our study, as our data is collected in a small geographically defined region with a predominantly white population. In addition, we only include a child if the mother describes herself and the child's father as white, and we adjust for ten ancestry-informative principal components derived from analysis of the genome wide association data (Bouaziz et al., 2011). In section 4.4, we evaluate the independence assumption by exploring the distribution of an extensive range of background characteristics by the value of the instrument. If the instrument is randomized, there should be no systematic differences in such characteristics.

Assumption 2: Exclusion

$$S_i(1, a) = S_i(0, a), \text{ for all } a.$$

Exclusion implies that the instrument can only affect the outcome via its effect on A. Hence, we can write $S_i(a, z) = S_i(a)$. If the exclusion restriction only holds conditional on X_i, we may specify the exclusion restriction conditional on these covariate(s).

The exclusion restriction can in principle be violated in different situations. First, we need to

consider the *mechanism* through which the variant affects alcohol exposure. This mechanism is relatively well understood, as discussed in section 2.2. Furthermore, we know that the *ADH1B* gene is predominantly expressed in the liver and (less so) in the lining of the stomach (Lee et al., 2006). The liver functions as the main organ in ethanol clearance; the stomach and small intestine are the principal absorption sites of ingested alcohol (Cortot et al., 1986).

Second, the exclusion restriction may be violated by pleiotropy, referring to the possibility that a SNP has multiple phenotypic associations. The gene expression and the well understood mechanisms of *ADH1B* decrease the likelihood that *ADH1B* directly influences behaviours other than alcohol consumption. However, we cannot rule this out. It may be possible, for example, that carriers of the *ADH1B* rare allele are more likely to become anxious due to, or take medication to counter, any negative side-effects of their alcohol intake, which in turn could directly affect foetal development, violating the exclusion restriction. We directly investigate this in Section 4.4, examining the distribution of an extensive set of maternal characteristics during pregnancy by genotype, including maternal diet, health and health conditions, physical activity, the use of medication, substance use, mental health, and the use of chemicals.

Third, Linkage Disequilibrium (LD) refers to certain genetic variants potentially being co-inherited with other variants. Whether this violates the exclusion restriction depends on the function(s) of any co-inherited variants. *ADH1B* is in weak LD with other variants on the Alcohol Dehydrogenase genes, such as *ADH1A* and *ADH1C*, but these have all been shown to relate to alcohol metabolism, rather than to behaviours other than drinking (Birley et al., 2009).

More generally, we investigate the potential violation of the exclusion restriction by searching the medical literature on the relationships between *ADH1B* and other variables. In addition to consistent evidence of an association between *ADH1B* and alcohol intake (see also below), the SNP is consistently associated with conditions such as liver cirrhosis (see e.g. Lorenzo et al., 2006), head and neck cancer (see e.g. Brennan et al., 2004; McKay et al., 2011), upper aerodigestive tract cancer (see e.g. Canova et al., 2009) and oesophageal cancer (see e.g. Zhang et al., 2006). These are all associated with alcohol consumption, strongly suggesting that the SNP affects the outcomes *through* its effect on alcohol intake.

Assumption 3: Nonzero effect of instrument on treatment

$$E[A_i(1) - A_i(0)] \neq 0$$

This implies that the instrument has some effect on treatment. It is essential for this association to be replicated in a large number of independent studies, as it has been shown that many initial

genetic associations fail to replicate in independent samples (Colhoun et al., 2003; see also Beauchamp et al., 2011). Individuals with the rare variant of *ADH1B* are predicted to consume less alcohol than those with two common alleles. With that, foetuses of mothers who carry the rare variant have a reduced exposure to alcohol compared to foetuses of mothers who carry the common variant. This negative association is very robust and has been replicated in numerous independent genetic studies (see e.g. Reich et al. (1998); Whitfield et al. (1998); Saccone et al. (2000, 2005); Loew et al. (2003); Wall et al. (2005); Duranceaux et al. (2006); Zintzaras et al. (2006); Luo et al. (2006); Zhang et al. (2007); Ghosh et al. (2008); Tolstrup et al. (2008); Zuccolo et al. (2009); MacGregor et al. (2009); Sherva et al. (2009)), confirming Assumption 3; we show the standard statistical tests below.

Assumption 4: Monotonicity

$$P[A_i(1) \leq A_i(0)] = 1 \qquad \text{for all } i.$$

This means that the potential exposure or treatment for child i whose mother does not carry the rare variant is at least as high as the potential treatment for the same child whose mother does carry the rare variant, for all i. As discussed above, *ADH1B* does not make individuals alcoholics, nor does it stop people from drinking altogether; it only affects intake by a small amount. As such, individuals will not be aware of their genotype, and it is therefore very unlikely that they would engage in any potential 'compensatory responses', such as drinking less because they may be genetically less 'protected' against drinking. Hence, we assume that the foetus is less exposed to alcohol if the mother carries the risk allele than if she does not.

We use assumptions 1 to 4 to interpret differences in average outcomes and treatments at different values of the instrument. Under these assumptions, the instrumental variables (Wald) estimand, defined as the ratio of the difference in average outcomes at two values of the instrument to the difference in average treatment at the same two values of the instrument, can be written as:

$$\hat{\beta}_{IV} = \frac{E[S_i|Z_i=1] - E[S_i|Z_i=0]}{E[A_i|Z_i=1] - E[A_i|Z_i=0]}. \qquad (1)$$

This is a Local Average Treatment Effect: the effect of *in utero* alcohol exposure on child academic achievement for children whose mother was induced by the instrument to reduce her alcohol intake. Our instrument picks up differences in children's exposure for mothers with and without the rare variant. Mothers who carry the rare variant are more likely to abstain in

pregnancy, less likely to binge, and on average consume less if they drink at all. We therefore start by exploring the effects of *any* alcohol exposure on academic achievement, but we are also interested in the effects of the *dose*, *pattern* and *duration* of exposure. However, estimating the effects of these additional treatments has implications for our IV approach. Indeed, with only one instrument, as we can only estimate the effect of one treatment at a time. When estimating the effect of an increase in the *duration*, for example, the exclusion restriction implies that our instrument Z only affects the outcome through its effect on the duration. However, Z may also affect the outcome through its effect on the dose and pattern of exposure. As such, specifying separate models for each treatment may violate our assumptions. In an attempt to deal with this, we start the analyses by defining treatment as a binary indicator equal to one if the foetus was exposed to *any* alcohol during the course of the pregnancy, and equal to zero otherwise. This measure picks up a *combined* effect of any alcohol exposure *in utero*, ranging from light to heavy exposure, and including shorter as well as longer exposures.

We then estimate the effects of the dose, pattern and duration of exposure, but recognize the potential limitation of this approach with respect to the IV assumptions. The *pattern* variable (binge drinking) is binary; the *dose* and *duration* are count variables. Using a variable treatment intensity for the *dose* and *duration*, the Wald estimand becomes

$$\hat{\beta}_{IV} = \sum_{a=1}^{\bar{a}} \omega_a E[S_i(a) - S_i(a-1) | A_i(1) \leq a < A_i(0)],$$

where $\bar{a}$ is the maximum of a, and the weights $\omega_a = \frac{P[A_i(1) \leq a < A_i(0)]}{\sum_{j=1}^{\bar{a}} P[A_i(1) \leq j < A_i(0)]}$ are non-negative and sum to one (Angrist and Imbens, 1995; Angrist and Pischke, 2009). Hence, the IV estimate with variable treatment intensity is a weighted average of the causal responses to a unit change in treatment, for those whose treatment status is affected by the instrument. The weight attached to the average of $S_i(a) - S_i(a-1)$ is proportional to the number of people who, because of the instrument, change their treatment intensity from more than a units to a or less (Angrist and Imbens, 1995). We show these weight functions in section 4.4.

3.2 Interpretation of the estimates

The interpretation of our estimates is not straightforward, but rather depends on two important issues. First, we note that we identify an 'overall' or 'total' effect of alcohol exposure, which includes any effects that alcohol has on other substance use that in turn may affect child development. Indeed, if we were interested in the effects of alcohol exposure *per se*, our estimates may be either upward or downward biased, depending on whether alcohol and other

substances are compliments or substitutes. For example, if alcohol and e.g. cannabis are substitutes (DiNardo and Lemieux, 2001) and prenatal exposure to cannabis negatively affects the child academic attainment *S*, the positive numerator of (1) will be reduced by the negative effect of cannabis. As the denominator is unchanged, the IV estimate would *under*estimate the effect of alcohol *per se*. Conversely, if alcohol and e.g. smoking are complements (Dee, 1999), and prenatal exposure to smoking negatively affects child development, the IV estimate would *over*estimate the effect of alcohol.

We directly explore any potential complements and substitutes of alcohol below, where we test whether there are any systematic differences by genotype in the use of a wide range of substances, including caffeine, smoking, cannabis, amphetamine, barbiturate, cocaine, heroin, methadone and ecstasy. We also examine whether maternal prenatal alcohol consumption affects her substance use using IV regressions. Our results show no systematic patterns, suggesting that the 'overall' effect we identify is similar to the 'alcohol-effect' *per se*.

The second issue to note regarding the interpretation of the estimates is that our treatment of interest is prenatal alcohol *exposure*. Foetal exposure to alcohol consists of three components: maternal consumption, maternal metabolism, and foetal metabolism. The rare allele of maternal *ADH1B* rs1229984 is negatively associated with exposure through maternal consumption and metabolism: it is associated with a reduction in intake and an increase in the metabolic rate. Hence, the numerator of the Wald estimand (1) captures this total, or *combined,* 'exposure effect'.

Ideally, therefore, we would like our treatment variable in the denominator of (1) to be a direct measure of exposure, such as foetal blood alcohol levels. For obvious practical and ethical reasons, however, we do not observe this. As we discuss below, we only observe one component of alcohol exposure: maternal alcohol consumption. This could be problematic, as, holding alcohol intake constant, blood alcohol levels may be lower in rare allele carriers of *ADH1B* due to the increased speed with which ethanol is broken down.

We search the literature to investigate the relative importance of the three components through which *ADH1B* may affect foetal alcohol exposure. As we discuss above, this shows clear evidence that *ADH1B* is an important determinant of the first component: alcohol intake. We also find this in our data: as we show below, those who carry the rare allele drink around 0.8 units a week less compared to those not carrying the rare allele; a difference similar to a 53% decrease relative to the mean. In addition, as alcohol consumed by the mother can cross the placenta without delay, it may immediately affect the foetus. Although there is no evidence on the importance of the effect of *ADH1B* on *foetal* metabolism, there is some – albeit little – evidence on adult metabolism. Neumark (2004) finds that *ADH1B* explains 8.5% of the variance in alcohol

elimination rate in a sample of 109 (Jewish) male students. Hence, although the evidence is limited, this would suggest that maternal metabolic rates do play a role, which we are not able to account for. In other words, as we only observe one of the three components of alcohol exposure in the denominator of (1), and since the numerator captures the full 'exposure effect', the IV estimate based on consumption alone is likely to be overestimated. Hence, although the sign of our estimates is correct, we cannot identify the exact magnitude, and we argue that our analysis provides an upper bound of the causal effect of alcohol exposure *in utero*.

4. Data

Our data are from a cohort of children born in one geographic area (Avon) of England. Women eligible for enrolment in the population-based Avon Longitudinal Study of Parents and Children (ALSPAC) had an expected delivery date between 1 April 1991 and 31 December 1992. Note that the first official guidelines on prenatal alcohol consumption, mentioning that pregnant women should not drink more than 1-2 units of alcohol once or twice a week, were only issued by the UK Department of Health in 1995; after this cohort was born. Despite this, the US Surgeon General advised women not to drink in pregnancy as early as 1981 (Office of the US Surgeon General, 1981), and it is unlikely that UK women were completely insulated from this information. Approximately 85% of eligible mothers enrolled, leading to about 14,000 pregnancies (ALSPAC is a cohort; there is no systematic data collection on siblings).[9] The Avon area has approximately 1 million inhabitants and is broadly representative of the UK as a whole, although slightly more affluent than the general population (Boyd et al., 2012; Fraser et al., 2012; see www.bristol.ac.uk/alspac for more a detailed description of the data).

Just over 12,000 children had at least one completed questionnaire. Our sample selection process is as follows. First, we exclude children whose mother or father is of non-white ethnic origin to reduce the risk of population stratification. Second, we select mothers for whom we observe both their and their child's genotype, leaving us with 5,531 observations.[10] Third, we

[9] Of the 14,676 foetuses with a known birth outcome, 14,062 were live births and 13,988 were alive at 1 year. As we do not observe the genotype of mothers whose children did not survive, we cannot directly explore whether alcohol exposure *in utero* affects survival rates. However, if the genotype affects the survival of foetuses, it would not be in Hardy-Weinberg equilibrium (which states that allele and genotype frequencies in a population remain constant from generation to generation in the absence of other evolutionary influences, such as non-random mating and selection). We checked this and *ADH1B* is in equilibrium.

[10] For our sample of mother-child pairs, we observe a total of 7,088 maternal genotypes, and 8,886 child genotypes at rs1229984. As we require both genotypes in the analyses, we can only use those observations for which we observe the two: n = 5,513. It is unlikely that missing genotype data introduces selection bias. First, empirical evidence on other data suggests that genotype frequencies are the same for general-population versus selected samples (e.g. the British 1958 birth cohort versus British blood donors from the Wellcome Trust Case–Control Consortium; see WTCCC, 2007). Second, empirical evidence shows that genotype frequencies do not differ by the timing of non-response to questionnaires (see Bhatti et al., 2005). And third, we examine potential bias in our data due to missing genotypes by investigating whether, conditional on observing genetic information, the probability of being in the final

drop observations with missing data on all measures of prenatal alcohol exposure (n = 134), resulting in 5,397 observations. We further restrict the sample to children for whom we observe their academic achievement at least once. Depending on the measure of alcohol exposure and on the outcome of interest, the final sample includes between 1,922 and 4,088 mother-child matches.[11]

4.1 Measures of academic achievement

We specify different measures of academic achievement. First, we use an entry assessment test, taken by all pupils about to start primary school (ages 4-5). Although there were no compulsory national assessment tests at this time, the Local Education Authorities covering the ALSPAC area used the same tests, which is available for 80% of (not privately owned) schools. In addition, we use four nationally set exams taken at ages 7, 11, 14 and 16 (also known as the Key Stage 1 (KS1), Key Stage 2 (KS2), Key Stage 3 (KS3) and Key Stage 4 (KS4, or GCSE) exam respectively). These measures of children's performance are objective and comparable across all children. Children's scores are obtained from the National Pupil Database, a census of all pupils in England within the state school system, which is matched into ALSPAC. For each of the Key Stage tests (1 to 4), we use an average score for the child's mandatory subjects, standardized on the full sample of children for whom data is available, with mean 0 and standard deviation 1.[12]

4.2 In Utero exposure and the genetic marker

We use the binary genetic instrument *ADH1B*, comparing those with genotype GA or AA to those with genotype GG (A being the rare allele, where the effect is dominant; i.e. carrying one rare allele, GA, has a similar effect on alcohol consumption as carrying two, AA). Depending on the specification of interest, between 4.7 and 5.2% of our sample carry as least one rare allele.[13]

As discussed above, we would ideally use a direct measure of alcohol exposure *in utero*, such as

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sample differs by maternal and child genotypes. In other words, we test whether the genotype frequencies for mother and child differ, comparing the sample where we observe both genotypes (i.e. our estimation sample) to the sample where we only observe just the mother's or just the child genotype. We find no evidence that mother or child genotype frequencies differ between the two samples ($p = 0.12$ and $p = 0.58$ respectively), suggesting that the missingness is unrelated to the instrument.

[11] The low sample sizes are mainly driven by third trimester alcohol intake for which an additional 35% (of the maximum of 5,397 observations) is missing. Lower educated women are more likely to be missing in the third trimester. However, this does not affect our results, which are robust the use of different samples. More generally, Boyd et al. (2012) and Fraser et al. (2012) show that the lower socio-economic groups are more likely to attrite.

[12] For KS1, this is an average of the child's reading, writing, spelling and maths scores; KS2 includes reading, writing, science and maths. For KS3 and KS4, the final score is an average of the child's English, maths and science.

[13] With our sample sizes, this corresponds to 106 to 267 mothers (presented in Table 1 below); a relatively low number.

foetal blood alcohol levels. As this is not available in the data, we proxy alcohol exposure *in utero* by maternal alcohol consumption during pregnancy. We start the analyses using a binary variable indicating whether the foetus was exposed to alcohol *in utero.* This equals one if the woman reports drinking any amount at any point during pregnancy, and equals zero if the woman reports not to drink in the first, second, as well as third trimester, and reports not to have binged (i.e. has non-missing values for alcohol intake in each trimester).[14] We then examine the effect of the *dose* of alcohol exposure, measured by the number of units consumed per week, averaged over the first, second, and third trimester. In addition, we examine the *pattern* and *duration* of alcohol exposure. We proxy the pattern by investigating the effects of bingeing, defined by drinking the equivalent of two pints of beer, four glasses of wine, or four pub measures of spirit in one day, measured in the second trimester. The duration is measured by a count variable ranging from 0 to 3, representing the number of trimesters during which the foetus was exposed to alcohol.

Several epidemiological studies distinguish between the effects of different *types* of beverages, noting increases in preterm births or decreases in birth weight primarily among beer drinkers (e.g. Kline et al., 1987). To investigate potential differences in the type of drink, we separately examine the effects of beer or wine consumption. This explores differences in (e.g.) wine consumption among those who report not consuming other alcoholic drinks. We do not use information on the consumption of spirits, as too few mothers report drinking spirits during pregnancy. The questionnaire explained that half a pint of ordinary strength beer, lager or cider, and a small glass of ordinary strength wine contains one (UK) unit of alcohol (similar to 10ml or 8 grams of ethanol).

Note that all measures of alcohol exposure may be subject to substantial measurement error. First, the concentration of alcohol in different types of beers and wines varies considerably. Second, the size of a glass of wine in a bar or restaurant can vary anywhere between 125ml to 250ml. Third, these standard measures of 125 or 250 ml are only used in bars and restaurants; measures at home are likely to differ. Fourth, women may under-report their consumption during pregnancy (e.g. Gray and Henderson, 2006). Combining the measurement error with the imprecision and bias related to the reporting of alcohol consumption, this can lead to considerable underestimation of the amount of alcohol actually consumed (Stockwell et al., 2004), which may drive OLS estimates towards the null, though the IV may partially correct for

[14] Alcohol consumption in the first, second, and third trimesters are obtained from questionnaires at 8, 18, and 32 weeks gestation respectively. Note that the first trimester questionnaire was only sent out to mothers who enrolled before 14 weeks gestation; this is almost half of all mothers in our data. The other half were asked about their first trimester alcohol consumption at a later date. For ease of description and discussion however, we refer to this as the week 8, or first trimester, questionnaire. In the first and third trimester, women were directly asked to report the number of alcoholic units consumed per week. In the second trimester, women were asked to report the number of units of beer, wine, spirits and other alcohol per week, which we sum to obtain the total number of units.

this, assuming that the instrument is unrelated to the measurement error. We explore this assumption indirectly in Section 4.4, showing no systematic correlation between the instrument and a wide range of covariates.

4.3 Covariates

Conditioning on covariates is not necessary to obtain unbiased estimates in Mendelian randomization studies, as the covariates do not enter the assignment (randomization) mechanism. In fact, it is unclear *which* covariates to include in a Mendelian randomization study, as any characteristic is measured post-randomization, and – with that – may be affected by the instrument (von Hinke Kessler Scholder et al., 2011, 2013). For this reason, we do not control for covariates in our main analysis, though we discuss and report the estimates that adjust for a wide variety of different sets of covariates in Section 5.9 and Appendix D.

The exception however, is that we include ten ancestry-informative principal components to account for any remaining population stratification, and we control for the *child's* genotype. We include the latter for two reasons. First, when alcohol consumed by the mother crosses the placenta, the child's *ADH1B* may also start oxidizing the ethanol (depending on whether the enzyme is expressed *in utero*). Second, the child's genotype is likely to be related to the child's alcohol consumption later in life, and may –through that– affect the child's academic achievement, although this is not likely for academic outcomes measured at younger ages. Including the child's *ADH1B* will account for these potential biases. However, the results are not sensitive to the inclusion or exclusion of the child's *ADH1B*.

4.4 Descriptive Statistics

As discussed in Section 3, the IV estimate for the dose and duration of alcohol exposure is a weighted average of the unit causal response. Figure 2 presents the weight function, plotting the differences (between those carrying no risk alleles and those carrying at least one risk allele for *ADH1B*) in the probability that alcohol intake is at or exceeds the level on the x-axis. This shows that those who carry no risk allele of *ADH1B* are between two and 13 percentage points more likely to drink, depending on the number of units examined. The intensity of the shift is highest around 2 to 3 units per week, declines thereafter, but remains positive throughout.

Table 1 presents descriptive statistics of the average alcohol consumption during pregnancy. We show these for the full sample (column 1), as well as by genotype (columns 2 and 3). Panel A shows that, on average, 62.7% of the sample drank any alcohol during pregnancy, but this varies

by genotype, with 63.3% of mothers who are homozygous for the common allele drinking alcohol, and 50.7% of those who carry at least one rare allele. Furthermore, we find that 17.0% of mothers who have two common alleles binged at least once in the second trimester, compared to 11.2% among those carrying at least one rare allele. Similarly, using the number of trimesters in which the mother drinks as a proxy for the duration or length of exposure, we find the average to be 0.99 for those carrying two common alleles, compared to 0.59 for those carrying at least one rare allele.

The average number of units of alcohol per week is just over 1.5. However, there is much variation around this: the average number across pregnancy ranges from 0-35, with the variation in the number of beers being larger than that for wine. There are again large differences by maternal genotype, as shown in columns 2 and 3. Mothers who are homozygous for the common allele, for example, drink an average of 1.55 units a week. This is 0.65 units a week among those carrying at least one rare allele.

The second part of the table shows the between and within standard deviations for the number of units of alcohol, wine and beer consumed for the full sample and the two genotypes separately. This shows that most of the variation lies between mothers, though there remains considerable variation within mothers. This suggests that mothers do alter their alcohol intake; it is not the case that mothers' alcohol consumption remains stable over the course of her pregnancy. In other words, our results are not based on one particular group of mothers who do not change their behaviour during pregnancy.

To provide evidence on the validity of our IV approach, we exploit the richness of our data and correlate the instrument to an unusually extensive range of maternal and paternal prenatal background characteristics (we explore activities after birth – i.e. those that may be affected by child development – in Section 5.5). This is presented in Appendix B, showing the mean and standard deviation of a wide range of variables by the value of the instrument. With random assignment of genetic variants, there should be no systematic variation in covariates by genotype.

We start by testing covariates that are related to the (potential) alcohol intake of the mother's genetically-related family. With each maternal allele having a 50% chance of being inherited by the child, children are more likely to carry the rare allele if their mother does. Similarly, we find that, among mothers who carry the rare allele, her mother and father are slightly less likely to have an alcohol problem. The mother's partner, however, is equally likely to drink during and after birth (at 8 months) for mothers with or without the rare allele, suggesting that potential assortative mating based on alcohol consumption is not an important issue.

Our further extensive range of covariates includes (i) a set of 'standard' covariates, (ii) maternal tea/coffee/milk consumption, (iii) parental diet and nutrition, (iv) parental attitudes to breastfeeding and other parenting issues, (v) religious beliefs, (vi) household and family characteristics, (vii) previous/current pregnancies and conditions during labour and delivery, (viii) mother's and partner's physical health, including a wide range of conditions measured both in the first and second trimester of pregnancy, (ix) mother's physical activity, (x) measures of parental mental health, (xi) maternal use of medication in the first and second trimester as well as after pregnancy, (xii) parental substance use, (xiii) mother's use of chemicals during pregnancy, (xiv) the extent of social support available to the mother and partner, and (xv) neighbourhood characteristics.

All tests are reported in Table B1, showing no systematic differences in the wide range of covariates by maternal genotype. We compare the number of correlations that are statistically significant with the number expected by chance if all variables were uncorrelated (excluding the characteristics of genetically-related family). We find no greater association between the genetic variant and the covariates than what would be expected by chance ($p = 0.32$ at the 10% level, $p = 0.46$ at 5%, and $p = 0.48$ at 1%), suggesting that the SNP is independent of behavioural or environmental factors that may affect the outcome of interest. Indeed, in the robustness checks in Appendix D, we test the sensitivity of our analysis by controlling for these covariates in the IV specification, leaving our findings unaffected.

5. Results

5.1 OLS results

Table 2 presents the OLS estimates of the associations between prenatal alcohol exposure and child educational attainment, controlling for the ancestry-informative principal components and the child's *ADH1B*. Panel A reports the estimates for *any* alcohol exposure, showing an insignificant relationship with the different measures of child educational attainment, presented in the columns. Panel B shows a clear negative association between maternal binge drinking and educational achievement, whilst a longer exposure to alcohol is positively correlated with children's academic attainment.

Examining the (average) number of units of alcohol in Panel C shows an ambiguous association; OLS coefficients are sometimes positive, sometimes negative, but most estimates cannot be distinguished from zero. In contrast, the table shows strong positive correlations for exposure to wine, but negative associations for exposure to beer. Although this could reflect differential effects of wine and beer, it is more likely to simply reflect other characteristics of mothers who

drink wine as opposed to beer during pregnancy.

Indeed, column 1 and 2 in Table 3 present the results from separate regressions of any alcohol and binge drinking respectively on the 'standard' covariates presented in Appendix B, showing a strong socio-economic gradient in prenatal alcohol exposure. Mothers of higher socio-economic position are more likely to drink alcohol, and less likely to binge, whereas length of exposure (column 3) is positively associated with socio-economic position. The positive gradient is stronger for wine consumption (column 5), than for mothers who drink beer or other alcoholic beverages (column 6): older, better educated, higher social class, employed mothers, and those with higher family income and a better educated, employed partner are more likely to consume wine, whilst smoking, lower educated mothers with worse mental health are more likely to drink beer. This social gradient in alcohol consumption and the inverse gradient for binge drinking is consistent with that observed in other US and UK surveys.[15]

5.2 IV results

Table 4 presents the first stage IV results, regressing prenatal alcohol exposure on the genetic instrument whilst controlling for the child's *ADH1B*. As expected, we find a negative correlation between maternal *ADH1B* and *in utero* alcohol exposure: mothers who carry at least one rare allele of *ADH1B* are less likely to drink any alcohol (column 1), less likely to binge (column 2), have a shorter duration of alcohol consumption (column 3), and drink fewer units of alcohol compared to those carrying two common alleles (columns 4-6). Hence, children born to these mothers have a reduced alcohol exposure during pregnancy. The *F*-statistic depends on the specification and sample size used, and is strongest when we consider the number of units of alcohol, ranging between 16 and 23. If we do not control for the child's genotype, this increases to 28-43, with similar point estimates and slightly smaller standard errors, suggesting that *ADH1B* predicts alcohol exposure well, but that the inclusion of child *ADH1B* reduces its precision. The coefficients suggest that those who carry the rare allele are between 11 and 15 percentage points less likely to consume any alcohol during pregnancy. They drink between 0.77 and 0.86 units a week less compared to those not carrying the rare allele. The wine and beer-specific effects are smaller, though in the same direction. As discussed above, alcohol intake is only one of the three components through which the foetus may be exposed to alcohol, and hence, this is likely to be an underestimate of the effect of *ADH1B* on actual *exposure*.

[15] Although the majority of these explore the social gradient in alcohol consumption in general (see e.g. Cutler and Lleras-Muney (2010), using the National Health and Interview Survey, the Health and Retirement Study, the National Longitudinal Survey of Youth 1979, and the National Child Development Study), others explore alcohol intake during or just after pregnancy (e.g. Bartley et al. (2005) and Dezateux et al. (2005) using the UK Millennium Cohort Study).

The second stage IV results are presented in Table 5. To deal with potential weak instruments, we report the weak-instrument robust 95% confidence bounds, based on the Anderson Rubin statistic (Andrews et al., 2006). This shows consistent negative effects of any prenatal alcohol exposure, bingeing, the duration, and the dose of alcohol exposure on all measures of child educational attainment, though due to the sometimes large standard errors, not all are significant. The magnitude of the estimates is considerable, though as we discuss above, we argue these are upper bounds of the causal effect of alcohol exposure.

Increasing the number of units of alcohol *in utero* lowers child academic attainment, with similar effect-sizes when examining the different educational outcomes. The estimates suggest that exposure to an additional unit of alcohol reduces academic achievement by up to 0.2 to 0.3 standard deviations. There is a slight suggestion that the negative effects of alcohol exposure increase as the child ages, with larger effects for the KS4 exam compared to the entry assessment or KS1 exams, indicating possible accumulation of educational gaps and complementarity of educational achievement over time.

Examining the two types of alcoholic beverages, we find similar negative effects to the 'average alcohol' specification, though they are less well defined due to the smaller sample sizes, and larger due to the weaker first stage association (and therefore smaller denominator in (1)). Note, however, that the instrument is not specific to wine or beer consumption, but to alcohol intake more generally. The estimates can therefore not be interpreted as the specific effect of wine or beer intake, but rather indicate that the OLS associations, suggesting that wine improves and beer worsens child development, are likely to be biased due to unobserved confounding.

Although we argue that our IV estimates are an upper bound of the true causal effect, we are not the first to estimate such large effects, or to see a different association from the OLS after attempting to account for residual confounding. Indeed, Nilsson (2008) finds substantially large effects of prenatal alcohol exposure on human capital outcomes in Sweden. Similarly, Rosenzweig and Wolpin (1994) and Wüst (2010) obtain considerably larger negative effects in within-mother specifications compared to more ambiguous results in the OLS or GLS. Furthermore, it is consistent with the literature on the long-term effects of early life conditions on later-life outcomes. This literature generally finds that foetal shocks have large impacts on later outcomes, including on test scores, educational attainment, and other developmental outcomes (see e.g. Currie, 2009; Almond and Currie, 2011). In addition and as discussed above, our measures of exposure are likely to be subject to considerable measurement error, which may drive OLS estimates towards the null. The IV, however, is not affected by this, resulting in larger estimates (in absolute value).

5.3 Reduced forms

Table 6 presents the reduced form estimates from separate regressions of the test scores on the maternal genotype, and regressions of the test scores on the child's genotype (Panel A); Panel B includes both genotypes simultaneously. All analyses control for the ancestry-informative principal components. Recall that exposure to alcohol *in utero* results from a combination of three components: maternal consumption, maternal metabolism, and foetal metabolism. These analyses therefore shed light on whether the effect we find is likely to come via the combined consumption and metabolism through the mother, or via the foetal metabolism. We find a strong positive estimate for the maternal genotype, with much smaller and close-to-zero estimates for the child's genotype, suggesting that the alcohol effect runs through maternal intake and metabolism, rather than via the child metabolizing its mother's alcohol.

5.4 The prenatal period

We are interested in the effect of *prenatal* alcohol exposure on child academic achievement. For mothers who carry a rare allele of *ADH1B*, however, *their* mother may also have been a carrier. As such, the mother's mother may have drunk less during her pregnancy, affecting the mother's cognitive abilities. This implies that we may not be able to attribute the entire observed effect to prenatal drinking by this generation of women alone, as there may also be indirect effects of drinking by the child's female ancestors. However, that does not provide evidence against a detrimental effect of prenatal alcohol exposure on child academic outcomes.

Furthermore, one may argue that our instrument does not solely explain prenatal drinking. In other words, mothers who carry the rare variant of *ADH1B* are likely to have had lower alcohol consumption throughout life. Hence, if the difference in alcohol exposure over the mother's lifetime changes her preferences or attitudes towards her child's education, the estimated effects are not necessarily solely due to *prenatal* alcohol consumption, but may partly reflect a more general alcohol intake.

Similarly, as alcohol consumption is correlated over the life cycle, our estimated negative effects may reflect the combined effects of alcohol consumption in different periods, rather than that specific to the prenatal period. For example, mothers who drink more may – perhaps because of that – spend less time with their children or pay less attention to their children's school performance. Or *children* whose mothers drink more may change their behaviour in response,

affecting their outcomes.[16] To examine these potential pathways, Table B1 (Appendix B), explores whether *ADH1B* rare allele carriers have systematically different behaviours compared to those who carry two common alleles. We find no evidence of systematic differences by genotype.

Another possibility to explicitly examine the effects of *prenatal* alcohol exposure is by using SNPs that only affect exposure during pregnancy. Although the *ADH1B* effect is not specific to the pregnancy period, there is evidence that *ADH1B* is a stronger predictor of alcohol intake and quitting during pregnancy, compared to that in other periods (Jacobson et al., 2006; Zuccolo et al., 2009; Wehby and von Hinke Kessler Scholder, 2013).[17] Hence, we can examine the effect of *quitting* during pregnancy. If prenatal alcohol exposure negatively affects child academic achievement, we would expect to find a positive effect on child academic attainment for those children whose mother's *ADH1B* induced them to quit drinking during pregnancy. To investigate this, we restrict the sample to women who drank prior to pregnancy and define quitters as those reporting not to drink at any point during pregnancy.[18] The findings (available from the authors upon request) show consistent positive effects of quitting during pregnancy on child educational attainment, with estimates of very similar (absolute) magnitude to those in Panel A, Table 5. As above, the results are likely to be an overestimate due to not being able to measure actual *exposure* to alcohol. Nevertheless, the direction of effect is as expected. Hence, although we are not able to fully deal with the specificity of the *prenatal* period, our results are at least suggestive that alcohol exposure during the intrauterine period affects the foetus.

5.5 Parental responsive investments

The large estimates of the effect of prenatal alcohol exposure on child educational attainment call for an investigation into the potentially differential investments that parents make in response to their child's development. The literature on parental responsive investments tends to explore whether they reinforce or compensate for initial endowment differences (for a recent overview of the literature, see Almond and Mazumder, 2013). Understanding these responses is of broad interest and can provide interesting insights into parental responsive investment behaviours.

[16] Although we observe some variables for maternal alcohol intake post-pregnancy, these are categorical variables and therefore the magnitude of any OLS or IV estimates are not comparable to those reported above.
[17] This could suggest an interaction between *ADH1B* and the environment; the latter being pregnancy. With women facing similar environments during pregnancy, those who carry *ADH1B* may find it easier to quit. Alternatively, it could mean that *ADH1B* causes other (physical) changes in pregnancy that lead these women to women quit drinking. Although there is no evidence of the latter, and we find no evidence of this in Table B1, it could violate the IV assumption depending on such other effects of the variant.
[18] In other words, this definition is perfectly negatively correlated with our definition of 'any alcohol' exposure, but the analysis is conditional on the sample of women who drank before pregnancy.

To explore this in detail, we estimate IV regressions to examine whether alcohol exposure *in utero* leads to differential parental responses, considering a wide range of post-birth characteristics and behaviours that parents have control over. These include (i) child diet and nutrition, (ii) immunisations and other health treatments (such as fluoride treatment and the use of vitamins), (iii) interactions between the parents and child, (iv) doctor and dentist visits, (v) parenting and teaching scores of both the mother and her partner, (vi) time use, (vii) maternal worries and concerns about her child, (viii) a set of post-birth household characteristics, (ix) the use of child care, and (x) the level of social support and social network available to the mother and her partner. In addition, many of these variables are observed multiple times after birth, allowing us to also explore whether any differences are systematic over time.

The results are presented in Table C1, Appendix C. These show some significant effects of alcohol exposure *in utero*. For example, consuming alcohol during pregnancy increases (decreases) the likelihood of having given the baby formula (a herbal drink) at age 6 months. However, we find little evidence of any *systematic* patterns in the data that would suggest that prenatal alcohol consumption leads to differential parental choices and behaviours. For example, parents are more likely (at age 6 months) to change nappies at night of babies exposed to alcohol *in utero*, but there is no difference in night-time nappy changing at age four weeks. Similarly, we find that parents of children who are exposed to alcohol *in utero* are less likely to take their child to the dentist or use a toothbrush/toothpaste at 38 month, but they are more likely to have a doctor visit at 18 and 30 months. The only finding that is consistent over time is that exposure to alcohol increases the likelihood that babies are regularly looked after by their grandparents at age 15, 24, and 38 months. Considering the wide range of parental choices explored, however, there seems to be little evidence of any systematic differences in parental responsive investments for children exposed to alcohol *in utero* compared to those not exposed, suggesting that most of the effect we find from prenatal alcohol consumption on academic achievement in foetal in origin.

5.6 Subgroup analysis

To examine whether the effects of alcohol exposure are different for different groups of children, we distinguish between child's gender, mother's age at birth, partner's social class at birth, maternal education, and family income. The results are reported in Table 7. Consistent with Nilsson (2009), the estimates are slightly larger for children of lower educated and lower income mothers. In contrast to previous findings that show boys to be more vulnerable to alcohol exposure *in utero* than girls (e.g. Nilsson, 2009; Barreca and Page, 2012), however, we

find no clear patterns by gender or social class.

5.7 Low-to-moderate drinking

The UK Department of Health suggests that, if women choose to drink during pregnancy, they should not exceed 1-2 units once or twice a week, as "at this low level, there is no evidence of any harm to the unborn baby". If there truly are non-linearities in the effects of alcohol exposure *in utero*, we cannot directly investigate this with only one instrument. To shed some more light on this however, Figure 3 plots the IV point estimates for mothers drinking 1-5, 6-10, 11-15, and 16 or more units a week, comparing each of them to mothers who do not drink. This shows that all estimates are negative, including the indicators for low-to-moderate consumption, though not all are very precisely estimated. Nevertheless, this does suggest that low-to-moderate alcohol exposure also harms the foetus.

5.8 The timing of exposure

For policy purposes, whether there is any differential effect in the timing of exposure to alcohol *in utero* is of substantial interest. Although we observe the number of drinks in each trimester and we can run the analyses separately by trimester, the interpretation of the estimates is limited by the fact that the instrument is not specific to a particular trimester. In other words, since the reduced form (the numerator in (1)) is similar in all analysis for a specific outcome variable (apart from differences due to the sample size), changes in the IV estimates are mainly driven by differences in the first stage (the denominator in (1)). Indeed, unsurprisingly, our results (available upon request) suggest the estimates are similar throughout pregnancy.

5.9 Robustness checks

We perform a range of checks to verify that our results are robust to different specifications, shown in Appendix D. We present the estimates of the average number of units per week during her pregnancy on Key Stage 1 scores, though the findings are robust to the use of the Entry Assessment test, or later Key Stage exams. The different model specifications control for different sets of covariates. We start by controlling for a set of alcohol-related variables (Panel A): specification 1 repeats the KS1 results from Table 5 for comparison; specification 2 includes an indicator for maternal smoking during pregnancy; specification 3 does not include the child's *ADH1B* (i.e. only including the principal components); specification 4 includes (binary) indicators for maternal post-natal alcohol intake when the child was 8, 21, 33, and 47 months

old; specification 5 includes binary indicators for the child's own alcohol consumption at 157, 166, and 185 months; specification 6 accounts for the mother's partner's alcohol consumption in the second trimester, the partner's alcohol intake and bingeing at 8 months, and whether the mother's parent's ever had an alcohol problem.

We next run multiple IV analyses, each time controlling for the different sets of characteristics and behaviours listed in table B1, Appendix B. For these analyses, we only control for the mother's characteristics, as sample sizes reduce substantially when controlling for partner's characteristics due to missing values. However, as most variables relate to the mother, this still controls for an extensive set of covariates that are generally not observed in survey data. Panel B shows that the use of different sets of control variables leads to different sample sizes due to missing values on some covariates. However, our results are very robust, with coefficients of similar magnitudes in all specifications.

6. Discussion and conclusion

This paper examines the effect of alcohol exposure *in utero* on child academic achievement. Simple correlations between alcohol exposure and child academic achievement show somewhat ambiguous results, with exposure to wine having a positive association, but exposure to beer being negative. Binge drinking is bad for the child, but a longer duration of exposure is positively associated with the child's academic performance. However, we present clear evidence of the endogeneity of alcohol intake, showing a strong social gradient in maternal alcohol consumption, with mothers of higher socio-economic status more likely to drink, and in particular, drink wine. In contrast, beer consumption is associated with lower education and worse mental health. To deal with the confounding, we use a genetic variant in the alcohol metabolism gene *ADH1B* as an instrument for alcohol exposure, and show that – in contrast to alcohol consumption – the genetic instrument is unrelated to potential confounders, examining an unusually wide range of maternal and paternal characteristics and behaviours. We include a detailed discussion of the IV assumptions that are required to estimate the causal effect of alcohol exposure. In stark contrast to the OLS, our IV estimates show large negative effects of prenatal alcohol exposure on child educational achievement, which are robust to a large set of model specifications. In addition, the reduced form regressions show that the effects are solely driven by the maternal genotype, with no impact of the child's genotype. Yet, despite the large negative effects, we find little evidence of differential parental responses to child development, exploring a wide range of parental postnatal investments and behaviours.

Our estimates are Local Average Treatment Effects, capturing the effect on children whose

mother was induced by her genotype to reduce her alcohol intake. Although we obviously cannot alter individuals' genotypes, we believe that our estimates remain policy relevant. As argued in Imbens (2010), if randomized experiments are unethical or infeasible, credible evaluations can be based on instrumental variable strategies. Although they are second best to randomized experiments, as they rely on additional assumptions and have less external validity, they are often all we have. The relatively small number of studies attempting to deal with the endogeneity of prenatal alcohol exposure indeed suggest that it is particularly difficult due to unobserved residual confounding. Using different methodological approaches, these studies find negative effects of prenatal alcohol exposure on child development (see e.g. Nilsson, 2008; Rosenzweig and Wolpin, 1994; Wüst, 2010; Zhang, 2010; Fertig and Watson, 2009). There is no evidence *a priori* to suggest that different sources of variation in alcohol exposure lead to different effects of exposure on academic achievement. In addition, if there is a *biological* effect of alcohol exposure (damaging the developing brain), any reduction in exposure should improve child outcomes. Hence, despite estimating a LATE, we believe that our estimates have some external validity and are relevant to policy.

Although the mothers in our sample were pregnant before the official UK guidelines on prenatal alcohol consumption were released, we believe our results are still likely to be relevant in today's context for three reasons. First, the US Surgeon General advised women not to drink during pregnancy as early as 1981, and it is unlikely that UK women were completely insulated from this information. Second, with the UK's most recent guidelines on alcohol consumption during pregnancy being very similar to their first guidelines, we assume that differences in the information available between the early 1990s and today are modest. Third, it is unlikely that the *biological* effects of alcohol exposure on child development have changed over time, suggesting that the results are also relevant for today's society.

Although we argue that our estimates may be an upper-bound, they are very robust to different model specifications. In addition, we are not the first to find such large effects: the few papers that attempt to deal with unobserved confounding in alcohol exposure also find large negative effects on child development (see e.g. Nilsson, 2008; Wüst, 2010; Zhang, 2010).

Nevertheless, the paper has several limitations. First, we are not able to fully deal with the specificity of the *prenatal* period. Second, we cannot make any strong statements about the specific effects of *low-to-moderate* versus *excessive* prenatal alcohol intake, though the analyses suggest that both negatively affect child academic attainment. Third, although the results suggest the effects are similar for alcohol intake throughout pregnancy, we cannot rule out differential effects of the timing of exposure. Fourth, as with any other IV analyses, the validity of independence and exclusion will never be known with complete certainty. However, the well-

known mechanism of *ADH1B*, its location on the chromosome, the literature search on the effects of *ADH1B*, and our extensive tests examining the distribution of child and family characteristics by genotype all suggest that the SNP is independent of behavioural or environmental factors that may affect the outcome of interest.

Hence, by examining the link between prenatal alcohol exposure and child educational outcomes, this paper contributes to the economic literature on the long-term effects of the early environment on later child outcomes (e.g. van den Berg et al., 2006; Almond, 2006; Currie, 2009; Almond and Currie, 2011; Almond and Mazumber, 2011), on potential differential investments by parents in response to child development (Almond and Mazumder, 2013), and on identifying critical and sensitive periods of parental investments *per se* (e.g. Cunha and Heckman, 2007). We also provide advice to policy makers, showing that low-to-moderate alcohol exposure *in utero* may have similar negative effects on the foetus that may be carried into childhood and adolescence. In addition, since it is unethical to design a randomized controlled trial to study foetal alcohol exposure, we show that quasi-experimental designs such as Mendelian randomization can provide powerful alternatives for causal inference.

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Appendix A: A Brief Introduction to Genetics

Each cell in the human body contains a nucleus in which most DNA (99.9995%) is located. DNA forms structures called chromosomes, where each chromosome contains a single continuous piece of DNA. All cells in the human body apart from gametes (i.e. germ cells) contain 46 chromosomes, organized into 23 chromosome pairs: one copy of chromosome 1-22 from each parent, plus an X-chromosome from the mother and either an X or a Y chromosome from the father.

Sites within DNA which vary between people are called polymorphisms. The most commonly studied form of polymorphism is a Single Nucleotide Polymorphism (SNP): a single base-pair variation in a particular location on the DNA sequence. As chromosomes come in pairs, humans have two base-pairs at each location (locus). Where there are two or more forms of DNA at a specific locus, these different forms are called alleles. The term genotype is used to describe the specific set of alleles inherited at a particular location on the chromosome. For example, individuals can have one of two alleles on each chromosome at the rs1229984 locus (A or G), this will result in three genotypes: they can be homozygous for the common allele (having two of the same common/most prevalent alleles: GG), heterozygous (AG), and homozygous for the rare allele (AA).

Appendix B: Tests of Independence

To provide evidence on the validity of our IV approach, Table B1 presents descriptives of the covariates presented in the first column by genotype. Column 3 shows the *p*-value of a test whether the mean among those homozygous for the common allele (column 1) equals the mean among those carrying at least one rare allele (column 2). With random assignment of genetic variants, there should be no systematic variation in covariates by genotype. Table B1 shows this for a wide range of maternal and paternal prenatal background characteristics and behaviours (we investigate activities after birth – i.e. those that may be affected by child development, exploring potential parental responsive investments – in section 5.5).

We compare the number of correlations that are statistically significant with the number expected by chance if all variables were uncorrelated (excluding the first set of covariates, which concern genetically-related family members). We find no greater association between the genetic variant and covariates than what would be expected by chance (*p = 0.32* at the 10% level, *p = 0.46* at 5%, and *p = 0.48* at 1%), suggesting that the SNP is independent of behavioural or environmental factors that may affect the outcome of interest.

Table B1: Descriptive statistics: mean and standard deviation of covariates

	(1) Mother is homozygous for the common allele at rs1229984 Mean (std dev)		(2) Mother carries at least one rare allele at rs1229984 Mean (std dev)		(3) t-test *p*-value
Alcohol-related covariates of mother's family					
Child's *ADH1B* (rs1229984)	0.029	(0.168)	0.471	(0.500)	<0.001
Mother's mother has alcohol problem	0.022	(0.147)	0.008	(0.091)	0.125
Mother's father has alcohol problem	0.054	(0.226)	0.034	(0.181)	0.094
Alcohol-related covariates of mother's partner					
Partner's drinks any alcohol (at 18 wks gestation)	0.705	(0.456)	0.728	(0.446)	0.436
Partner's drinks any alcohol (at 8 months)	0.749	(0.434)	0.702	(0.457)	0.573
Freq. partner drinks>4units (8 month; 0=never,5=daily)	2.088	(1.390)	1.966	(1.558)	0.315
'Standard' covariates[1]					
Girl	0.482	(0.500)	0.505	(0.501)	0.449
Child's age at KS1 (in months)	88.727	(3.735)	88.302	(3.673)	0.096
Mother's age at child's birth (in years)	28.543	(4.666)	28.651	(4.555)	0.709
Older siblings (0, 1, or 2+)	0.726	(0.748)	0.727	(0.746)	0.972
Younger siblings (0, 1, or 2+)	0.048	(0.220)	0.075	(0.279)	0.068
Father's education: O-level	0.309	(0.462)	0.293	(0.456)	0.582
Father's education: A-level	0.275	(0.447)	0.293	(0.456)	0.533
Father's education: University degree	0.190	(0.392)	0.202	(0.402)	0.646
Mother's education: O-level	0.444	(0.497)	0.451	(0.499)	0.809
Mother's education: A-level	0.233	(0.423)	0.257	(0.438)	0.366
Mother's education: University degree	0.146	(0.353)	0.153	(0.361)	0.749
Social class: Semi-skilled	0.098	(0.297)	0.070	(0.255)	0.145
Social class: Skilled manual	0.301	(0.459)	0.332	(0.472)	0.304
Social class: Skilled non-manual	0.114	(0.318)	0.082	(0.275)	0.119
Social class: Managerial/Technical	0.349	(0.477)	0.361	(0.481)	0.718
Social class: Professional	0.114	(0.317)	0.119	(0.324)	0.798

Ln(income)	5.331	(0.479)	5.352	(0.452)	0.510
Mother employed	0.499	(0.500)	0.444	(0.498)	0.103
Father employed	0.873	(0.333)	0.897	(0.305)	0.274
CCEI [score ranging from 0-44]	13.009	(7.485)	12.943	(7.222)	0.894
EPDS [score ranging from 0-23]	6.629	(4.723)	6.440	(4.760)	0.538
Smoking (first trimester)	0.172	(0.377)	0.136	(0.343)	0.131
Mother's tea, coffee & milk, 8 weeks gestation					
Drink tea	0.799	(0.401)	0.749	(0.434)	0.050
Drink decaf tea	0.035	(0.184)	0.034	(0.182)	0.951
Drink coffee	0.511	(0.500)	0.492	(0.501)	0.556
Drink decaf coffee	0.157	(0.364)	0.130	(0.337)	0.249
Drink cola	0.347	(0.476)	0.391	(0.489)	0.149
Drink decaf cola	0.090	(0.287)	0.080	(0.272)	0.576
Drink milk	0.586	(0.493)	0.604	(0.490)	0.561
Parental diet and nutrition[2]					
Mother eats sausages/burgers	0.608	(0.488)	0.584	(0.494)	0.448
Mother eats pies or pastries	0.550	(0.498)	0.506	(0.501)	0.169
Mother eats meat	0.913	(0.281)	0.898	(0.303)	0.400
Mother eats poultry	0.906	(0.292)	0.898	(0.303)	0.665
Mother eats offal	0.093	(0.290)	0.075	(0.263)	0.320
Mother eats white fish	0.823	(0.382)	0.843	(0.364)	0.413
Mother eats oily fish	0.593	(0.491)	0.612	(0.488)	0.543
Mother eats shellfish	0.193	(0.394)	0.196	(0.398)	0.893
Mother eats eggs or quiche	0.861	(0.346)	0.859	(0.349)	0.908
Mother eats cheese	0.945	(0.227)	0.953	(0.212)	0.600
Mother eats pizza	0.571	(0.495)	0.643	(0.480)	0.024
Mother eats chips	0.819	(0.385)	0.776	(0.417)	0.085
Mother eats roast potatoes	0.697	(0.460)	0.702	(0.458)	0.858
Mother eats boiled or baked potatoes	0.975	(0.156)	0.980	(0.139)	0.587
Mother eats boiled rice	0.767	(0.423)	0.788	(0.409)	0.432
Mother eats pasta	0.811	(0.392)	0.816	(0.389)	0.843
Mother eats crisps	0.792	(0.406)	0.769	(0.423)	0.372
Mother eats fried food	0.486	(0.500)	0.427	(0.496)	0.067
Mother eats baked beans	0.853	(0.354)	0.859	(0.349)	0.803
Mother eats peas or corn	0.933	(0.251)	0.941	(0.236)	0.592
Mother eats cabbage	0.904	(0.294)	0.898	(0.303)	0.745
Mother eats other green vegetables	0.938	(0.242)	0.925	(0.263)	0.429
Mother eats carrots	0.929	(0.257)	0.929	(0.257)	0.970
Mother eats root vegetables (not carrots)	0.629	(0.483)	0.580	(0.494)	0.120
Mother eats salad	0.916	(0.277)	0.933	(0.250)	0.339
Mother eats fresh fruit	0.979	(0.143)	0.988	(0.108)	0.320
Mother drinks tinned juice	0.188	(0.391)	0.122	(0.327)	0.008
Mother drinks pure non-tinned juice	0.788	(0.408)	0.831	(0.375)	0.101
Mother eats pudding	0.759	(0.428)	0.780	(0.415)	0.432
Mother eats oat cereals	0.559	(0.497)	0.537	(0.500)	0.491
Mother eats bran cereals	0.686	(0.464)	0.722	(0.449)	0.234
Mother eats other cereals	0.677	(0.468)	0.659	(0.475)	0.544
Mother eats cakes or buns	0.869	(0.338)	0.890	(0.313)	0.320
Mother eats crispbreads	0.318	(0.466)	0.322	(0.468)	0.913
Mother eats biscuits	0.913	(0.282)	0.914	(0.281)	0.969
Mother eats chocolate bars	0.839	(0.367)	0.820	(0.385)	0.406
Mother eats pulses	0.239	(0.427)	0.294	(0.457)	0.047
Mother eats nuts	0.317	(0.465)	0.310	(0.463)	0.809
Mother eats bean curd	0.024	(0.154)	0.047	(0.212)	0.025
Mother eats tahini	0.024	(0.154)	0.043	(0.204)	0.059
Mother eats soya or similar non-meat	0.080	(0.271)	0.078	(0.269)	0.945
Mother eats chocolate	0.763	(0.426)	0.780	(0.415)	0.515
Mother eats sweets	0.595	(0.491)	0.533	(0.500)	0.050
Mother drinks diet drinks	0.755	(0.430)	0.700	(0.459)	0.056
Partner eats sausages or burgers	0.738	(0.440)	0.709	(0.455)	0.341
Partner eats pies or pastries	0.711	(0.454)	0.644	(0.480)	0.034
Partner eats meat	0.949	(0.220)	0.891	(0.312)	<0.001
Partner eats poultry	0.925	(0.263)	0.886	(0.318)	0.036
Partner eats offal	0.226	(0.418)	0.177	(0.383)	0.092

Partner eats white fish	0.807	(0.394)	0.814	(0.390)	0.820
Partner eats oily fish	0.533	(0.499)	0.523	(0.501)	0.775
Partner eats shellfish	0.232	(0.422)	0.183	(0.388)	0.096
Partner eats fried food	0.759	(0.428)	0.714	(0.453)	0.131
Partner eats cabbage	0.888	(0.316)	0.900	(0.301)	0.579
Partner eats carrots	0.918	(0.275)	0.918	(0.275)	0.979
Partner eats other vegetables	0.969	(0.174)	0.973	(0.163)	0.736
Partner eats salad	0.868	(0.339)	0.923	(0.268)	0.018
Partner eats fresh fruit	0.881	(0.324)	0.872	(0.335)	0.687
Partner drinks tinned juice	0.227	(0.419)	0.191	(0.394)	0.212
Partner drinks pure non-tinned juice	0.714	(0.452)	0.682	(0.467)	0.298
Partner eats nuts	0.363	(0.481)	0.341	(0.475)	0.507
Partner drinks diet drink	0.566	(0.496)	0.556	(0.498)	0.777
Mother eats mostly white bread	0.575	(0.494)	0.549	(0.499)	0.411
Partner eats mostly white bread	0.780	(0.415)	0.750	(0.434)	0.384
Mother eats mostly brown/granary bread	0.446	(0.497)	0.475	(0.500)	0.367
Partner eats mostly brown/granary bread	0.641	(0.480)	0.653	(0.478)	0.770
Mothers eats mostly wholemeal bread	0.506	(0.500)	0.506	(0.501)	1.000
Partner eats mostly wholemeal bread	0.612	(0.487)	0.580	(0.495)	0.465
Mothers eats mostly chappati's	0.013	(0.114)	0.008	(0.088)	0.457
Partner eats mostly chappati's	0.055	(0.228)	0.020	(0.140)	0.124
Mother doesn't usually eat any bread	0.021	(0.143)	0.031	(0.175)	0.257
Partner doesn't usually eat any bread	0.075	(0.264)	0.041	(0.199)	0.264
Mother has takeaway meals	0.704	(0.457)	0.738	(0.440)	0.242
Partner has takeaway meals	0.689	(0.463)	0.687	(0.465)	0.954
Mother is vegetarian or vegan	0.131	(0.338)	0.157	(0.365)	0.233
Partner is vegetarian or vegan	0.033	(0.178)	0.064	(0.246)	0.013
Mother buys organic vegetables	0.306	(0.461)	0.296	(0.457)	0.737
Mother buys organic meat	0.143	(0.350)	0.148	(0.356)	0.831
Mother buys other organic foods	0.038	(0.191)	0.035	(0.184)	0.809
Parental attitudes					
Mother's attitude to breastfeeding[ranging from 4-23][3]	16.204	(3.279)	16.458	(3.198)	0.228
Partner's attitude to breastfeeding[ranging from 6-22][3]	15.591	(2.679)	15.731	(2.951)	0.461
Proportion agreeing (mother):					
Should pick up crying baby	0.483	(0.500)	0.532	(0.500)	0.129
Regular feed & sleep pattern is important	0.903	(0.296)	0.900	(0.301)	0.852
Should always be fed when they are hungry	0.942	(0.233)	0.933	(0.251)	0.536
Babies need stimulation to develop well	0.977	(0.150)	0.984	(0.126)	0.467
Babies should not be disturbed too much	0.550	(0.498)	0.560	(0.497)	0.735
Parents should adapt lives to baby's demands	0.523	(0.500)	0.552	(0.498)	0.365
Baby should fit into parents' routine	0.576	(0.494)	0.571	(0.496)	0.884
Babies should develop naturally	0.429	(0.495)	0.417	(0.494)	0.730
It is important to talk to a baby	0.999	(0.025)	0.996	(0.063)	0.069
Cuddling baby is very important	0.999	(0.032)	0.996	(0.063)	0.195
Proportion agreeing (partner):					
Should pick up crying baby	0.397	(0.489)	0.427	(0.496)	0.387
Regular feed & sleep pattern is important	0.918	(0.274)	0.949	(0.221)	0.113
Should always be fed when they are hungry	0.870	(0.336)	0.882	(0.323)	0.618
Babies need stimulation to develop well	0.978	(0.146)	0.962	(0.191)	0.125
Babies should not be disturbed too much	0.590	(0.492)	0.640	(0.481)	0.147
Parents should adapt lives to baby's demands	0.635	(0.481)	0.626	(0.485)	0.787
Baby should fit into parents' routine	0.502	(0.500)	0.498	(0.501)	0.900
Babies should develop naturally	0.411	(0.492)	0.500	(0.501)	0.010
It is important to talk to a baby	0.997	(0.051)	1.000	(0.000)	0.458
Cuddling baby is very important	0.997	(0.053)	1.000	(0.000)	0.436
Attitude to fatherhood score [ranging from 8-45]	38.477	(5.183)	38.596	(5.788)	0.758
Work and parenthood score [ranging from 1-12]	8.751	(2.029)	8.675	(2.060)	0.635
Religious beliefs					
Mother believes in a divine power	0.503	(0.500)	0.539	(0.499)	0.264
Partner believes in a divine power	0.360	(0.480)	0.408	(0.493)	0.149
Mother feels helped by divine power	0.339	(0.474)	0.377	(0.486)	0.209
Partner feels helped by divine power	0.240	(0.427)	0.271	(0.445)	0.308
Mother appeals to God for help if in trouble	0.474	(0.499)	0.506	(0.501)	0.323
Partner appeals to God for help if in trouble	0.352	(0.478)	0.426	(0.496)	0.028

Household characteristics					
Home is mortgaged/owned	0.796	(0.403)	0.829	(0.377)	0.191
Total number of rooms [ranging from 0-18]	4.942	(1.507)	4.879	(1.417)	0.508
Use of garden or yard	0.950	(0.218)	0.973	(0.161)	0.084
Working phone in home	0.920	(0.271)	0.933	(0.251)	0.461
Use of car by mum or partner	0.922	(0.268)	0.963	(0.190)	0.015
House has damp condensation or mould	0.481	(0.500)	0.448	(0.498)	0.295
Partner is father of child	0.994	(0.074)	0.996	(0.061)	0.699
Partner lives with mum	0.952	(0.214)	0.970	(0.171)	0.178
Age of partner [ranging from 16-60]	30.963	(5.602)	30.643	(5.349)	0.378
Marital status (8 wks gestation)	0.796	(0.403)	0.841	(0.367)	0.076
Total no. of persons (8 wks gestation)	2.929	(1.093)	2.901	(1.031)	0.675
Pregnancy					
Seen doctor for possible infertility	0.131	(0.337)	0.136	(0.343)	0.815
Used treatments to help conceive	0.033	(0.179)	0.051	(0.220)	0.128
Has previously been pregnant	0.660	(0.474)	0.655	(0.476)	0.868
Has previously had a miscarriage	0.206	(0.404)	0.217	(0.413)	0.663
Has previously had an abortion or termination	0.134	(0.340)	0.098	(0.299)	0.099
Has previously had a stillbirth	0.008	(0.088)	0.011	(0.106)	0.530
Previous child born alive but died later	0.013	(0.111)	0.011	(0.106)	0.874
Mother's age when first pregnant [ranging from 12-42]	24.986	(4.868)	24.978	(4.719)	0.977
This pregnancy was intentional	0.730	(0.444)	0.780	(0.415)	0.074
Mother happy with pregnancy when first pregnant	0.717	(0.450)	0.756	(0.431)	0.177
Motherhood means personal sacrifice	0.705	(0.456)	0.667	(0.472)	0.184
Mother is currently happy with pregnancy	0.888	(0.316)	0.925	(0.265)	0.062
Partner is happy about pregnancy	0.869	(0.338)	0.867	(0.340)	0.928
Partner's first reaction was supportive	0.838	(0.368)	0.861	(0.347)	0.332
Partner is currently supportive	0.897	(0.304)	0.911	(0.286)	0.483
Mother already knew a lot about pregnancy	0.617	(0.486)	0.644	(0.480)	0.388
Self-induced vomiting for weight loss prior to pregnancy	0.053	(0.224)	0.073	(0.261)	0.156
Self-induced vomiting during this pregnancy	0.010	(0.102)	0.015	(0.124)	0.453
Laxative use for weight loss prior to pregnancy	0.042	(0.200)	0.035	(0.183)	0.593
Laxative use during this pregnancy	0.003	(0.054)	0.000	(0.000)	0.381
Mother had pain relief during labour	0.873	(0.333)	0.867	(0.340)	0.798
Mother had caesarean section	0.103	(0.303)	0.080	(0.272)	0.259
Partner was with mother during labour	0.882	(0.322)	0.884	(0.320)	0.912
Partner was with mother during delivery	0.854	(0.353)	0.873	(0.334)	0.429
Mother intends to work after child's birth	0.471	(0.499)	0.464	(0.500)	0.823
Mother's and partner's physical health					
Partner is well (8 wks gestation)	0.963	(0.190)	0.955	(0.208)	0.524
Mother is well prior to pregnancy	0.926	(0.261)	0.934	(0.249)	0.659
Mother is well in first trimester	0.407	(0.491)	0.457	(0.499)	0.114
Mother is well in second trimester	0.754	(0.431)	0.766	(0.424)	0.668
Mother is well in third trimester	0.766	(0.423)	0.776	(0.417)	0.697
Partner is well (8 month post birth)	0.968	(0.176)	0.962	(0.192)	0.614
Height of mother (in cm)	164.183	(6.767)	164.057	(6.960)	0.772
Weight of mother pre-pregnancy (in kg)	62.086	(11.030)	60.483	(9.620)	0.025
Mother visited dentist in preg (measured post-preg)	0.771	(0.420)	0.842	(0.366)	0.055
Mother: Nausea in first trimester	0.706	(0.456)	0.737	(0.441)	0.272
Mother: Vomiting in first trimester	0.417	(0.493)	0.390	(0.489)	0.388
Mother: Diarrhoea in first trimester	0.172	(0.378)	0.170	(0.376)	0.923
Mother: Vaginal Bleeding in first trimester	0.158	(0.365)	0.181	(0.386)	0.314
Mother: Jaundice in first trimester	0.001	(0.025)	0.000	(0.000)	0.687
Mother: Urinary infection in first trimester	0.048	(0.213)	0.062	(0.241)	0.299
Mother: Influenza in first trimester	0.084	(0.278)	0.081	(0.273)	0.850
Mother: Rubella in in first trimester	0.000	(0.014)	0.000	(0.000)	0.816
Mother: Thrush in first trimester	0.089	(0.284)	0.108	(0.311)	0.286
Mother: Genital herpes in first trimester	0.001	(0.038)	0.000	(0.000)	0.537
Mother: Other infection in first trimester	0.047	(0.212)	0.062	(0.241)	0.284
Mother: Any infection in first trimester	0.232	(0.422)	0.266	(0.443)	0.202
Mother: Injury or shock in first trimester	0.046	(0.211)	0.078	(0.268)	0.023
Mother: Sugar in urine in first trimester	0.020	(0.139)	0.039	(0.193)	0.036
Mother: X-ray in first trimester	0.018	(0.132)	0.031	(0.174)	0.125

Mother: Amniocentesis in in first trimester	0.006	(0.078)	0.004	(0.062)	0.654
Mother: Chorionic Villus Sampling in first trimester	0.009	(0.092)	0.008	(0.088)	0.886
Mother: Spina bifida test in first trimester	0.125	(0.331)	0.140	(0.347)	0.505
Mother: Ultrasound scan in first trimester	0.265	(0.441)	0.310	(0.463)	0.111
Mother: Admitted to hospital in first trimester	0.037	(0.188)	0.012	(0.107)	0.034
Mother: Nausea in second trimester	0.364	(0.481)	0.391	(0.489)	0.393
Mother: Vomiting in second trimester	0.220	(0.414)	0.234	(0.424)	0.581
Mother: Diarrhoea in second trimester	0.310	(0.462)	0.246	(0.432)	0.032
Mother: Vaginal bleeding in second trimester	0.043	(0.202)	0.039	(0.194)	0.773
Mother: Jaundice in second trimester	0.001	(0.029)	0.000	(0.000)	0.643
Mother: Urinary infection in second trimester	0.057	(0.232)	0.031	(0.174)	0.081
Mother: Cold in second trimester	0.401	(0.490)	0.367	(0.483)	0.277
Mother: Influenza in second trimester	0.056	(0.229)	0.039	(0.194)	0.257
Mother: Rubella in second trimester	0.000	(0.000)	0.000	(0.000)	-
Mother: Thrush in second trimester	0.132	(0.338)	0.102	(0.303)	0.162
Mother: Genital herpes in second trimester	0.003	(0.054)	0.008	(0.088)	0.178
Mother: Other infection in second trimester	0.053	(0.224)	0.055	(0.228)	0.900
Mother: Any infection in second trimester	0.253	(0.435)	0.211	(0.409)	0.132
Mother: Injury or shock in second trimester	0.076	(0.265)	0.070	(0.256)	0.731
Mother: Sugar in urine in second trimester	0.128	(0.335)	0.117	(0.322)	0.600
Mother: X-ray in second trimester	0.009	(0.093)	0.027	(0.163)	0.003
Mother: Amniocentesis in second trimester	0.018	(0.132)	0.016	(0.124)	0.812
Mother: Chorionic Villus Sampling in second trimester	0.008	(0.087)	0.004	(0.063)	0.506
Mother: Spina bifida test in second trimester	0.232	(0.422)	0.293	(0.456)	0.026
Mother: Ultrasound in second trimester	0.427	(0.495)	0.430	(0.496)	0.937
Mother: Headache in second trimester	0.604	(0.489)	0.574	(0.495)	0.335
Mother: Backache in second trimester	0.789	(0.408)	0.754	(0.432)	0.185
Mother: Varicose veins in second trimester	0.144	(0.351)	0.148	(0.356)	0.842
Mother: Admitted to hospital in second trimester	0.066	(0.248)	0.055	(0.228)	0.490
Mother's physical activity					
Mother exercises at least once a week	0.693	(0.461)	0.615	(0.488)	0.008
Mother usually walks	0.263	(0.440)	0.206	(0.405)	0.045
Mother usually cycles	0.009	(0.096)	0.012	(0.108)	0.693
Mother usually uses public transport	0.074	(0.262)	0.054	(0.227)	0.244
Mother usually uses the car	0.721	(0.449)	0.774	(0.419)	0.063
Mother: Jogging	0.019	(0.138)	0.012	(0.108)	0.395
Mother: Aerobics	0.050	(0.217)	0.051	(0.221)	0.905
Mother: Ante-natal exercise	0.242	(0.428)	0.251	(0.434)	0.732
Mother: Keep fit exercises	0.136	(0.343)	0.142	(0.349)	0.790
Mother: Yoga	0.030	(0.170)	0.032	(0.175)	0.868
Mother: Squash	0.005	(0.069)	0.004	(0.063)	0.859
Mother: Tennis or badminton	0.030	(0.170)	0.032	(0.176)	0.852
Mother: Swimming	0.453	(0.498)	0.420	(0.495)	0.310
Mother: Brisk walking	0.753	(0.431)	0.719	(0.450)	0.215
Mother: Weight training	0.006	(0.079)	0.008	(0.089)	0.746
Mother: Cycling	0.061	(0.239)	0.071	(0.258)	0.501
Mother: Other exercise	0.083	(0.276)	0.105	(0.307)	0.219
Parental mental health					
Bachman self-esteem score [-4-2]	0.015	(0.987)	0.035	(0.969)	0.760
Mother's self-perceived change score [11-35][4]	23.860	(2.734)	24.206	(2.811)	0.050
Mother's self-perceived feel good score [7-30][4]	16.799	(3.866)	16.659	(3.877)	0.576
Mother's perception of *partner's* change score [9-35][4]	20.938	(1.674)	20.928	(1.853)	0.930
Mother's perception of *partner's* feel good score [7-31][4]	13.734	(4.026)	13.498	(3.863)	0.373
Partner's self-perceived change score [9-35][4]	20.647	(2.309)	20.832	(2.069)	0.251
Partner's self-perceived feel good score [7-30][4]	15.791	(3.806)	15.690	(3.786)	0.705
Partner's perception of *mother's* change score [10-35][4]	20.368	(1.538)	20.257	(1.538)	0.309
Partner's perception of *mother's* feel good score [7-32][4]	14.901	(3.839)	14.557	(4.082)	0.208
Mother: Interpersonal awareness score [7-28]	18.324	(4.659)	18.835	(4.866)	0.085
Mother: Need for approval score [8-32]	25.836	(3.581)	26.073	(3.122)	0.296
Mother: Separation anxiety score [8-32]	16.211	(4.612)	16.275	(4.939)	0.827
Mother: Timidity score [8-32]	20.644	(4.503)	21.111	(4.362)	0.101
Mother: Fragile inner-self score [5-20]	8.701	(2.919)	8.748	(2.954)	0.799
Mother: Total interpersonal sensitivity score [36-140]	89.704	15.828)	91.034	(15.818)	0.185
Partner: Interpersonal awareness score [7-28]	16.229	(4.854)	16.467	(4.683)	0.487

Partner: Need for approval score [0-32]	24.540	(4.319)	24.507	(4.344)	0.914
Partner: Separation anxiety score [0-32]	14.692	(4.386)	14.519	(4.567)	0.577
Partner: Timidity score [3-32]	18.896	(4.697)	18.877	(4.794)	0.955
Partner: Fragile inner-self score [5-20]	8.187	(2.725)	8.267	(2.635)	0.680
Partner: Total interpersonal sensitivity score [29-138]	82.456	16.270)	82.519	(15.482)	0.956
Mother: Pre-17 life event score [0-63]	8.751	(8.324)	8.685	(8.096)	0.901
Partner: Pre-17 life event score [0-74]	9.890	(8.700)	10.552	(9.027)	0.272
Partner's affection score (mother reported) [6-30][5]	11.340	(4.087)	11.363	(3.913)	0.930
Partner's affection score (partner reported) [6-30][5]	10.929	(3.905)	10.970	(4.033)	0.886
Partner's aggression score (mother reported) [3-15][5]	10.082	(1.750)	9.945	(1.671)	0.224
Partner's aggression score (partner reported) [3-15][5]	9.915	(1.862)	9.782	(1.927)	0.328
Maternal use of medication					
Any medications used since start of pregnancy	0.705	(0.456)	0.702	(0.458)	0.918
Medication for nausea in first trimester	0.043	(0.202)	0.064	(0.245)	0.093
Medication for heartburn in first trimester	0.071	(0.256)	0.042	(0.200)	0.070
Medication for vomiting in first trimester	0.031	(0.173)	0.049	(0.216)	0.101
Medication for anxiety in first trimester	0.005	(0.068)	0.004	(0.061)	0.843
Medication for infection in first trimester	0.082	(0.274)	0.095	(0.293)	0.461
Medication for migraine in first trimester	0.124	(0.329)	0.106	(0.309)	0.396
Medication for sleeping in first trimester	0.008	(0.087)	0.000	(0.000)	0.154
Medication for pain in first trimester	0.123	(0.328)	0.102	(0.304)	0.321
Medication for allergies in first trimester	0.030	(0.170)	0.030	(0.171)	0.979
Medication for skin condition in first trimester	0.073	(0.260)	0.075	(0.265)	0.886
Medication for bleeding in first trimester	0.006	(0.075)	0.000	(0.000)	0.221
Medication for depression in first trimester	0.005	(0.069)	0.000	(0.000)	0.258
Medication for piles in first trimester	0.022	(0.146)	0.023	(0.149)	0.934
Medication for constipation in first trimester	0.054	(0.225)	0.038	(0.191)	0.260
Medication for cough in first trimester	0.052	(0.222)	0.064	(0.245)	0.388
Medication for other reasons in first trimester	0.067	(0.250)	0.057	(0.232)	0.533
Taking iron in first trimester	0.197	(0.397)	0.177	(0.382)	0.427
Taking zinc in first trimester	0.015	(0.120)	0.015	(0.122)	0.956
Taking calcium in first trimester	0.032	(0.175)	0.045	(0.208)	0.222
Taking folic acid in first trimester	0.086	(0.280)	0.094	(0.292)	0.645
Taking vitamins in first trimester	0.160	(0.367)	0.198	(0.399)	0.107
Taking other supplements or diet foods in first trimester	0.030	(0.170)	0.019	(0.138)	0.327
Ever used homeopathic medicine (trimester 1)	0.103	(0.304)	0.102	(0.303)	0.933
Taking aspirin in first trimester	0.042	(0.201)	0.053	(0.224)	0.396
Taking paracetamol in first trimester	0.550	(0.498)	0.491	(0.501)	0.060
Taking codeine or anadin in first trimester	0.024	(0.154)	0.015	(0.122)	0.342
Taking sleeping tablets in first trimester	0.004	(0.063)	0.000	(0.000)	0.302
Taking tranquiliser in first trimester	0.003	(0.051)	0.008	(0.087)	0.141
No. of medications used in first trimester [0-17]	1.350	(1.446)	1.330	(1.370)	0.825
Medication for nausea in second trimester	0.025	(0.156)	0.008	(0.088)	0.082
Medication for heartburn in second trimester	0.367	(0.482)	0.332	(0.472)	0.251
Medication for vomiting in second trimester	0.016	(0.126)	0.004	(0.063)	0.125
Medication for anxiety in second trimester	0.007	(0.083)	0.012	(0.108)	0.382
Medication for infection in second trimester	0.107	(0.309)	0.090	(0.287)	0.389
Medication for migraine in second trimester	0.077	(0.267)	0.070	(0.256)	0.692
Medication for sleeping disorder in second trimester	0.032	(0.177)	0.031	(0.174)	0.925
Medication for pain in second trimester	0.155	(0.362)	0.117	(0.322)	0.105
Medication for allergies in second trimester	0.046	(0.211)	0.035	(0.185)	0.400
Medication for skin condition in second trimester	0.108	(0.311)	0.145	(0.352)	0.070
Medication for bleeding in second trimester	0.003	(0.058)	0.000	(0.000)	0.352
Medication for depression in second trimester	0.007	(0.081)	0.004	(0.063)	0.606
Medication for piles in second trimester	0.077	(0.266)	0.090	(0.287)	0.450
Medication for constipation in second trimester	0.070	(0.255)	0.063	(0.243)	0.650
Medication for cough in second trimester	0.076	(0.266)	0.094	(0.292)	0.313
Medication for other reason in second trimester	0.107	(0.309)	0.094	(0.292)	0.514
Taken iron in last second trimester	0.426	(0.494)	0.422	(0.495)	0.907
Taken zinc in last second trimester	0.013	(0.115)	0.012	(0.108)	0.812
Taken calcium in last second trimester	0.032	(0.175)	0.035	(0.185)	0.751
Taken folic acid in second trimester	0.193	(0.395)	0.191	(0.394)	0.947
Taken vitamins in second trimester	0.114	(0.318)	0.117	(0.322)	0.873
Taken other supplements in second trimester	0.026	(0.159)	0.027	(0.163)	0.904
Ever use homeopathic medicine (trimester 2)	0.156	(0.363)	0.162	(0.369)	0.788

Taken aspirin use in second trimester	0.028	(0.166)	0.027	(0.164)	0.942
Taken paracetamol in second trimester	0.434	(0.496)	0.361	(0.481)	0.022
Taken codein or anadin in second trimester	0.017	(0.130)	0.024	(0.152)	0.459
Taken sleeping pill in second trimester	0.007	(0.086)	0.012	(0.108)	0.431
Taken tranquilizer in second trimester	0.002	(0.041)	0.004	(0.063)	0.412
No. of medications used in second trimester [0-11]	1.661	(1.568)	1.673	(1.542)	0.906
Taken sleeping pill since birth (measured at 8 month)	0.015	(0.120)	0.004	(0.064)	0.176
Taken cannabis since birth (measured at 8 month)	0.030	(0.169)	0.025	(0.155)	0.652
Taken tranquilliser since birth (measured at 8 month)	0.007	(0.082)	0.008	(0.090)	0.804
Taken anti-depressant since birth (meas. at 8 month)	0.043	(0.204)	0.029	(0.167)	0.271
Taken hormone tablet since birth (meas. at 8 month)	0.009	(0.092)	0.016	(0.127)	0.210
Taken antibiotic since birth (measured at 8 month)	0.267	(0.442)	0.246	(0.432)	0.469
Taken painkiller since birth (measured at 8 month)	0.818	(0.386)	0.803	(0.398)	0.555
Taken amphetamine since birth (measured at 8 month)	0.005	(0.071)	0.004	(0.064)	0.833
Taken the pill since birth (measured at 8 month)	0.515	(0.500)	0.516	(0.501)	0.958
Taken opiate or cocaine since birth (meas. at 8 month)	0.002	(0.045)	0.000	(0.000)	0.486
Taken anticonvulsant since birth (measured at 8 month)	0.003	(0.051)	0.004	(0.064)	0.672
Taken steroid since birth (measured at 8 month)	0.017	(0.128)	0.008	(0.090)	0.303
Taken iron since birth (measured at 8 month)	0.208	(0.406)	0.225	(0.419)	0.526
Taken vitamin since birth (measured at 8 month)	0.254	(0.435)	0.254	(0.436)	0.999
Taken other substance since birth (meas. at 8 month)	0.184	(0.387)	0.168	(0.375)	0.532
Parental substance use					
Mother smoked pre-pregnancy	0.299	(0.458)	0.270	(0.445)	0.310
Mother ever smoked	0.567	(0.495)	0.523	(0.500)	0.164
Father ever smoked	0.763	(0.425)	0.744	(0.437)	0.483
Partner smokes (at 18 weeks gest)	0.341	(0.474)	0.346	(0.477)	0.855
Partner's number of cigarettes (at 8 months) [0-60]	3.712	(7.698)	3.846	(7.598)	0.794
Mother smoked cannabis during pregnancy	0.023	(0.149)	0.019	(0.138)	0.726
Mother smoked cannabis in 6 mths prior to pregnancy	0.043	(0.204)	0.039	(0.194)	0.735
Mother used amphetamine during pregnancy	0.001	(0.028)	0.004	(0.062)	0.125
Mother used barbiturate during pregnancy	0.000	(0.020)	0.000	(0.000)	0.745
Mother used crack during pregnancy	0.000	(0.000)	0.000	(0.000)	-
Mother used cocaine during pregnancy	0.001	(0.025)	0.000	(0.000)	0.690
Mother used heroin during pregnancy	0.000	(0.014)	0.000	(0.000)	0.819
Mother used methadone during pregnancy	0.000	(0.014)	0.000	(0.000)	0.818
Mother used ecstasy during pregnancy	0.003	(0.051)	0.000	(0.000)	0.700
Mother used other drug during pregnancy	0.002	(0.040)	0.004	(0.062)	0.402
Mother used hard drugs during pregnancy	0.003	(0.058)	0.008	(0.087)	0.270
Partner smoked cannabis in 6 mths prior to pregnancy	0.117	(0.322)	0.104	(0.307)	0.654
Partner smoked cannabis in first trimester	0.095	(0.294)	0.090	(0.288)	0.843
Partner used amphetamine in first trimester	0.006	(0.080)	0.000	(0.000)	0.235
Partner used barbiturate in first trimester	0.001	(0.036)	0.000	(0.000)	0.596
Partner used crack in first trimester	0.001	(0.028)	0.000	(0.000)	0.682
Partner used cocaine in first trimester	0.002	(0.046)	0.000	(0.000)	0.502
Partner used heroin in first trimester	0.001	(0.032)	0.000	(0.000)	0.636
Partner used methadone in first trimester	0.001	(0.032)	0.000	(0.000)	0.636
Partner used ecstasy in first trimester	0.005	(0.073)	0.000	(0.000)	0.613
Partner used other in first trimester	0.010	(0.098)	0.015	(0.120)	0.490
Partner used hard drugs in first trimester	0.015	(0.123)	0.014	(0.117)	0.871
Mother used ganja in last 2 months of pregnancy	0.018	(0.132)	0.013	(0.112)	0.560
Mother used ganja since birth (measured at 8 weeks)	0.026	(0.158)	0.013	(0.112)	0.210
Mother used hard drugs in last 2 months of pregnancy	0.001	(0.033)	0.000	(0.000)	0.606
Mother used hard drugs since birth (meas. at 8 weeks)	0.003	(0.057)	0.008	(0.090)	0.208
Mother's use of chemicals during pregnancy					
Disinfectant	0.874	(0.332)	0.841	(0.366)	0.117
Bleach	0.845	(0.362)	0.841	(0.366)	0.872
Window cleaner	0.621	(0.485)	0.601	(0.491)	0.521
Carpet cleaner	0.376	(0.484)	0.358	(0.480)	0.548
Oven or drain cleaner	0.416	(0.493)	0.380	(0.486)	0.244
Dry cleaning fluid	0.059	(0.235)	0.063	(0.243)	0.790
Turps or white spirit	0.217	(0.412)	0.188	(0.392)	0.261
Paint stripper	0.058	(0.234)	0.048	(0.214)	0.481
House paint or varnish	0.326	(0.469)	0.277	(0.448)	0.094
Weed killer	0.076	(0.264)	0.063	(0.243)	0.433

Pesticide	0.276	(0.447)	0.255	(0.436)	0.450
Aerosol or spray	0.823	(0.382)	0.815	(0.389)	0.754
Hair dye or bleach	0.163	(0.370)	0.144	(0.352)	0.396
Hair removal cream	0.110	(0.312)	0.100	(0.300)	0.607
Air freshener	0.697	(0.460)	0.657	(0.476)	0.165
Use of other chemicals	0.061	(0.240)	0.066	(0.249)	0.736
Electrical mixer	0.539	(0.499)	0.551	(0.498)	0.695
Hoover use	0.966	(0.181)	0.958	(0.200)	0.507
Floor polisher	0.056	(0.230)	0.023	(0.149)	0.020
Electrical iron	0.964	(0.186)	0.951	(0.216)	0.270
Electrical hair appliance	0.876	(0.330)	0.879	(0.326)	0.867
Electrical typewriter	0.161	(0.368)	0.204	(0.404)	0.069
Photocopier or fax	0.407	(0.491)	0.453	(0.499)	0.142
PC or VDU	0.409	(0.492)	0.479	(0.501)	0.024
Power tool	0.059	(0.235)	0.045	(0.208)	0.361
Sunbed or lamp	0.015	(0.121)	0.019	(0.136)	0.601
Microwave	0.777	(0.417)	0.767	(0.423)	0.719
Other electrical equipment	0.099	(0.299)	0.083	(0.276)	0.391
Dental amalgam	0.013	(0.112)	0.015	(0.121)	0.780
Ceramic or enamel	0.019	(0.135)	0.015	(0.121)	0.648
Dry cleaning	0.021	(0.143)	0.033	(0.179)	0.178
Electroplating	0.001	(0.028)	0.000	(0.000)	0.642
Glue	0.258	(0.438)	0.283	(0.451)	0.359
Leather working	0.004	(0.061)	0.000	(0.000)	0.310
Fabric and textile	0.167	(0.373)	0.169	(0.376)	0.936
Dye	0.043	(0.203)	0.026	(0.159)	0.163
Insecticide	0.112	(0.316)	0.110	(0.314)	0.918
Plastics	0.039	(0.194)	0.022	(0.147)	0.155
Metal cleaner	0.219	(0.414)	0.191	(0.394)	0.275
Petrol	0.390	(0.488)	0.375	(0.485)	0.629
Paint	0.287	(0.453)	0.246	(0.432)	0.145
Photo chemical	0.015	(0.121)	0.018	(0.135)	0.650
ELEC wiring	0.031	(0.173)	0.029	(0.169)	0.893
Machining	0.046	(0.210)	0.048	(0.214)	0.903
Soldering	0.006	(0.077)	0.004	(0.061)	0.629
Radiation	0.025	(0.158)	0.029	(0.169)	0.690
Social support					
Mother's social network score (at 12 wks gest) [5-29][6]	23.615	(3.690)	23.605	(4.047)	0.965
Partner's social network score (at 18 wks gest) [1-29][6]	22.503	(3.890)	22.605	(3.880)	0.706
Mother's social support score (at 12 wks gest) [0-30][6]	19.963	(4.914)	20.358	(5.115)	0.223
Partner's social support score (at 18 wks gest) [1-30][6]	17.930	(4.859)	18.205	(4.889)	0.415
Neighbourhood characteristics					
Mother thinks neighbourhood is a good place to live	0.933	(0.251)	0.928	(0.259)	0.770
Partner thinks neighbourhood is a good place to live	0.932	(0.251)	0.918	(0.275)	0.440
Mother: People in neighbourhood visit	0.550	(0.498)	0.587	(0.493)	0.234
Mother: People in neighbourhood argue with mother	0.044	(0.204)	0.026	(0.159)	0.164
Mother: People in neighbourhood look after children	0.202	(0.401)	0.238	(0.427)	0.151
Mother: People in neighbourhood keep to themselves	0.822	(0.382)	0.807	(0.396)	0.520
Mother visits others in neighbourhood	0.496	(0.500)	0.524	(0.500)	0.368
Mother argues with people in neighbourhood	0.037	(0.189)	0.022	(0.148)	0.208
Mother looks after neighbours' children	0.216	(0.411)	0.257	(0.438)	0.113
Mother keeps to herself	0.807	(0.394)	0.792	(0.407)	0.526
Partner: People in neighbourhood visit	0.516	(0.500)	0.549	(0.499)	0.370
Partner: People in neighbourhood argue with mother	0.051	(0.221)	0.031	(0.174)	0.206
Partner: People in neighbourhood look after children	0.211	(0.408)	0.313	(0.465)	0.001
Partner: People in neighbourhood keep to themselves	0.881	(0.324)	0.870	(0.337)	0.673
Partner visits others in neighbourhood	0.378	(0.485)	0.421	(0.495)	0.229
Partner argues with people in neighbourhood	0.041	(0.199)	0.036	(0.187)	0.725
Partner looks after neighbours' children	0.155	(0.362)	0.179	(0.384)	0.387
Partner keeps to himself	0.871	(0.335)	0.845	(0.363)	0.293
Mother is worried about possible burglary	0.845	(0.361)	0.863	(0.345)	0.454
Mother is worried about possible mugging/robbery	0.655	(0.475)	0.664	(0.473)	0.758
Mother is worried about possible sex assault	0.640	(0.480)	0.656	(0.476)	0.597
Mother is worried about possible vandalism to home	0.700	(0.458)	0.714	(0.453)	0.627

Partner is worried about possible burglary	0.871	(0.335)	0.896	(0.306)	0.322
Partner is worried about possible mugging/robbery	0.496	(0.500)	0.537	(0.500)	0.274
Partner is worried about possible sex assault	0.226	(0.418)	0.212	(0.410)	0.655
Partner is worried about possible vandalism to home	0.737	(0.441)	0.773	(0.420)	0.258
Mother thinks neighbourhood is lively	0.569	(0.495)	0.553	(0.498)	0.604
Mother thinks neighbourhood is friendly	0.932	(0.252)	0.940	(0.238)	0.624
Mother thinks neighbourhood is noisy	0.511	(0.500)	0.515	(0.501)	0.903
Mother thinks neighbourhood is clean	0.915	(0.278)	0.914	(0.282)	0.918
Mother thinks neighbourhood is attractive	0.833	(0.373)	0.827	(0.379)	0.797
Mother thinks neighbourhood is polluted or dirty	0.285	(0.451)	0.274	(0.447)	0.712
Partner thinks neighbourhood is lively	0.319	(0.467)	0.231	(0.439)	0.507
Partner thinks neighbourhood is friendly	0.881	(0.324)	0.846	(0.376)	0.704
Partner thinks neighbourhood is noisy	0.244	(0.430)	0.231	(0.439)	0.913
Partner thinks neighbourhood is clean	0.825	(0.381)	0.769	(0.439)	0.612
Partner thinks neighbourhood is attractive	0.710	(0.455)	0.538	(0.519)	0.190
Partner thinks neighbourhood is polluted or dirty	0.132	(0.339)	0.231	(0.439)	0.314

Notes: All variables are measured during pregnancy, unless otherwise stated. All variables are binary unless otherwise stated, indicating the range of the values, e.g. [0-30]. [1]The educational indicators are: less than ordinary (O) level (ref), O-level only, advanced (A) level that permits higher educational study, and university degree. The social class variables use the standard (reversed, so that higher values correspond to higher social classes) UK classification of social class based on occupation (professional, managerial/technical, non-manual skilled, manual skilled, semi-skilled and unskilled). Family income is an average of two observations (when the child is aged 3 and 4) and is in 1995 prices. It is adjusted for family size and composition (equalised) using the OECD equivalence scale to allow for a comparison of incomes for all households. EPDS and CCEI refer to the mother's Edinburgh Postnatal Depression Score and the Crown-Crisp Experimental Index. EPDS indicates to what extent the mother is at risk of perinatal depression; CCEI captures a broader definition of mental health, measuring general anxiety, depression and somaticism. Higher scores mean the mother is more affected. [2]Mother's diet is measured at 32 weeks gestation; partner's diet is measured at 18 weeks gestation. [3]'Attitude to breastfeeding', 'attitude to fatherhood', and 'work and parenthood' are derived from multiple questions, with higher scores indicating more positive attitudes. [4]The self-perceived change and feel good scores relate to physical, emotional and behavioural changes during early pregnancy, with higher scores indicating more positive changes. [5]The partner's affection (aggression) scores are derived from multiple questions, where higher scores indicate less affection (aggression). [6]The social network and social support scores are derived from multiple questions, where higher scores indicate a larger network and more support.

Appendix C: Parental responsive investments

Table C1: Potential parental investments in response to child development

	(1) Coefficient on average no. of units during pregnancy	(2) Standard error	(3) Mean	(4) First stage F-statistic	(5) N
Child diet and nutrition					
Baby has fruit juice (4 weeks)	0.004	(0.042)	0.125	14.651	2620
Baby has vitamins (4 weeks)	0.004	(0.034)	0.071	14.651	2620
Baby has glucose solution (4 weeks)	0.010	(0.011)	0.006	14.651	2620
Baby has cereal (4 weeks)	0.008	(0.023)	0.019	14.651	2620
Baby has other diet supplements (4 weeks)	-0.013	(0.041)	0.100	14.651	2620
Child had formula (6 months)	0.149**	(0.070)	0.825	13.790	2546
Child had follow-on milk (6m)	-0.075	(0.049)	0.093	13.790	2546
Child had soya milk (6m)	0.007	(0.024)	0.029	13.790	2546
Child had goats milk (6m)	0.001	(0.001)	0.001	13.790	2546
Child had hypo-allergenic formula (6m)	-0.011	(0.013)	0.002	13.790	2546
Child had cows' milk (6m)	-0.079	(0.060)	0.198	13.790	2546
Child had plain baby rice (6m)	-0.033	(0.039)	0.887	13.790	2546
Child had flavoured baby rice (6m)	0.032	(0.064)	0.382	13.790	2546
Child had other cereal (6m)	0.024	(0.051)	0.818	13.790	2546
Child had sweetened rusks (6m)	-0.023	(0.059)	0.225	13.790	2546
Child had plain rusks (6m)	-0.017	(0.065)	0.612	13.790	2546
Child had bread or toast (at 6m)	-0.022	(0.065)	0.375	13.790	2546
Child had biscuits (6m)	-0.011	(0.057)	0.223	13.790	2546
Child had prepared savoury meat (6m)	0.066	(0.054)	0.832	13.790	2546
Child had prepared savoury fish (6m)	-0.102	(0.072)	0.359	13.790	2546
Child had prepared savoury veg (6m)	-0.033	(0.039)	0.898	13.790	2546
Child had prepared fruit pudding (6m)	0.011	(0.043)	0.873	13.790	2546
Child had prepared milk pudding (6m)	-0.036	(0.065)	0.583	13.790	2546
Child had home cooked egg (6m)	-0.022	(0.047)	0.145	13.790	2546
Child had home cooked meat (6m)	0.031	(0.067)	0.479	13.790	2546
Child had home cooked fish (6m)	-0.090	(0.068)	0.303	13.790	2546
Child had home cooked potatoes (6m)	-0.037	(0.039)	0.883	13.790	2546
Child had home cooked veg (6m)	-0.058	(0.047)	0.816	13.790	2546
Child had home-made fruit puddings (6m)	-0.035	(0.068)	0.463	13.803	2539
Child had home-made milk puddings (6m)	-0.055	(0.059)	0.189	13.790	2546
Child had coca cola or pepsi (6m)	-0.001	(0.012)	0.011	13.790	2546
Child had other fizzy drink (6m)	0.014*	(0.007)	0.008	13.790	2546
Child had apple juice (6m)	0.016	(0.059)	0.246	13.790	2546
Child had a little alcohol (6m)	0.005	(0.015)	0.024	13.790	2546
Child had blackcurrant/rosehip syrup (6m)	-0.068	(0.068)	0.344	13.790	2546
Child had other fruit drink (6m)	0.028	(0.067)	0.557	13.790	2546
Child had herbal drink (6m)	-0.138*	(0.072)	0.495	13.790	2546
Child had gripe water (6m)	0.033	(0.067)	0.542	13.790	2546
Child had tea (6m)	0.042	(0.029)	0.072	13.790	2546
Child had coffee (6m)	0.021**	(0.010)	0.010	13.790	2546
Child had raw fruit (6m)	-0.047	(0.067)	0.418	13.790	2546
Child had crisps (6m)	-0.027	(0.028)	0.022	13.790	2546
Child had chocolates (6m)	0.011	(0.054)	0.207	13.790	2546
Child had sweets (6m)	0.005	(0.007)	0.012	13.790	2546
Child had raw veg (6m)	-0.092	(0.061)	0.167	13.790	2546
Child had packet soup (15m)	-0.060	(0.038)	0.082	22.616	2482
Child had canned soup (15m)	0.019	(0.057)	0.429	23.377	2489
Child had liver (15m)	0.018	(0.048)	0.198	22.857	2490
Child had kidney (15m)	0.014	(0.026)	0.067	23.050	2489
Child had shell fish (15m)	0.025	(0.030)	0.089	22.752	2491
Child had baked beans (15m)	0.011	(0.030)	0.927	22.662	2495
Child had green peas (15m)	0.021	(0.029)	0.938	22.637	2494
Child had other legumes (15m)	-0.102*	(0.061)	0.270	22.069	2476

Child had yoghurt (15m)	-0.005	(0.017)	0.965	21.959	2488
Child had fig (15m)	-0.008	(0.025)	0.040	21.574	2474
Child had raw apple (15m)	-0.020	(0.039)	0.833	22.754	2485
Child had other raw fruit (15m)	-0.019	(0.018)	0.965	22.002	2488
Child had raw carrot (15m)	-0.029	(0.058)	0.454	22.798	2483
Child had other raw vegetables (15m)	0.003	(0.039)	0.171	23.304	2316
Child had nuts (15m)	-0.000	(0.036)	0.082	22.161	2483
Child had crisps (15m)	-0.050	(0.054)	0.637	22.108	2485
Child had other savoury snacks (15m)	0.003	(0.055)	0.672	22.242	2476
Child had chocolate (15m)	0.081	(0.052)	0.841	22.011	2486
Child had mints (15m)	0.004	(0.027)	0.041	22.383	2478
Child had sweets (15m)	-0.053	(0.057)	0.302	22.748	2480
Child ever had gravy or soy sauce (15m)	0.059	(0.051)	0.805	22.553	2484
Child ever had salt (15m)	0.035	(0.043)	0.229	22.663	2485
Child ever had herbs (15m)	-0.029	(0.058)	0.430	22.604	2467
Child ever had spices (15m)	0.002	(0.043)	0.188	22.605	2482
Child ever had tomato ketchup (15m)	0.020	(0.050)	0.275	22.244	2484
Child ever had other sauce (15m)	-0.007	(0.037)	0.117	22.723	2338
Child ever had sugar (15m)	-0.012	(0.053)	0.275	21.705	2467
Child ever had smoked or cured food (15m)	0.057	(0.058)	0.410	22.573	2490
Child ever had microwave meal (15m)	0.050**	(0.023)	0.064	22.609	2489
Child ever had BBQ food (15m)	0.052	(0.039)	0.144	22.381	2488
Child ever had sports drink (15m)	0.011***	(0.003)	0.012	22.376	2492
No. of meals a day (6m) [ranging from 1-4]	-0.008	(0.057)	2.903	13.775	2539
No. of meals a day (38m) [ranging from 1-4]	-0.025	(0.029)	2.944	12.080	2324
Feeding difficulties (6m)	0.072	(0.066)	0.353	13.226	2528
Cereal added to child's bottle (6m)	-0.018	(0.020)	0.022	14.223	2506
Sugar added to child's food/bottle (6m)	0.012	(0.034)	0.071	13.558	2532
Child uses dummy (6m)	0.105	(0.071)	0.463	13.790	2546
Immunisation and other treatment					
Began to immunise baby at 4weeks	0.019	(0.025)	0.044	14.241	2608
BCG (tuberculosis) immunisation (6m)	-0.018	(0.018)	0.008	13.790	2546
DTP immun. incl. whooping cough (6m)	-0.026	(0.038)	0.916	13.790	2546
DT immun. excl. whooping cough (6m)	-0.020	(0.029)	0.044	13.790	2546
Polio immunisation (6m)	0.061	(0.055)	0.829	13.790	2546
Hib (meningitis) immunisation (6m)	-0.006	(0.056)	0.239	13.790	2546
Fluoride treatment (6m)	-0.017	(0.021)	0.013	10.560	2307
Child has vitamins (24m)	0.054	(0.056)	0.246	11.543	2383
Child has vitamins (38m)	-0.027	(0.061)	0.291	12.476	2364
(Night-time) interactions[1]					
Partner ever feeds baby at night (4w)	-0.009	(0.063)	0.668	13.894	2561
Feed baby when wakes at night (4w)	0.014	(0.019)	0.988	14.704	2581
Give baby water when wakes at night (4w)	0.107**	(0.047)	0.139	14.704	2581
Cuddle baby when wakes at night (4w)	-0.019	(0.036)	0.886	14.704	2581
Give baby dummy when wakes at night (4w)	0.070	(0.066)	0.405	14.704	2581
Baby to mother's bed when wakes (4w)	0.034	(0.062)	0.668	14.704	2581
Nappy change when wakes at night (4w)	0.009	(0.025)	0.966	14.704	2581
Other activity when baby wakes (4w)	-0.001	(0.024)	0.040	14.704	2581
Ever wake baby for feed (4w)	0.005	(0.054)	0.764	14.793	2599
Give baby milk when wakes at night (6m)	-0.075	(0.068)	0.557	13.331	2362
Give baby other drink when wakes (6m)	0.158**	(0.070)	0.307	13.331	2362
Cuddle baby when wakes at night (6m)	0.078	(0.063)	0.748	13.331	2362
Give baby dummy when wakes at night (6m)	0.107	(0.069)	0.429	13.331	2362
Baby to mum's bed when wakes (6m)	0.014	(0.066)	0.487	13.331	2362
Nappy change when wakes at night (6m)	0.136*	(0.072)	0.644	13.331	2362
Other activity when baby wakes (6m)	0.029	(0.036)	0.111	13.331	2362
Partner interaction score (42m) [0-36]	-0.464	(0.816)	21.778	10.989	2223
Mother interaction score (42m) [0-36]	-0.172	(0.589)	28.966	12.812	2328
Other person interaction score (42m) [0-36]	-0.754	(0.749)	18.219	25.219	1102
Doctor and dentist visits					
Child uses toothbrush (15m)	0.010	(0.028)	0.953	22.580	2483
Child uses toothbrush (24m)	0.005	(0.008)	0.997	11.160	2376
Child uses toothbrush (38m)	-0.034**	(0.014)	0.978	12.476	2364

Child uses toothpaste (15m)	-0.025	(0.038)	0.896	22.429	2482
Child uses toothpaste (24m)	0.027	(0.023)	0.989	10.782	2373
Child uses toothpaste (38m)	-0.026**	(0.011)	0.979	12.476	2364
Child ever visited dentist (38m)	-0.118**	(0.048)	0.829	12.476	2364
Mother took baby to health clinic (4w)	-0.051	(0.059)	0.689	14.337	2593
Doctor called to home for child (6m)	-0.000	(0.060)	0.271	13.353	2534
Doctor called to home for child (18m)	0.128*	(0.075)	0.378	11.722	2474
Doctor called to home for child (30m)	0.126*	(0.067)	0.280	14.059	2373
Specialist checked child (24m)	0.020	(0.052)	0.188	12.694	2358
Child had surgery visit (30m)	-0.015	(0.055)	0.814	13.079	2364
Child had routine check with doctor (30m)	-0.037	(0.055)	0.172	12.726	2332
Parenting and teaching scores[2]					
Child's activity score (6m) [0-20]	-0.067	(0.330)	14.480	13.804	2543
Child's activity score (30m) [0-29]	0.032	(0.424)	18.589	14.381	2392
Child's activity score (42m) [0-28]	0.172	(0.364)	18.724	12.818	2324
Mother's parenting score (6m) [0-12]	-0.135	(0.193)	10.542	13.668	2539
Mother's parenting score (18m) [6-51]	-0.254	(0.572)	40.860	13.025	2481
Mother's parenting score (24m) [20-40]	0.462	(0.394)	34.547	10.632	2324
Mother's parenting score (38m) [4-30]	-0.291	(0.405)	25.250	12.614	2356
Partner's parenting score (6m) [10-30]	0.311	(0.496)	23.599	14.612	2493
Partner's parenting score (18m) [0-40]	1.057	(0.944)	24.486	11.804	2406
Partner's parenting score (38m) [0-30]	-0.097	(0.700)	21.447	11.186	2248
Mother's teaching score (30m) [0-8]	-0.007	(0.159)	6.637	14.167	2380
Mother's teaching score (42m) [0-8]	0.190	(0.179)	6.993	12.817	2325
Child's toy score (24m) [5-36]	-0.532	(0.497)	23.512	9.978	2317
Child's toy score (42m) [1-9]	-0.097	(0.090)	8.180	12.817	2325
Maternal care score (18m) [0-24]	0.196	(0.683)	20.044	15.367	2655
Maternal overprotective score (18m) [0-20]	-0.342	(0.553)	6.288	15.367	2655
Maternal enjoyment score (8m) [0-15]	-0.254	(0.230)	13.243	13.240	2506
Maternal confidence score (8m) [4-18]	-0.033	(0.249)	15.088	13.240	2506
Maternal bonding score (8m) [4-33]	-0.286	(0.401)	28.331	13.240	2506
Time spent doing different activities					
TV is on for most of the day (30m)	0.033	(0.066)	0.463	14.043	2224
TV is on for most of the day (42m)	0.052	(0.083)	0.475	9.271	2166
Hours p/wk spent in car (38m) [0-14]	-0.084	(0.211)	3.928	12.854	2331
Hours p/wk spent outdoors (38m)[0-14]	0.811	(0.500)	9.652	12.394	2319
Hours p/wk spent watching TV (38m)[0-14]	-0.181	(0.488)	7.487	12.872	2327
Hours p/wk spent w/ other kids (38m)[0-14]	0.009	(0.464)	11.668	12.411	2312
Mother has nights out each week (8m)	-0.010	(0.052)	0.196	12.954	2417
Mother worried that child may:					
Get accident (18m)	0.093	(0.065)	0.717	13.032	2477
Get meningitis (18m)	0.057	(0.065)	0.639	13.019	2472
Get asthma (18m)	0.073	(0.065)	0.350	11.574	2429
Get fits (18m)	0.005	(0.049)	0.162	12.996	2470
Be mentally handicapped (18m)	0.011	(0.030)	0.052	13.020	2471
Get AIDS (18m)	-0.005	(0.035)	0.098	12.818	2470
Worried about any aspect of behaviour (42m)	-0.123*	(0.063)	0.194	13.224	2259
Household characteristics[3]					
Other children in house (6m)	-0.003	(0.067)	0.540	13.178	2529
Other children in house (18m)	-0.077	(0.070)	0.574	12.343	2471
Older children in house (18m)	-0.038	(0.068)	0.538	12.285	2468
Younger children in house (18)	-0.042	(0.035)	0.047	12.441	2456
Total number of hh members (8m) [1-14]	-0.117	(0.143)	3.793	13.131	2461
Financial difficulties score (8m) [0-15]	-0.147	(0.467)	2.752	13.348	2497
Child care					
Expect to use partner (at 32 wks gest)	0.075*	(0.041)	0.163	15.699	2670
Expect to use family (at 32 wks gest)	0.051	(0.049)	0.188	15.469	2661
Expect to use child minder (at 32 wks gest)	-0.004	(0.039)	0.116	15.314	2648
Expect to use nanny (at 32 wks gest)	-0.017	(0.024)	0.038	14.801	2647
Expect to use nursery (at 32 wks gest)	0.028	(0.028)	0.046	15.386	2620
Expect to use other (at 32 wks gest)	-0.015	(0.016)	0.017	15.465	2663

Partner regularly looks after child (15m)	0.032	(0.050)	0.778	21.799	2473
Grandparent regularly looks after child (15m)	0.103*	(0.057)	0.443	21.799	2473
Other relative reg. looks after child (15m)	-0.014	(0.034)	0.099	21.799	2473
Friend regularly looks after child (15m)	-0.056	(0.043)	0.097	21.799	2473
Child minder regularly looks after child (15m)	0.010	(0.039)	0.142	21.799	2473
Nanny regularly looks after child (15m)	-0.022	(0.030)	0.062	21.799	2473
Nursery regularly looks after child (15m)	0.056**	(0.024)	0.061	21.799	2473
Someone else reg. looks after child (15m)	0.020	(0.016)	0.017	21.799	2473
Partner regularly looks after child (24m)	0.062	(0.064)	0.720	11.060	2363
Grandparent regularly looks after child (24m)	0.171**	(0.081)	0.447	11.060	2363
Other relative reg. looks after child (24m)	0.021	(0.042)	0.116	11.060	2363
Friend regularly looks after child (24m)	-0.001	(0.047)	0.140	11.060	2363
Child minder regularly looks after child (24m)	-0.011	(0.051)	0.147	11.060	2363
Nanny regularly looks after child (24m)	0.019	(0.035)	0.066	11.060	2363
Nursery regularly look after child (24m)	0.041	(0.043)	0.101	11.060	2363
Other person regularly looks after child (24m)	0.017	(0.019)	0.012	11.060	2363
Partner regularly looks after child (38m)	0.009	(0.057)	0.766	12.476	2364
Grandparents regularly look after child (38m)	0.136*	(0.071)	0.429	12.476	2364
Other relative reg. looks after child (38m)	-0.038	(0.044)	0.094	12.476	2364
Friend regularly looks after child (38m)	-0.016	(0.043)	0.122	12.476	2364
Child minder regularly looks after child (38m)	-0.083	(0.051)	0.094	12.476	2364
Nanny regularly looks after child (38m)	0.041	(0.033)	0.073	12.476	2364
Nursery regularly looks after child (38m)	0.052	(0.067)	0.359	12.476	2364
Other person regularly looks after child (38m)	-0.111	(0.072)	0.319	12.476	2364
Number of types of child care (38m) [0-6]	-0.010	(0.157)	2.255	12.476	2364
Social support[4]					
Mother's social support score (8w) [0-30]	0.334	(0.646)	20.374	15.599	2578
Partner's social support score (8w) [0-30]	-0.647	(0.607)	19.422	20.743	1991
Mother's social help score (8w) [0-24]	-0.696	(0.522)	16.306	15.596	2577
Partner's social help at home (8w) [0-27]	-1.384**	(0.621)	15.298	21.418	1998
Partner's social help with child (8w) [0-35]	0.871	(0.802)	20.669	21.418	1998

Notes: All variables are measured after the child is born, unless otherwise stated. All variables are binary unless otherwise stated, indicating the range of the variable, e.g. [0-30]. The coefficients (column 1) and standard errors (column 2) denote the estimates from an IV regression of the effect of alcohol exposure *in utero* on the outcome of interested listed in the first column, where the mother's *ADH1B* is used as the instrument. Column 3 shows the mean of the outcome of interest, column 4 shows the first-stage *F*-statistic, and column 5 shows the sample size for each analysis. All 'score-variables' are derived from multiple questions. [1]The interaction scores indicate the frequency and type of interactions with the child, with higher scores indicating more interactions. [2]The activity scores measure activities such as going to the park, supermarket, visiting friends, etc., with higher scores indicating more activity. The parenting scores measure activities such as reading stories, eating together, cuddling, slapping, singing to the child, etc., where higher scores indicate better parenting. The teaching scores capture activities such as teaching numbers, rhymes, shapes, politeness, etc., where higher scores indicate more teaching. The toy scores capture the number and types of toys the child has, such as push/pull, co-ordination toys, lego, books, etc., where higher scores indicate more toys. The maternal care and overprotective scores measure the relationship between the mother and her mother (e.g. whether the mother's mother was friendly, cold, controlling, affectionate, etc.). The maternal enjoyment, confidence and bonding scores capture whether the mother enjoys looking after, is confident, and bonds with her baby. [3]The financial difficulties score measures how difficult it is to afford food, clothing, heating, rent, etc. [4]The social support score measures the extent of support available to the mother and partner (including emotional support, sharing happiness, relying on each other, etc.). The social help scores measure the extent to which the mother and partner receive help with the baby, doing shopping, cleaning, cooking, washing, etc.

Appendix D: Robustness checks

Table D1: Robustness checks on use of covariates, IV estimates with Key Stage 1 as the outcome variable and the number of alcoholic units consumed as the treatment variable.

	(1) Coefficient on average no. units during pregnancy	(2) Standard error	(3) First stage F-statistic	(4) N
Panel A: Controlling for additional alcohol-related covariates				
1: Replicates the results from Table 5	-0.245**	(0.114)	16.366	2433
2: Includes maternal smoking during pregnancy as covariate	-0.242**	(0.114)	15.909	2431
3: Excludes child *ADH1B* (i.e. only the principal components)	-0.182**	(0.084)	33.526	2433
4: Includes binary indicators for maternal post-natal alcohol intake when the child was 8, 21, 33, and 47 months old	-0.204	(0.138)	7.922	1861
5: Includes binary indicators for the child's own alcohol intake at 157, 166, and 185 months	-0.140	(0.119)	11.816	1125
6: Includes mother's partner's and parents' alcohol consumption	-0.232**	(0.113)	14.216	2035
Panel B: Controlling for covariates specified in Appendix B				
7: Includes all 'standard' covariates	-0.217*	(0.122)	10.856	1551
8: Same as model (7), but using (single) multivariate imputation for missing values on the covariate to obtain the same sample size as the original specification	-0.273**	(0.128)	11.030	2433
9: Includes mother's tea, coffee and milk intake, 8 wks gestation	-0.299**	(0.150)	11.373	2345
10: Includes mother's diet and nutrition, 32 weeks gestation	-0.198*	(0.105)	14.975	2241
11: Includes mother's attitude to parenting	-0.209*	(0.121)	12.881	2254
12: Includes mother's religious believes	-0.234**	(0.118)	14.168	2385
13: Includes household characteristics	-0.319**	(0.130)	12.888	2292
14: Includes variables related to the mother's pregnancy	-0.221	(0.142)	7.479	1914
15: Includes mother's physical health during pregnancy	-0.294*	(0.153)	9.274	1273
16: Includes mothers' physical activity during pregnancy	-0.211**	(0.095)	28.892	2280
17: Includes mother's mental health during pregnancy	-0.160	(0.116)	12.127	2200
18: Includes mother's use of medication during pregnancy	-0.206**	(0.100)	15.147	2246
19: Includes mother's substance use during pregnancy	-0.199*	(0.113)	12.940	2096
20: Includes mother's use of chemicals	-0.183*	(0.101)	16.751	2426
21: Includes mother's social support network	-0.225*	(0.117)	14.856	2296
22: Includes mother's perception of neighbourhood	-0.222**	(0.108)	16.577	2339

Notes: All estimates come from separate regressions. All regressions also control for the ten ancestry-informative principal components and the child's *ADH1B*, apart from specification 3 that only controls for the principal components. Robust standard errors are in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

Tables and Figures

Figure 1: The Metabolism of Alcohol

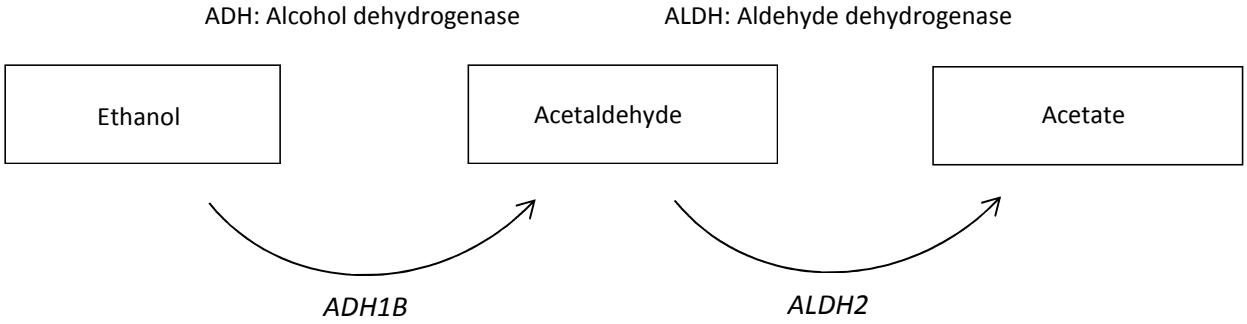


Figure 2: Weight functions

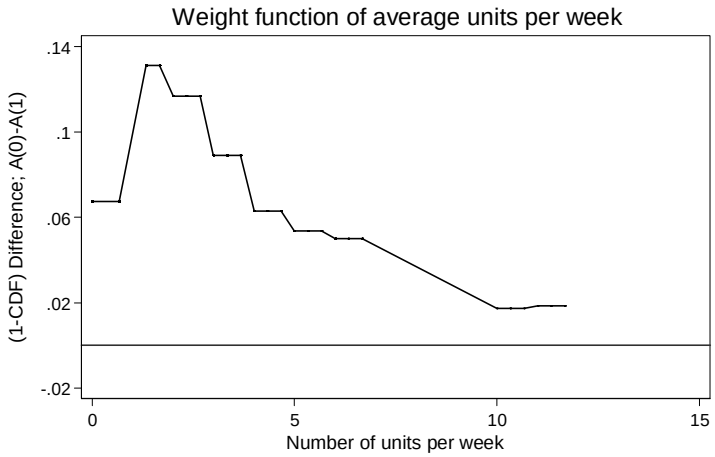
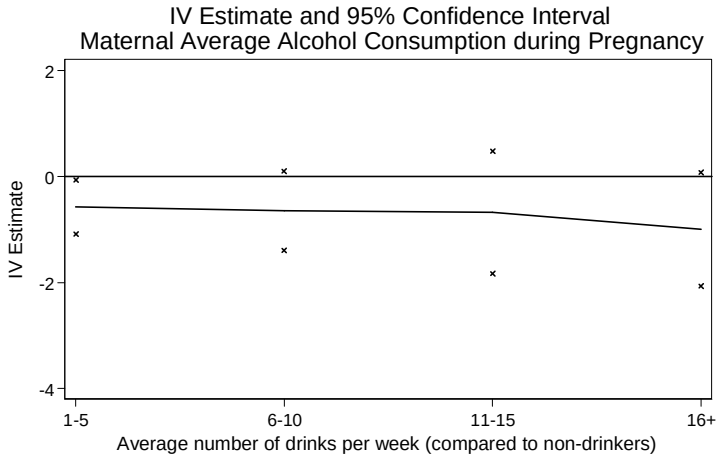


Figure 3: The effect of low-to-moderate and heavy drinking on the child's KS1 score



Note: The 95% confidence intervals are presented as two points above and below the estimate.

Table 1: Descriptive statistics, mean and standard deviation of variables of interest

	(1) Full sample	(2) Homozygous for the *ADH1B* common allele	(3) Carrying at least one *ADH1B* rare allele	(4) t-test
	Mean (std dev)	Mean (std dev)	Mean (std dev)	*p*-value
Panel A: Any alcohol consumption				
Any alcohol (binary)	0.627 (0.484)	0.633 (0.482)	0.507 (0.501)	0.001
N	4201	3990	211	
Panel B: Pattern and duration				
Bingeing (trimester 2)	0.167 (0.373)	0.170 (0.375)	0.112 (0.316)	0.022
N	4714	4482	232	
Length of exposure	0.971 (1.165)	0.991 (1.172)	0.592 (0.963)	<0.001
N	2880	2733	147	
Panel C: Average alcohol consumption				
No. of units p/w	1.503 (2.980)	1.549 (3.031)	0.646 (1.583)	<0.001
[min - max]	[0 35]	[0 35]	[0 11]	
N	2781	2639	142	
No. of units of wine	0.565 (1.388)	0.584 (1.421)	0.261 (0.608)	0.012
[min - max]	[0 17]	[0 17]	[0 3]	
N	2116	1991	125	
No. of units of beer	0.377 (1.543)	0.395 (1.582)	0.101 (0.552)	0.057
[min - max]	[0 35]	[0 35]	[0 5]	
N	1803	1697	106	

Standard deviations	Between	Within	Between	Within	Between	Within
All alcohol	3.318	1.881	3.370	1.911	1.975	1.177
Wine	1.796	1.143	1.818	1.153	1.285	0.930
Beer	1.966	1.268	2.004	1.288	0.988	0.809

Note: The *p*-value is based on a test of equality between the mean for the homozygotes for the common allele and those carrying at least one rare allele. 'Any alcohol' is a binary variable indicating whether the foetus was exposed to any alcohol *in utero*. 'Length of exposure' ranges from zero to three trimesters. The average number of units of wine is calculated among women who either indicate to drink no beer, spirits or other alcoholic drinks, or who did not report their beer, spirit or other alcoholic consumption (i.e. have missing values for beer, spirit and other alcoholic drinks). Similarly, the average number of units of beer is calculated among women who either indicate to drink no wine, spirits or other alcoholic drinks, or who did not report their wine, spirit or other alcoholic consumption. Therefore, the sample sizes of the number of units of wine and beer do not add up to the total number of units. Indeed, some mothers may report to drink alcohol, but do not define which drink they consumed.

Table 2: OLS regressions of child academic achievement on maternal prenatal alcohol consumption

	Entry Assessment	KS1, age 7	KS2, age 11	KS3, age 14	KS4, age 16
Panel A: Any alcohol intake					
Any alcohol intake	0.054	-0.037	0.026	0.026	-0.033
	(0.039)	(0.033)	(0.034)	(0.037)	(0.035)
N	2614	3319	3132	2872	3201
Panel B: Pattern and duration					
Bingeing	-0.107**	-0.210***	-0.159***	-0.225***	-0.235***
	(0.045)	(0.038)	(0.040)	(0.041)	(0.040)
N	3238	4088	3868	3572	3955
Length of exposure	0.061***	0.028*	0.053***	0.046***	0.044***
	(0.019)	(0.015)	(0.015)	(0.017)	(0.016)
N	1982	2518	2372	2179	2428
Panel C: Average alcohol intake					
Average units of alcohol	0.010	-0.010*	-0.002	-0.006	-0.005
	(0.007)	(0.006)	(0.007)	(0.007)	(0.006)
N	1922	2433	2293	2106	2345
Average units of wine	0.064***	0.033**	0.053***	0.052***	0.041***
	(0.016)	(0.014)	(0.013)	(0.017)	(0.014)
N	1473	1862	1747	1600	1795
Average units of beer	-0.015	-0.044***	-0.039*	-0.061***	-0.049***
	(0.019)	(0.016)	(0.022)	(0.015)	(0.015)
N	1275	1569	1475	1381	1521

Notes: The table presents the correlations between academic achievement shown in the columns and the measures of alcohol exposure shown in the rows. All estimates come from separate regressions and control for ancestry-informative principal components and the child's *ADH1B*. Robust standard errors are in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

Table 3: The correlation between alcohol consumption and background characteristics

	(1) Any alcohol intake	(2) Binge drinking	(3) Length of exposure	(4) Average no. of units of alcohol	(5) Average no. of units of wine	(6) Average no. of units of beer
Covariates						
Child's *ADH1B*	-0.116***	-0.026	-0.325***	-0.637***	-0.260**	-0.269**
	(0.038)	(0.024)	(0.090)	(0.203)	(0.132)	(0.108)
Girl	-0.031*	-0.006	-0.047	-0.121	0.019	-0.080
	(0.016)	(0.011)	(0.043)	(0.113)	(0.066)	(0.065)
Mother's age	0.008***	0.001	0.034***	0.068***	0.073***	0.016*
	(0.002)	(0.001)	(0.005)	(0.014)	(0.008)	(0.008)
Older siblings	0.032***	0.031***	0.041	0.214***	0.107**	0.114**
	(0.011)	(0.008)	(0.030)	(0.080)	(0.047)	(0.052)
Younger siblings	-0.006	0.021	0.062	0.152	0.250	0.097
	(0.038)	(0.028)	(0.107)	(0.298)	(0.200)	(0.194)
Father's education	0.035***	-0.024***	0.163***	0.169***	0.260***	-0.027
	(0.008)	(0.005)	(0.021)	(0.059)	(0.035)	(0.035)
Mother's education	0.026***	-0.039***	0.148***	0.043	0.249***	-0.141***
	(0.009)	(0.006)	(0.025)	(0.068)	(0.039)	(0.042)
Father's social class	0.027***	-0.021***	0.103***	0.098**	0.176***	-0.017
	(0.006)	(0.004)	(0.017)	(0.040)	(0.024)	(0.023)
Ln(income)	0.063***	-0.062***	0.359***	0.158	0.466***	-0.118
	(0.018)	(0.013)	(0.049)	(0.137)	(0.075)	(0.078)
Mother employed	0.056***	0.004	0.193***	0.128	0.214***	0.025
	(0.017)	(0.011)	(0.046)	(0.112)	(0.071)	(0.063)
Father employed	0.016	-0.065***	0.148**	-0.196	0.291***	-0.434**
	(0.027)	(0.019)	(0.070)	(0.241)	(0.096)	(0.189)
CCEI	0.005***	0.006***	0.007**	0.036***	0.008	0.020***
	(0.001)	(0.001)	(0.003)	(0.011)	(0.005)	(0.007)
EPDS	0.008***	0.009***	0.010**	0.058***	0.017**	0.031***
	(0.002)	(0.001)	(0.005)	(0.017)	(0.008)	(0.010)
Smoke (Trimester 1)	0.084***	0.163***	0.108*	1.004***	0.010	0.775***
	(0.021)	(0.018)	(0.061)	(0.236)	(0.104)	(0.153)

Notes: The coefficient estimates are obtained from separate regressions of the alcohol exposure of interest (denoted in the columns) on each of the covariates in column 1. Robust standard errors are in parentheses, * p<0.10, ** p<0.05, *** p<0.01.

Table 4: First Stage IV results

	(1) Any alcohol intake	(2) Binge drinking	(3) Length of exposure	(4) Average no. of units of alcohol	(5) Average no. of units of wine	(6) Average no. of units of beer
Sample for Entry Assessment						
ADH1B	-0.131**	-0.062**	-0.327***	-0.818***	-0.325**	-0.245***
	(0.051)	(0.028)	(0.113)	(0.189)	(0.128)	(0.063)
First stage *F*-statistic	6.62	4.95	8.32	18.74	6.40	15.17
N	2614	3238	1982	1922	1473	1275
Sample for Key Stage 1						
ADH1B	-0.131***	-0.061**	-0.364***	-0.822***	-0.396***	-0.239***
	(0.046)	(0.025)	(0.108)	(0.203)	(0.115)	(0.051)
First stage *F*-statistic	8.18	5.90	11.48	16.37	11.90	21.54
N	3319	4088	2518	2433	1862	1569
Sample for Key Stage 2						
ADH1B	-0.147***	-0.070***	-0.375***	-0.859***	-0.417***	-0.241***
	(0.048)	(0.025)	(0.106)	(0.189)	(0.111)	(0.049)
First stage *F*-statistic	9.52	7.79	12.51	20.66	13.98	24.76
N	3132	3868	2372	2293	1747	1475
Sample for Key Stage 3						
ADH1B	-0.108**	-0.071***	-0.282**	-0.773***	-0.338***	-0.265***
	(0.050)	(0.026)	(0.118)	(0.208)	(0.131)	(0.058)
First stage *F*-statistic	4.61	7.31	5.74	13.84	6.69	20.57
N	2872	3572	2179	2106	1600	1381
Sample for Key Stage 4						
ADH1B	-0.147***	-0.067***	-0.379***	-0.857***	-0.391***	-0.254***
	(0.047)	(0.025)	(0.105)	(0.180)	(0.107)	(0.049)
First stage *F*-statistic	9.96	7.41	12.97	22.77	13.26	26.46
N	3201	3955	2428	2345	1795	1521

Notes: All estimates come from separate regressions and control for ancestry-informative principal components and the child's *ADH1B*. Robust standard errors in parentheses. * p<0.10, ** p<0.05, *** p<0.01.

Table 5: Second Stage IV results

	(1) Entry Assessment	(2) KS1, age 7	(3) KS2, age 11	(4) KS3, age 14	(5) KS4, age 16
Panel A: Any alcohol intake					
Any alcohol intake	-0.685	-1.372†	-1.536†	-1.724	-1.557†
95% Confidence intervals	[-4.45, 0.84]	[-4.85, -0.24]	[-4.59, -0.43]	[-18.6, -0.23]	[-4.57, -0.47]
N	2614	3319	3132	2872	3201
Panel B: Pattern and duration					
Bingeing	-1.782	-2.623†	-2.855†	-2.618†	-3.134†
95% Confidence intervals	[-13.8, 1.51]	[-12.7, -0.46]	[-9.68, -0.84]	[-9.84, -0.58]	[-11.1, -1.06]
N	3238	4088	3868	3572	3955
Length of exposure	-0.486	-0.591†	-0.693†	-0.665	-0.610†
95% Confidence intervals	[-2.21, 0.13]	[-1.67, -0.14]	[-1.81, -0.20]	[-3.74, 0.01]	[-1.64, -0.13]
N	1982	2518	2372	2179	2428
Panel C: Average alcohol intake					
Average units of alcohol	-0.193	-0.245†	-0.298†	-0.232	-0.274†
95% Confidence intervals	[-0.57, 0.06]	[-0.57, -0.05]	[-0.64, -0.08]	[-0.63, 0.02]	[-0.60, -0.06]
N	1922	2433	2293	2106	2345
Average units of wine	-0.480	-0.554†	-0.657†	-0.520	-0.621†
95% Confidence intervals	[-2.95, 0.21]	[-1.60, -0.10]	[-1.66, -0.17]	[-2.24, 0.14]	[-1.68, -0.10]
N	1473	1862	1747	1600	1795
Average units of beer	-0.895	-1.061†	-1.462†	-1.176†	-1.105†
95% Confidence intervals	[-2.53, 0.09]	[-2.39, -0.25]	[-2.96, -0.54]	[-2.54, -0.35]	[-2.40, -0.22]
N	1275	1569	1475	1381	1521

Notes: All estimates come from separate regressions and control for ancestry-informative principal components and the child's *ADH1B*. Weak-instrument robust 95% confidence bounds in square brackets. † p<0.05 using weak-instrument robust 95% confidence bounds.

Table 6: Reduced form estimates – academic achievement regressed on mother's and/or offspring *ADH1B*

	(1) Entry Assessment	(2) KS1, age 7	(3) KS2, age 11	(4) KS3, age 14	(5) KS4, age 16
Panel A: Separate regressions					
Maternal *ADH1B* (rs1229984)	0.030	0.159**	0.180***	0.142*	0.214***
	(0.086)	(0.068)	(0.068)	(0.074)	(0.069)
N	2564	3255	3067	2812	3138
Offspring *ADH1B* (rs1229984)	-0.146*	0.011	-0.007	-0.011	0.040
	(0.088)	(0.071)	(0.080)	(0.078)	(0.065)
N	2564	3255	3067	2812	3138
Panel B: Including both genotypes simultaneously					
Maternal *ADH1B* (rs1229984)	0.118	0.198***	0.239***	0.192**	0.250***
	(0.096)	(0.075)	(0.082)	(0.085)	(0.079)
Offspring *ADH1B* (rs1229984)	-0.202**	-0.082	-0.122	-0.103	-0.075
	(0.098)	(0.079)	(0.093)	(0.089)	(0.074)
N	2564	3255	3067	2812	3138

Notes: All estimates come from separate regressions that control for ten ancestry-informative principal components. Robust standard errors in parentheses, * p<0.10, ** p<0.05, *** p<0.01.

Table 7: Subgroup analysis, number of alcoholic units

	(1) Entry Assessment	(2) KS1, age 7	(3) KS2, age 11	(4) KS3, age 14	(5) KS4, age 16
By gender					
Boys	-0.167	-0.278**	-0.217	-0.240*	-0.390**
	(0.170)	(0.128)	(0.133)	(0.141)	(0.168)
First stage F-statistic	12.832	15.681	15.618	12.007	15.307
N	1000	1239	1151	1060	1188
Girls	-0.182	-0.185	-0.438	-0.180	-0.087
	(0.212)	(0.207)	(0.274)	(0.310)	(0.192)
First stage F-statistic	7.838	4.200	7.533	3.740	9.415
N	922	1194	1142	1046	1157
By mother's age at birth					
Mothers aged 27 or less	0.150	-0.233	-0.420	-0.412	-0.174
	(0.239)	(0.227)	(0.307)	(0.291)	(0.221)
First stage F-statistic	5.362	6.317	5.141	4.864	7.030
N	789	962	909	867	928
Mothers aged over 27	-0.424**	-0.265**	-0.261**	-0.158	-0.326**
	(0.185)	(0.126)	(0.129)	(0.162)	(0.141)
First stage F-statistic	11.197	9.545	13.909	7.712	13.849
N	1133	1471	1384	1239	1417
By social class					
Low social class	-0.221	-0.255*	-0.440**	-0.305*	-0.293*
	(0.213)	(0.144)	(0.204)	(0.172)	(0.176)
First stage F-statistic	7.232	9.245	10.037	7.951	9.939
N	817	977	941	889	952
High social class	-0.262	-0.303*	-0.184	-0.184	-0.258
	(0.237)	(0.180)	(0.164)	(0.240)	(0.178)
First stage F-statistic	8.050	6.593	9.273	5.496	11.589
N	1010	1346	1254	1118	1287
By maternal educational level					
Low education	-0.188	-0.279	-0.507	-0.232	-0.433*
	(0.313)	(0.209)	(0.310)	(0.230)	(0.257)
First stage F-statistic	3.422	5.770	4.878	4.241	6.395
N	1231	1478	1414	1353	1444
High education	-0.156	-0.140	-0.060	-0.106	-0.051
	(0.126)	(0.105)	(0.086)	(0.114)	(0.100)
First stage F-statistic	20.346	10.947	20.855	11.266	21.018
N	688	952	876	750	898
By income					
Low income (less than median)	-0.404	-0.319	-0.405	-0.258	-0.321
	(0.272)	(0.195)	(0.260)	(0.271)	(0.212)
First stage F-statistic	6.580	8.471	7.814	4.602	8.437
N	853	1027	978	939	1005
High income (more than median)	0.007	-0.081	-0.104	-0.087	-0.061
	(0.199)	(0.131)	(0.110)	(0.139)	(0.136)
First stage F-statistic	7.161	5.263	8.165	4.775	9.427
N	820	1090	1020	883	1040

Notes: All estimates come from separate regressions where the treatment of interest is the number of alcoholic units consumed. All analyses control for ancestry-informative principal components and the child's *ADH1B*. Robust standard errors in parentheses. Low social class indicates non-skilled, semi-skilled or skilled manual occupations; High social class indicates skilled non-manual, managerial or professional occupations. Low education denotes O-level or less, high education indicates A-level or university degree. * p<0.10, ** p<0.05, *** p<0.01.