



Birth weight and adult earnings: a systematic
review and meta-analysis

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Review

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Abstract

While substantial evidence has identified low birth weight (LBW; <2500 g) as a risk factor for early life morbidity, mortality and poor childhood development, relatively little is known on the links between birth weight and economic outcomes in adulthood. The objective of this study was to systematically review the economics (EconLit) and biomedical literature (Medline) and estimate the pooled association between birth weight and adult earnings. A total of 15 studies from mostly high-income countries were included. On average, each standard deviation increase in birth weight was associated with a 2.75% increase in annual earnings [(95% CI: 1.44 to 4.07); 9 estimates]. A negative, but not statistically significant, association was found between being born LBW and earnings, compared to individuals not born LBW [mean difference: −3.41% (95% CI: −7.55 to 0.73); 7 estimates]. No studies from low-income countries were identified and all studies were observational. Overall, birth weight was consistently associated with adult earnings, and therefore, interventions that improve birth weight may provide beneficial effects on adult economic outcomes.

Introduction

According to the latest global estimates, 18 million infants were born low birth weight (LBW; <2500 g) globally in 2010.¹ The primary causes of LBW are prematurity and intrauterine growth restriction.² LBW infants are at increased risk of infant morbidity and mortality³ and are also more likely to experience linear growth faltering during childhood.⁴ There is also a growing literature indicating that LBW infants may be at greater risk for suboptimal neurodevelopmental outcomes during childhood,^{5,6} with potentially important implications across the life course.

The developmental origin of health and disease theory suggests that in utero exposures can increase the risk of adverse health outcomes later in life and across generations. Original studies showed that restricted fetal development, as measured by LBW, was associated with increased risk of adult hypertension, insulin resistance, obesity and other non-communicable diseases.⁷ Following Barker's original work,^{8,9} positive associations between early life growth restriction and adult risk of chronic disease have been documented both in animal¹⁰ and human studies,¹¹ even though disease trajectories among humans seem to be partially conditioned by early life catch-up growth.¹² However, more recent evidence suggests wider implications for immunological, mental health and reproductive outcomes.^{13,14} Fetal development may also affect human capital outcomes across the life course.¹⁵

Much less is known regarding the long-term implications of LBW on adult incomes or earnings as the primary measures of socio-economic well-being. In this paper, we present the results of a systematic review and meta-analysis of the economics and the biomedical literature designed to investigate this empirical association. Characterising the long-run human capital effects of adverse birth outcomes, in addition to health-related outcomes, is important to estimate the broader societal impact of adverse birth outcomes and the potential benefits of interventions and policies to support vulnerable infants.

Methods**Search strategy**

We conducted a systematic review and analysis of published literature following PRISMA guidelines. We searched both the economics literature, which was indexed through the EconLit search platform, and the biomedical literature via Pubmed (Medline) for wage and earnings outcomes using the following search: (birthweight OR 'birth weight') AND (wage OR earnings OR education OR schooling OR 'human capital' OR 'labor force' OR unemployment). We included

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broader labour market measures in the outcome-level search terms since these may also include secondary analyses relevant to earnings. We reviewed all publications and working papers from database conception to 28th February 2019 with data on birth weight and the outcome measures of wages and earnings at any age. Only studies using individual-level data and written in English were included.

Study selection

Two reviewers independently screened titles and abstracts and then reviewed full texts of selected studies to assess eligibility. Disagreements between reviewers were resolved by consensus. The inclusion criteria were that the studies used individual-level data; the exposure was birth weight either defined as a continuous variable or categorically [e.g. LBW or extremely low birth weight (ELBW), <1000 g]; the outcome was one related to the seven outcomes defined in our search; the outcome was measured at age 10 or above; and when the outcome was measured on a wide range of ages and the upper bound of the range is above 10. The exclusion criteria were outcomes where parental investment in their children or adult health outcomes; birth weight was measured as a categorical variable with more than two weight brackets; the outcomes were behavioural measures or measures of mental health; and association estimates were unadjusted (bivariate correlation coefficients).

Data extraction

Two reviewers independently extracted data using a standardised data extraction form. The data collected from each study included study design, birth weight sample mean and standard deviation, birth weight definition (continuous or dichotomous LBW), outcome definition, outcome mean and standard deviation, age at which outcome was assessed, statistical model used to assess associations, confounders, number of observations, sample type (twins, siblings or singletons) and birth year of study participants.

If more than one relevant outcome, more than one birth weight measurement or more than one dataset were used in the same study, data were extracted separately for each. Disagreements were resolved through discussion or by consulting a third reviewer.

Data standardisation

Some studies reported a continuous measure of birth weight exposure in grams, kilograms or ounces while others reported birth weight on the logarithmic scale. Studies which used log birth weight only reported standard deviations of birth weight in linear form. To ensure comparability of linear and logarithmic birth weight estimates, we derived an expression for the standard deviation of log birth weight.

We first calculated a first-order Taylor approximation of the logarithm of birth weight evaluated at the mean, and then calculated the variance and the standard deviation of the expression. The final expression (3) describes the standard deviation of the logarithm of birth weight as a function of mean birth weight and standard deviation of birth weight, which we estimated with their sample analogues, extracted from the set of included studies:

$$\ln(X) \sim \ln[\mu] + \frac{1}{\mu}(X - \mu)$$

$$\text{Var}(\ln(X)) = \frac{1}{\mu^2} \sigma^2$$

$$SD(\ln(X)) = \frac{1}{\mu} \sigma$$

For both linear and log birth weight estimates, we then multiplied the estimated coefficients with the standard deviation of the exposure variable used. The resulting scaled coefficients capture the average change in the outcome for one standard deviation increase in birth weight. To ensure log-transformed models yielded on average the same results as linear models, we ran a series of simulation models. The results (shown in Supplementary Appendix 1) suggest an almost perfect alignment between linear and log-linear models in our settings as long as the marginal effect of birth weight is constant.

Statistical analysis

The objective of the meta-analysis was to produce a quantitative estimate of the relationship of two birth weight exposures: (i) a standard deviation in birth weight or (ii) being born LBW, with the mean difference in annual earnings, the primary outcome. To calculate the pooled summary coefficient, we used the DerSimonian and Laird method with random effects. We report the Cochran's Q *P*-value and the I² statistic to quantify the fraction of total variation across studies attributable to heterogeneity.

Each analysis lists the individual studies, their country and the sample type (i.e., twins, siblings or singletons) since these might give rise to between-study heterogeneity. In addition, we stratified studies by continuous and LBW categorical exposure and recalculated the pooled summary associations for each subgroup, when there was substantial heterogeneity. Finally, we assessed publication bias by including the *P*-values for Egger's test.

Results

Literature search

Fig. 1 presents the study selection cascade for earnings outcomes. A total of 150 potentially relevant records were identified via EconLit and Pubmed. The initial search also yielded a review of studies containing one relevant article which we added to the pool.¹⁶ After removing duplicates, we screened the 139 remaining titles and abstracts and identified 19 studies for full-text review. After a detailed full-text review, we included 15 studies in the final database.

Study characteristics

The 15 studies with earnings outcome data were observational datasets from high-income countries apart from 1 observational study from China (middle-income). Some studies reported multiple effect estimates if they used different samples or reported analyses for birth weight defined on a continuous scale as well as categorically as LBW. We therefore refer to the number of effect estimates, rather than the number of studies hereafter. We present study-level information in Tables 1 and 2 for studies measuring birth weight as a continuous and binary variable, respectively. In addition, we qualitatively summarised two studies that reported on ELBW. There were a total of nine estimates based on continuous birth weight measures and seven based on LBW binary measures.

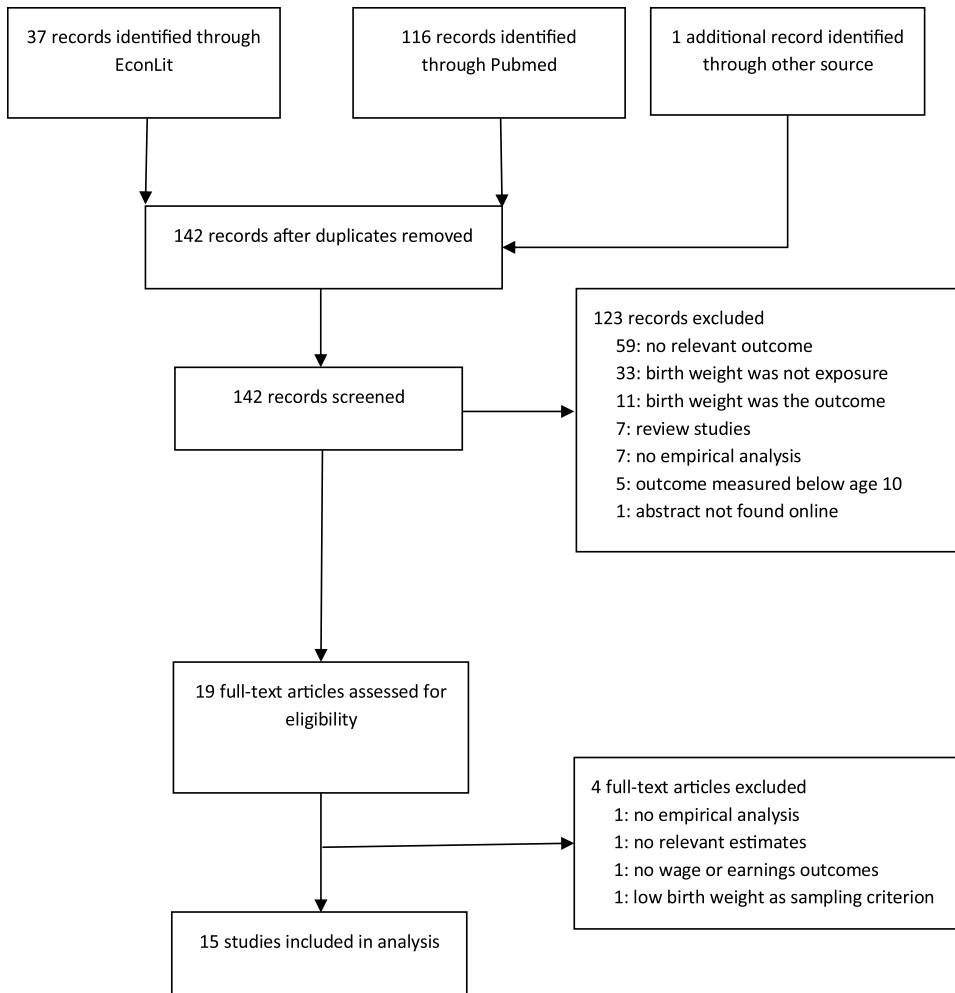


Fig. 1. Study selection – earnings outcomes.

Annual earnings

Seven studies reported nine estimates on the relationship between birth weight and annual earnings.^{17–23} The pooled estimates indicated that each standard deviation increase in birth weight was associated with a 2.75% increase in annual earnings [95% CI: 1.44% to 4.07%]; 9 estimates; Fig. 2]. Seven out of nine estimates used twin sampling methods. Overall, there was low heterogeneity ($I^2 = 28%$, Cochran's $Q P = 0.2$).

We performed four sensitivity analyses. First, Supplementary Figure S1 presents pooled estimates in twin studies (two non-twin estimates out of nine omitted); the findings were qualitatively the same and each standard deviation increase in birth weight among twins was associated with a 2.3% increase in annual earnings (95% CI: 1.1% to 3.4%). Second, we conducted a sensitivity analysis limited to studies in high-income countries and omitted the two estimates from studies conducted in China (Supplementary Figure S2); the pooled estimate remained similar (mean difference 2.4%; 95% CI: 1.3 to 3.4%). Third, we stratified studies by those using linear birth weight and log birth weight in Supplementary Figure S3. The magnitude of the association appeared slightly reduced for studies examining log birth weight (mean difference 1.8%; 95% CI: 0.9% to 2.8%) as compared to studies that examined linear birth weight (mean difference 5.6%; 95% CI: 0.3% to 8.3%); however, both indicated a statistically significant relationship between birth weight and annual earnings. Finally, we present the pooled association after removing the two studies that adjusted

for education in Supplementary Figure S4; this did not affect our overall findings.

Six studies presented seven estimates on the relationship between being born LBW and annual earnings.^{24–29} No statistically significant association was found between being born LBW and annual wages, although the pooled estimate was negative [mean difference: $-3.41%$ (95% CI: $-7.55%$ to $0.73%$); 7 estimates; Fig. 3].

In addition to the continuous measures of birth weight and the LBW indicator, we identified two studies conducted in Canada that compared earnings outcomes between ELBW individuals (birth weight <1000 g) and individuals born above 2500 g. While they are not directly comparable to the commonly used LBW measures, the estimates are negative, as expected, and larger in magnitude. The first study found that being born ELBW was associated with a 25.3% significant reduction in annual earnings for males and a 6.5% non-significant reduction in annual earnings for females,³⁰ while the second reported that ELBW individuals earned \$17,210 less annually, than those born above 2500 g.³¹

Publication bias

We performed Egger's test for each of the two analyses presented above. There was suggestive evidence of publication bias in the association between continuous birth weight and annual earnings, presented in Fig. 2 (Egger's test P -value < 0.01), and no evidence for bias in the association of LBW and earnings, presented in Fig. 3 (Egger's test P -value = 0.54). However, the number of studies per

Table 1. Study information – annual earnings in studies where outcome is a continuous measure of birth weight

Study	Country	N	Birth years	Exposure	Sample	Covariates	Outcome definition
Bharadwaj <i>et al</i> , 2018	Sweden	22,126	1926–1958	Log	Twins	Twin FE; sex	Average annual earnings between ages 25 and 33
Bharadwaj <i>et al</i> , 2018	Sweden	8352	1973–1981	Log	Twins	Twin FE; sex	Average annual earnings between ages 25 and 33
Black <i>et al</i> , 2007	Norway	5952	1967–1977	Log	Twins	Twin FE; sex; birth order	Annual earnings for FT employees including labour earnings and benefits from sickness, unemployment, parental leave and pensions
Cook and Fletcher, 2015	USA	820	1939–1940	Linear	Siblings	Maternal education; SES; race; sex birth year; birth order; father's education	Hourly wage in 1992–1993
Kim and Wickrama, 2017	USA	12,278	1976–1983	Linear	Singletons	Maternal education; race, height	Index combining average annual personal earnings before tax and household assets
Miller <i>et al</i> , 2005	Australia	556	1964–1971	Linear	Twins – MZ	Twin FE; years of education; marital status of child; full-time employment y/n	Annual earnings
Rosenzweig and Zhang, 2013	China	744	1973–1984	Linear	Twins – males	Twin FE	Monthly wage
Rosenzweig and Zhang, 2013	China	744	1973–1984	Linear	Twins – females	Twin FE	Monthly wage
Sandewall <i>et al</i> , 2014	Sweden	1494	1950–1975	Linear	Twins – male MZ	Twin FE; schooling years	Annual taxable earnings in 2005, defined as the sum of wage earnings, income from own business, pension income and unemployment compensation. Capital income not included

Table 2. Study information – annual earnings in studies where outcome is a low birth weight (LBW) binary variable

Study	Country	N	Birth years	Exposure	Sample	Covariates	Outcome definition
Beach and Saavedra, 2015	USA	437	1975–1996	LBW	Singletons	Maternal education; SES; family zip code income; paternal education; sex; parent's income category; child's age; number of children in family	Income
Behrman and Rosenzweig, 2004	USA	804	1936–1955	LBW	Twins – female MZ	Twin FE	FT equivalent annual earnings in 1993 or last job held
Currie and Hyson, 1999	UK	3360	1958–1958	LBW	Singletons – females	Maternal age; maternal education; SES; maternal smoking; twins yes/no; maternal marital status; family size; birth order	Hourly wage
Currie and Hyson, 1999	UK	3421	1958–1958	LBW	Singletons – males	Maternal age; maternal education; SES; maternal smoking; twins yes/no; maternal marital status; family size; birth order	Hourly wage
Johnson and Schoeni, 2011	USA	19,830	1951–1975	LBW	Siblings – males	Maternal age; birth order; two parent family y/n; parental fertility timing preference variables; race; birth year	Total labour market earnings during the previous calendar year, in 1997 dollars, conditional on positive earnings
Nakamuro <i>et al</i> , 2013	Japan	1832	1952–1992	LBW	Twins – MZ	Twin FE; age, age squared, gender, father's education, living standard at the age 15, years of schooling, marital status, years of tenure at the current employment, hours of work per day	Annual wage in 2010 before taxes, split into 16 categories from 'no income' to 'income above 15 million JPY'
Schwandt, 2018	Denmark	2,934,255	1980–1993	LBW	Siblings	Maternal age; maternal education; current calendar year; current age; region of birth; sex; marital status	Annual wage measured in real 2010 USD, excluding government transfers

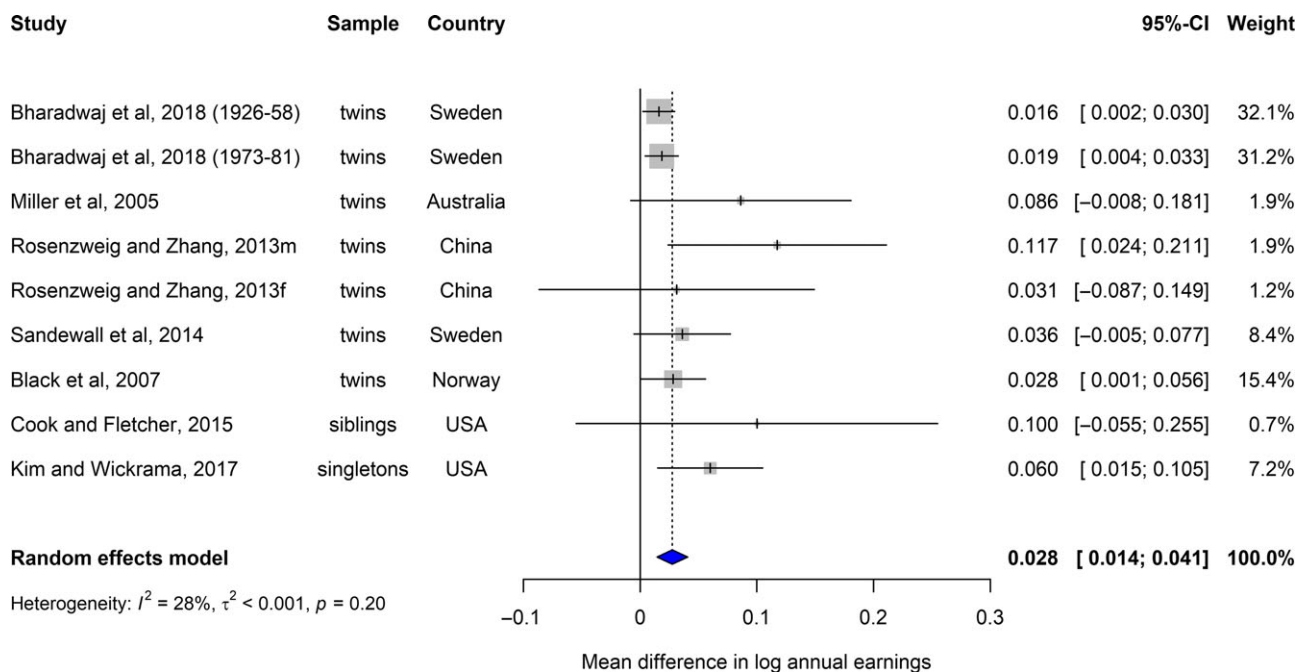


Fig. 2. Meta-analysis of the association of one standard deviation increase in birth weight with annual earnings.

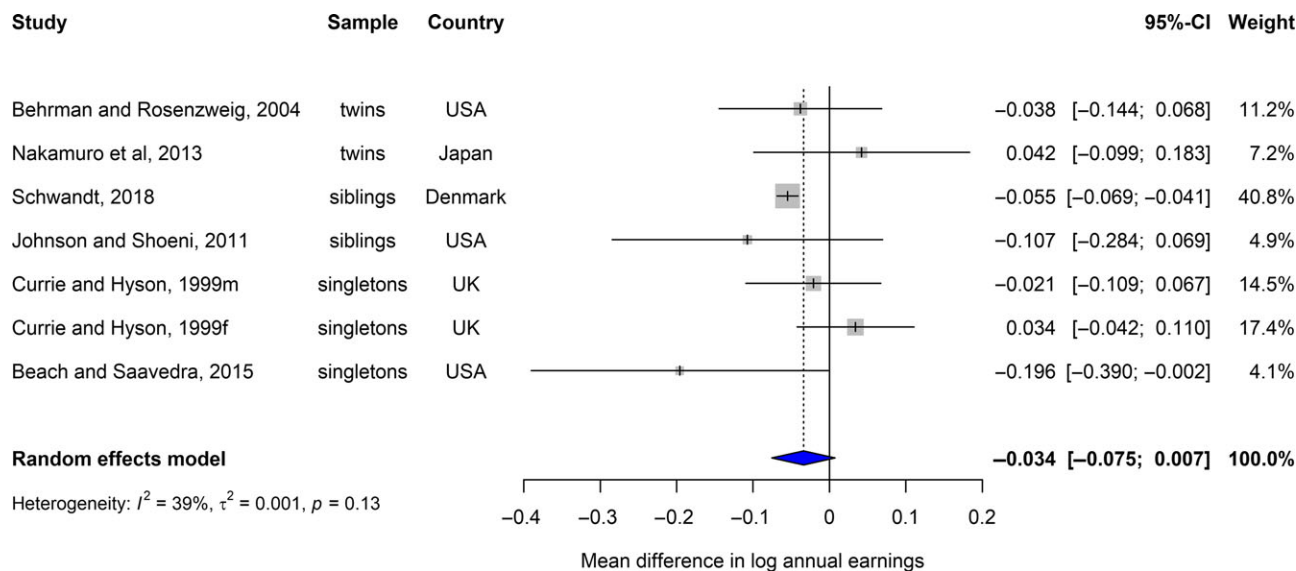


Fig. 3. Meta-analysis of the association of low birth weight (LBW) with annual earnings.

analysis was relatively low (i.e. below 10 effect estimates per meta-analysis), so these results should be treated with caution.

Discussion

In this study, we presented the results of a systematic review of the economics and biomedical literature on the long-term effects of birth weight on adult earnings. On average, pooled estimates indicated that each standard deviation (500 g) increase in birth weight was associated with 2.8% additional annual earnings. Further, LBW appeared to be negatively associated with annual earnings, but the results were not statistically significant. While the percentage increase in earnings per standard deviation of birth weight may

seem small in magnitude, the estimates are economically meaningful. In a high-income setting like the USA, this implies that a one standard deviation decrease in birth weight (which corresponds to about ~500 g) is associated with a loss of lifetime earnings of about USD 33,600, assuming a median base wage of USD 30,000 and 40 years of work.

Our findings are aligned with the literature to date highlighting the positive association between birth weight and measures of human capital in high-income settings.¹⁵ Conceptually, there are multiple mechanisms that may link birth weight to adult earnings. There is a relatively large literature linking LBW with suboptimal brain development^{32,33} through pathways related to reduced brain volume and deficits in neuron proliferation, synaptogenesis and

myelination.^{34,35} Of note, a longitudinal birth cohort study conducted in the UK found LBW was associated with reduced cognitive ability in childhood, adolescence and persisted through adulthood.³⁶ Further, LBW has also been linked to lower educational attainment in a number of studies.^{17,18,29,37} In addition, mechanisms related to risk of disability may also be relevant, particularly for ELBW children, who have been found to be at greater risk for cerebral palsy, intellectual disability, blindness and deafness.^{30,31} While disabilities are associated with reduced earnings, they fall outside of the scope of this paper which focused on economic outcomes; however, the two studies included in our review that analysed ELBW found large wage reductions of up to 25%.^{30,31} Additional research, including mediation analyses, is needed to inform the mechanistic pathways that link birth weight to adult earnings.

Although, to the best of our knowledge, this is the largest review of evidence linking birth weight to earnings and later life human capital outcomes to date, our analysis has some limitations. First, our review yielded almost exclusively studies from high-income countries. Given that long-term follow-up data from birth cohorts in low- and middle-income countries (LMICs) are relatively scarce this is not surprising – it does however raise concerns regarding the external validity of these estimates. It is noteworthy, however, that there is a growing literature linking birth weight to cognitive function and schooling in LMICs.³⁸ Nevertheless, infants born with LBW are likely to obtain substantially more parental and governmental support in high than in low-income settings, and this could reduce the developmental gap. Therefore, differences in economic outcomes between lower and higher birth weight individuals may remain larger in low-income settings. Additional research is needed globally and among disadvantaged populations in high-income countries to explore these nuances.

One of the central challenges in estimating the effect of LBW and adverse pregnancy outcomes on later life outcomes is the inability to conduct randomised trials. Thus, all available estimates rely on observational data which are inherently prone to bias. The majority of published studies have examined the relationship of birth weight with human capital outcomes in twin populations; twins share genetic material and intrauterine conditions and are often raised in the same environment during childhood and adolescence which may minimise confounding due to environmental factors. Nevertheless, most of the reported studies do not distinguish between monozygotic and dizygotic twins meaning that within-twin pair differences in genetic factors might explain some of the variability in birth weight and in human capital outcomes. A notable example is sex. Most included studies pooled male and female observations to produce the association between birth weight and earnings, while a smaller number of studies analysed single-sex samples. Female children are born on average lower birth weight than male children. In addition, women tend to earn less than men due to differences in access to labour market opportunities or education. Treating men and women as a homogeneous sample could therefore bias estimated associations upwards, in addition to resulting in poorer model fit. While these are important considerations, all included studies except one addressed this concern by either explicitly including sex as a covariate or stratifying the sample by sex.

Family socio-economic factors in observational studies are another potential source of confounding in the association between birth weight and adult earnings. Poorer families may have poorer access to high-quality nutrition, maternal and perinatal healthcare, increasing the likelihood of LBW children. Their children may also lack the financial resources that their richer peers benefit from,

during crucial developmental stages in early childhood, in addition to having fewer opportunities to enrol in high-quality educational programmes and poorer access to key networks that facilitate job hunting and higher earnings potential. All included studies except one addressed this confounding concern either via twin or sibling fixed effects (within family comparisons) or by explicitly including a measure of family status in their statistical model.

Although most studies controlled for measures reflecting the family or parental background of the child at birth, some studies also included educational attainment of the child in the main regression model, which may adjust out a key mediating pathway between birth weight and adult earnings. In theory, including education would likely result in a smaller association between birth weight and earnings. In our sample, however, the few studies that included education as a covariate yielded higher associations than the other studies, which may be due to cross-study differences in the populations studied. Regardless, the exclusion of studies that adjusted for education did not affect our overall findings.

Finally, there was little consensus regarding the best measure of birth weight in the pool of included studies. Most studies measuring birth weight on a continuous scale assumed a linear relationship between birth weight and earnings, while a few opted for the natural logarithm of birth weight. While we standardised all estimates and their standard errors to be comparable in interpretation, different assumptions underlie these two models. Using the natural logarithm of birth weight allows for some non-linearity in the association between birth weight and earnings and assumes that the association varies across the birth weight distribution. A non-linear association makes intuitive sense: we expect that improving perinatal outcomes for children born in the lower tail of the birth weight distribution will also improve their cognitive abilities and human capital substantially more than their peers of average birth weight. Although we find that the studies using log birth weight yield, on average, a smaller association than those using linear birth weight, it is difficult to determine the underlying reason for this difference; this may be due to differences between the sample populations across studies. Alternatively, since the models using logarithmic exposure give more weight to increases in birth weight in the lower tail of the distribution, it could also be that the association is smaller (relative to the linear exposure model) when evaluated at the mean, as we do in our standardisation procedure. It would therefore be highly beneficial for future studies to estimate both linear and non-linear models on the same dataset to be able to directly compare effect estimates to other studies.

Further, both linear and logarithmic birth weight models fail to capture the potentially non-linear relationship between birth weight and earnings. As previously discussed, ELBW children born in the lower tail of the distribution may have particularly large deficits in earnings. Further, there might be a point where additional weight at birth in the upper tail of the distribution is associated with poorer human capital outcomes or yields no additional benefit. In such a case, a model trying to compare the returns of birth weight to earnings between low and average birth weight children would bias associations downwards. For instance, fetal macrosomia (birth weight > 4000 g) is estimated to affect between 5% and 20% of newborns worldwide.³⁹ Children with macrosomia may be at increased risk of metabolic disease, obesity and type II diabetes in later life,⁴⁰ and some studies have reported a negative association between macrosomia and cognitive development scores.^{41,42} Therefore, since cognitive ability is a key human capital pathway to earnings potential, earnings may decrease for adults who were born with macrosomia. While some evidence suggests

that these negative associations may disappear after controlling for family-level confounders,⁴³ further research is warranted considering the high prevalence of maternal obesity in some high-income countries which is a strong risk factor for macrosomia.⁴⁴ To capture these heterogeneous associations along the birth weight distribution, non-linear or non-parametric statistical models should be used to explore the shape of the relationship between birth weight and human capital outcomes.

Overall, our meta-analysis indicates that birth weight is consistently associated with adult annual earnings. As a result, the potential returns to early life investments in interventions to improve birth weight may translate into a significant reductions in early cognitive deficits and a substantial increase in economic outcomes. To quantify the return on investment more precisely, further research needs to carefully consider study design, including key mediating pathways and confounding factors. In addition, relaxing the assumption of a linear association will be essential to uncover the populations most likely to benefit from interventions.

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Conflicts of interest. None.

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