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Neonatal Health and Long-Term Outcomes: Twin-Based Evidence From Linked Scandinavian Registers

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Abstract

This study examines the long-term consequences of neonatal health using three birth anthropometric measures — weight, length, and head circumference — and analyzes their differential associations with outcomes across the life course. Using linked Swedish and Norwegian population registers with follow-up into adulthood, we compare birth measures of singletons and twins and further estimate within-twin-pair fixed-effects models that control for shared genetic and family environmental factors. Our samples comprise up to approximately 679,000 singletons and 10,400 twins in Sweden, and 347,841 singletons and 6,762 twins in Norway, followed into adulthood. We find that different birth measures capture distinct aspects of fetal development with varying predictive validity across outcome domains. Birth length emerges as the strongest predictor of health outcomes (infant mortality, adult height), consistent with its role as a cumulative indicator of skeletal growth throughout gestation. Birth weight retains stronger associations with cognitive and educational outcomes (grade point average [GPA], years of schooling) in conditional models. Head circumference shows weak and inconsistent associations across specifications. Using within-pair head circumference differences to classify twins as symmetrically versus asymmetrically growth restricted, we find that symmetric intrauterine growth restriction is associated with substantially worse long-term outcomes than asymmetric restriction. In Norwegian twin pairs, growth restriction is associated with lower general cognitive ability (measured at military enlistment) relative to the unaffected co-twin; this within-pair deficit is more than twice as large for symmetric as for asymmetric restriction. We also document significant intergenerational transmission of birth anthropometrics, suggesting both environmental and genetic contributions. Finally, our register-based design with near-complete population coverage minimizes selection bias and attrition while providing statistical power for within-pair analyses across multiple outcomes. Exclusive reliance on birth weight may obscure important information about early-gestation developmental insults.

Keywords: Birth weight; Birth length; Head circumference; Twin studies; Fetal origins; Intrauterine growth restriction; Linkage to administrative data

JEL codes: I14, I12, J13, J24.

Twin studies have long served as a cornerstone for disentangling genetic and environmental contributions to human traits and disease (Boomsma et al., 2002). The classical twin design exploits differences in genetic similarity between monozygotic (MZ) and dizygotic (DZ) twins to estimate heritability, while within-pair analyses of MZ twins provide a powerful natural experiment to isolate environmental effects while almost perfectly controlling for genetic background (Boomsma et al., 2002; van Dongen et al., 2012). This approach has proven particularly valuable for understanding the developmental origins of health and disease, where prenatal environmental exposures may have lasting consequences otherwise confounded by genetic factors (Silventoinen et al., 2017).

The Developmental Origins of Health and Disease (DOHaD) hypothesis proposes that adverse early-life conditions, particularly in utero, program long-term health and developmental trajectories (Barker et al., 1989; Gluckman et al., 2008). Birth weight has been the predominant phenotype in this literature, with twin studies demonstrating that the lighter twin at birth experiences worse outcomes across multiple domains including cardiovascular health, cognitive function, and educational attainment (Behrman & Rosenzweig, 2004; Black et al., 2007; Figlio et al., 2014). Large-scale twin registries have confirmed these associations, with meta-analyses suggesting that a 500 g within-pair difference in birth weight corresponds to differences of a few IQ points and several months of schooling in adulthood (Petersen et al., 2011). Within-MZ-pair designs are especially informative, as birth-weight discordance between genetically identical twins must reflect differential intrauterine environments such as unequal placental sharing, cord insertion differences, or twin-to-twin transfusion (Lewi et al., 2010).

However, birth weight as a phenotype has important limitations. Weight is gained predominantly in the third trimester, meaning birth weight primarily reflects late-gestation conditions and may miss critical earlier developmental windows when organogenesis occurs (Torche & Conley, 2016). The same birth weight can result from markedly different intrauterine growth trajectories (e.g., steady growth throughout gestation vs. early slowing with later catch-up), limiting its utility as a comprehensive marker of prenatal development (Conti et al., 2020). Furthermore, genomewide association studies (GWAS) have identified substantial genetic contributions to birth weight, with recent meta-analyses identifying over 200 associated loci explaining approximately 5% of phenotypic variance (Juliusdottir et al., 2021; Warrington et al., 2019). These loci show enrichment for genes involved in insulin signaling, glucose metabolism, and skeletal development, complicating interpretation in population-based studies.

We extend the twin literature by examining two additional birth anthropometric measures — birth length and head circumference. We refer to birth weight, birth length, and head circumference collectively as measures of health at birth that may capture distinct aspects of fetal development and reflect different critical periods. Unlike weight, skeletal growth and brain development begin early in gestation, with rapid cranial expansion occurring from the first trimester onward (Martini et al., 2009). During the first trimester, cell division proceeds rapidly and the embryo develops into a fetus, with brain, spinal cord, and heart development beginning as early as week 3. During weeks 6–10, most organs and systems develop in a particularly sensitive period. From conception until week 20, the fetus exhibits rapid growth in length, after which the growth rate decelerates while the fetus primarily stores fat in the third trimester.

Head circumference at birth correlates strongly with brain volume and is a well-established predictor of neurodevelopmental outcomes (Gale et al., 2006; Heinonen et al., 2008). Recent GWAS have identified genetic variants associated with infant head circumference showing positive genetic correlations with adult intracranial volume, educational attainment, and general cognitive ability (Vogelezang et al., 2022). A systematic review examining head circumference and long-term outcomes found consistent associations with intelligence, academic achievement, and occupational outcomes, though effect sizes varied by measurement timing and population characteristics (Freire et al., 2024, with follow-up from childhood into adulthood). Birth length similarly reflects cumulative skeletal growth and strongly predicts adult height, which itself shows robust associations with cognitive and socioeconomic outcomes — though the height–cognition correlation is typically only about 0.1–0.2, so height accounts for on the order of 1–4% of the variance in these outcomes (Pietiläinen et al., 2001; Silventoinen, 2003).

A key advantage of examining multiple-birth measures simultaneously is the ability to distinguish patterns of intrauterine growth restriction (IUGR) that carry different prognostic implications. Symmetric IUGR, typically resulting from early insults, chromosomal abnormalities or congenital infections, proportionally reduces all body dimensions through impaired cellular proliferation. Asymmetric IUGR, more commonly arising from placental insufficiency in late pregnancy, preferentially spares head growth through redistribution of cardiac output to the brain — the 'brain-sparing' effect documented extensively in fetal medicine (Miller et al., 2016; Unterscheider et al., 2013). Fetal MRI studies confirm that asymmetrically growth-restricted fetuses show relative preservation of brain volume compared to abdominal circumference (Egaña-Ugrinovic et al., 2013). These distinct growth patterns have markedly different prognostic implications: symmetric restriction is associated with worse neurodevelopmental outcomes across cognitive domains, while brain-sparing may be partially protective (Figueras & Gratacós, 2014).

The present study uses Swedish and Norwegian population registers linked to the Medical Birth Register to examine several cohorts of twins with follow-up into adulthood. Our study is based on nationwide administrative registers, with information on twin births obtained directly from the Medical Birth Registry. Because all births are recorded in the registry, twin births are identified as part of the administrative data rather than through a separate twin registry. Linking birth records to registers covering health, education, and earnings (and, for men, military enlistment) through unique personal identifiers yields population-scale, longitudinal coverage with minimal attrition. It also carries limitations — most notably that zygosity is not recorded, and that the Swedish and Norwegian data cannot be pooled for data-integrity reasons, so all analyses are run separately by country within each country's secure data environment.[1] To ensure that the results are directly comparable, however, we harmonized the data and analysis across countries by constructing equivalent variables and applying the same inclusion criteria, model specifications, and estimation procedures in both settings. We employ within-twin-pair fixed effects models, which control for all genetic factors shared between twins (100% for MZ pairs, 50% on average for DZ pairs) as well as shared family environment, maternal characteristics, socioeconomic factors, and pregnancy-level exposures. This design isolates the effects of twin-specific intrauterine exposures reflected in birth size differences, providing stronger causal inference than population-based observational studies.

Our study makes several contributions. Throughout, we benchmark the full singleton population against within-twin-pair estimates that additionally net out shared genetic and family factors. First, we directly compare the predictive value of birth weight, length, and head circumference for short-term (infant mortality), medium-term (childhood cognition, school performance), and long-term (educational attainment, adult wages) outcomes, in two countries. Second, we use within-pair head circumference differences to classify twins as symmetrically versus asymmetrically growth restricted, testing whether brain-sparing confers protection for cognitive outcomes as suggested by clinical studies. Third, because the developmental-origins literature implies that early-life disadvantage may be transmitted across generations, we study intergenerational correlations in birth anthropometrics using mother-child pairs, employing grandmother fixed effects to distinguish environmental from genetic transmission channels. Fourth, our register-based design with near-complete population coverage minimizes selection bias and attrition while providing sufficient statistical power for within-pair analyses across multiple outcome domains.

Materials and Methods

Data

We used data on all individuals born in Sweden between 1973–1979 and in Norway between 1978–1984. The main data source for both countries is the Medical Birth Register, which contains personal identifiers for the child, mother, and father, as well as information on time of birth and health measures including birth weight, birth length, head circumference, and gestational length.[2-3] The personal identifiers allow us to link the Medical Birth Register with other administrative registers, including children's educational achievements, data from the Military Enlistment Register, and parental socioeconomic status.

In Sweden, the number of observations ranges from 633,706 to 678,848 for singletons and from 9564 to 10,400 for twins, depending on the outcome. In Norway, the sample comprises 347,841 singletons (birth cohorts 1978–1984; mean age 45.0, *SD* 2.0, in 2026) and 6,762 twins (mean age 45.0, *SD* 2.0). Among Norwegian twins, there are 2,442 male–male pairs (mean age 44.9, *SD* 2.0), 2,292 female–female pairs (mean age 45.1, *SD* 2.0), and 2,028 opposite-sex (‘mixed’) individuals (mean age 45.1, *SD* 2.0); 2,734 individuals are members of complete same-sex pairs (mean age 45.0, *SD* 2.0).

We grouped the analysis variables into three sets. The birth measures — birth weight, birth length, and head circumference — are recorded at delivery in each country’s Medical Birth Registry and enter the analysis both in levels and in logs.

The long-term outcomes span health (infant mortality; adult height), cognition and education (GPA, cognitive test scores, and completed years of schooling), and labor-market success (earnings). These outcomes were selected to be directly comparable across Sweden and Norway and are defined as consistently as the two data sources allow; where a measure is available in only one country (e.g., GPA in Sweden and the general-ability score in Norway), we note this and estimate the corresponding models separately. We study several outcomes chosen to be representative of those examined in the literature to date. The first outcome is infant death, defined as death before age one, recorded in the Cause of Death Register and the Medical Birth Register. We also study GPA (available only for Sweden) at the end of compulsory school (around age 16), standardized by birth cohort, and educational attainment measured as the highest observed attainment at age 35. Additionally, we study men’s height and cognitive skills at age 18, derived from the Military Enlistment Register. The cognitive test scores are derived from a nonstandard IQ test comprising four parts testing logical, spatial, verbal, and technical comprehension, summarized into a stanine scale ranging from 1 to 9 (Öhman, 2015).

In the singleton models, the control variables are the child’s sex, mother’s age and years of schooling, birth order, year-by-month of birth, and gestational age. In the within-twin-pair models, because twin pairs share all mother- and birth-specific characteristics, the only remaining controls are the child’s sex and within-pair birth order. We include these because the outcomes examined differ systematically by sex and birth order, so adjusting for them improves the precision and comparability of the estimates (see e.g., Black et al., 2005); in the within-twin-pair specifications, sex and birth order are the sources of variation that remain after shared family factors are differenced out.

Methods

We estimated the relation between different measures of health at birth and various individual outcomes.[4] For singletons, we estimated via ordinary least squares:

$$Outcome_i = \alpha + \beta\, ln(Health\ at\ Birth_i) + \gamma' X_i + \varepsilon_i$$

where *i* indexes the individual child, and the vector of controls *X* includes indicators for child gender, mother's age and years of schooling, birth order, year by month of birth, and gestational age (weeks). The parameter β represents the difference in outcome associated with a one percent change in the respective birth measure.

To address concerns about unobserved factors (e.g., prenatal care, genetic factors) affecting both birth health and outcomes, we estimated a twin fixed effects (FE) model:

$$Outcome_{ij} = \alpha + \beta\, ln(Health\ at\ Birth_{ij}) + \mu_j + \gamma' X_{ij} + \varepsilon_{ij}$$

where *j* indexes the twin-pair and μ_j is the twin-pair fixed effect. In this model, *X* controls only for gender and within-pair birth order, since twin pairs share all mother- and birth-specific characteristics. The parameter β is identified from within-pair variation in birth health, which arises from differences in fetal growth related to nutritional uptake, placental position, or cord placement (Black et al., 2007). We estimated this model in levels, absorbing the twin-pair fixed effect μ_j directly. Black et al. (2007) present the equivalent specification in first-differenced form: subtracting the equation of one twin from that of the co-twin eliminates the pair-specific intercept $(\alpha + \mu_j)$, leaving $\Delta Outcome_j = \beta\, \Delta ln(Health\ at\ Birth_j) + \gamma' \Delta X_j + \Delta \varepsilon_j$, where Δ denotes the difference between the two twins in pair *j*. For pairs of size two the two formulations are numerically identical, so β is identified in both from within-pair variation in birth health.

For both singleton and twin specifications, we estimated two sets of models: *unconditional models* that include each birth measure separately, and *conditional models* that include all three birth measures (weight, length, and head circumference) simultaneously. The unconditional models show the total association of each measure with outcomes, while the conditional models reveal the independent contribution of each measure after accounting for the others.

In common with all previous studies using administrative data, our sample includes both MZ and DZ twins, meaning that we cannot fully control for shared genetic endowments across twins. This concern is nonetheless attenuated when we examine outcomes for which the sample is restricted to same-sex twin pairs. Note that while within-pair variation may credibly identify quasi-causal effects from differences in utero (Turkheimer & Harden, 2014), the results do not necessarily generalize to the population in general.

For the analysis of symmetric and asymmetric IUGR, the classification is at the individual level: a child is coded as symmetrically restricted if they fall below both a birth-weight and a head-circumference cutoff, and as asymmetrically restricted if they fall below the birth-weight cutoff but have a relatively preserved (high) head circumference. The classification therefore applies to each twin separately, not to the pair as a whole.

We then estimated, for twin *i* in pair *j*:

$$Outcome_{ij} = \alpha + \beta_1 I_{asym,ij} + \beta_2 I_{sym,ij} + \gamma' X_{ij} + \mu_j + \varepsilon_{ij},$$

where $I_{asym,ij}$ and $I_{sym,ij}$ indicate that twin i is asymmetrically or symmetrically growth-restricted respectively, with nonrestricted children as the reference category, and μ_j is a twin-pair fixed effect. Because the classification is individual-level, β_1 and β_2 are identified from discordant pairs — those in which one twin is (symmetrically or asymmetrically) restricted while the co-twin is not — so the estimates compare a restricted twin with their own nonrestricted co-twin.

Lastly, to measure the intergenerational transmission of birth anthropometrics, we estimated the following equation for each birth measure (illustrated here for birth weight):

$$y_{ic} = \alpha + \beta\, y_{im} + \gamma\, female_{ic} + \delta_t + \mu_m + \pi_g + \theta_a + \alpha_n + \varepsilon_{ic}$$

where:

- α is a constant term;
- y_{ic} is the birth measure (e.g. birth weight) of child i in maternal family n;
- y_{im} is the same birth measure of that child's mother, so β is the intergenerational transmission coefficient (the parameter of interest);
- $female_{ic}$ is an indicator for the child's sex;
- δ_t are child birth-year fixed effects;

μ_m are child birth-month fixed effects;

π_g are child gestational-length fixed effects;

θ_a are maternal-age-at-birth fixed effects;

α_n is a maternal-family ('grandmother') fixed effect, included in the grandmother-fixed-effects specification only; and

ε_{ic} is the error term.

Standard errors are clustered on the maternal-family identifier. In the baseline specification we omitted the maternal-family fixed effect α_n, so that β is estimated across all mother–child pairs. In the grandmother-fixed-effects specification we added α_n, which absorbs all factors shared within the maternal family; β is then identified from comparisons among children whose mothers are sisters, differencing out shared family genetic and environmental influences. Hence, we included controls for gender, gestational age, birth year, birth month and maternal age in the analysis of singletons; in the twin fixed-effects regressions, we included controls for within-pair birth order and gender.

Throughout, we used a standard procedure to account for within-cluster error correlation, based on the Huber–White sandwich estimator (e.g., Cameron & Miller, 2015).

Results

Descriptive Statistics

Table 1 presents descriptive statistics across singleton and twin births in Sweden and Norway. Twins were on average lighter, shorter, and had smaller head circumference compared to singletons, with higher rates of infant mortality and IUGR. Mean birth weight for twins was approximately 2,620 grams in Sweden and 2,601 grams in Norway — about 900 grams lower than singletons. Mean birth length was nearly 3.5 cm shorter in twins. Infant mortality was markedly higher among twins (2.3% in Sweden, 3.3% in Norway) compared to singletons (0.5% and 0.8%). The rate of IUGR was substantially elevated in twins, with symmetric IUGR affecting 11.5% of Swedish twins and 15.5% of Norwegian twins. The larger relative gap for birth weight (25–26%) compared to length (7%) and head circumference (4.5%) likely reflects the concentration of weight gain in late gestation, with twins' shorter gestational duration disproportionately affecting third-trimester weight accumulation.

[Table 1 about here]

All three measures of neonatal health vary within most twin pairs, sometimes substantially. For the Swedish sample, the average within-pair difference is 323 grams for birth weight, 1.56 cm for birth length, and 1.06 cm for head circumference. Among twin pairs, 57% have birth-weight differences over 200 g, 22% over 500 g, 9% have birth-length differences above 3 cm, and 8% have head-circumference differences above 2 cm. The numbers for the Norwegian sample are remarkably similar: the average within-pair difference is 313 grams for birth weight, 1.47 cm for birth length, and 1.06 cm for head circumference. Among twin pairs, 55% have birth-weight differences over 200 g, 20% over 500 g, 9% have birth-length differences above 3 cm, and 8% have head-circumference differences above 2 cm. Figure A1 (see Appendix) displays the full distributions of birth weight, birth length, and head circumference for twins and singletons in both countries, while Figure A2 shows the distribution of within-pair differences for all twins.

Parametric Estimates

Table A1 (see Appendix) presents ordinary least squares (OLS) regression results for singletons in both Sweden and Norway. In unconditional models, all three birth measures were strongly associated with each outcome in both countries. In Sweden, a 10% increase in birth weight decreased infant mortality risk by 0.29 percentage points, increases height at age 18 by 1.6 cm, increases GPA by 0.04 standard deviations, increases cognitive test scores by 0.10 points, increases years of schooling by 0.07 years, and increases earnings by 1.5%. Effects are even larger in Norway for several outcomes: a 10% increase in birth weight reduces infant mortality by 1.1 percentage points and increases earnings by 20%. Effects for birth length and head circumference are two to three times larger in magnitude in both countries (Table A1, columns 1–2), though direct comparisons are complicated by distributional differences (Figure A1). In conditional models including all three measures simultaneously, the effect of birth weight on infant mortality is only marginally reduced in Sweden, whereas the effect on height is reduced by approximately 80%. For cognitive and educational outcomes, birth weight effects are attenuated by roughly 50% (Table 2, columns 3–4). Birth length retains strong associations with height (52.5 cm in Sweden, 51.3 cm in Norway) and cognitive outcomes in both countries, while head circumference effects are substantially attenuated but remain significant in Sweden; in Norway, head circumference effects on height become insignificant while effects on cognitive skills and earnings persist.

[Table 2 about here]

Table 2 presents within-twin-pair fixed effects estimates controlling for shared genetic and family background factors. In unconditional models (columns 1 and 2), all three birth measures showed significant associations with most outcomes. In Sweden, a 10% increase in birth weight is associated with a 0.35 percentage point reduction in infant mortality, 0.66 cm greater height, 0.03 *SD* higher GPA, and 0.08 additional years of schooling. Birth length showed larger unconditional effects: a 10% increase is associated with a 2.0 percentage point reduction in infant mortality and 2.7 cm greater height. In Norway, birth-length effects were particularly strong for infant mortality (−0.36) and height (33.3 cm).

In conditional models controlling for all three measures simultaneously (columns 3 and 4), birth weight effects on infant mortality and height became statistically insignificant, while effects on GPA (0.20 *SD*, $p < .10$) and years of schooling (0.83 years, $p < .01$) remain significant in Sweden.

Birth length emerged as the primary predictor of health outcomes: in conditional models, a 10% increase in birth length reduced infant mortality by 2.4 percentage points in Sweden and is associated with 18.9 cm greater height in Sweden and 24.4 cm in Norway ($p < .05$). Head circumference effects were uniformly attenuated to insignificance in conditional models. We assessed the external validity of these within-pair estimates by comparing them to singleton and unadjusted twin estimates in Tables A2–A3. In Sweden, the pattern of effects was consistent across singletons (e.g., birth weight→GPA: 0.08 *SD*), twins without fixed effects (0.06 *SD*), and twins with fixed effects (0.06 *SD*), though precision decreased with sample size. Similar consistency appeared in Norway. These results suggest that within-pair findings are likely to generalize to broader birth cohorts.

Nonparametric Analysis

To examine whether the log-linear specification adequately captures the relationship between birth measures and outcomes, we estimated non-parametric models using binned indicators (100 g bins for weight, 1 cm bins for length and head circumference). Figure A3 presented these relationships for singletons. For birth weight, the relationship with infant mortality was strongly nonlinear, with mortality risk declining steeply until approximately 2,500 g before flattening. The relationship with height and earnings was approximately linear throughout the distribution. For cognitive and educational outcomes, a hump-shaped pattern emerged, with outcomes improving up to around 4,000 g before declining slightly — potentially reflecting complications associated with macrosomia (i.e., high birth weight); a similar pattern appears after 50 cm of birth length. Figure 1 presents analogous nonparametric estimates from twin fixed-effects models. These show a steep decline in infant mortality risk at low birth weights (below 2,000 g), mirroring clinical viability thresholds. For cognitive and educational outcomes, the slope is steeper at the lower end of the distribution but flattens considerably above 3,000–3,200 g. Overall, these patterns support our log-linear parameterization, which gives relatively more weight to the bottom of the distribution where effects are strongest.

[Figure 1 about here]

Same-Sex Twin Analyses

Table 3 presents estimates restricted to same-sex twin pairs, which contain a higher proportion of MZ twins and eliminate sex-related genetic variation. Because same-sex pairs still include both MZ and DZ twins, they control for genetic confounding only partially. In Sweden, birth weight effects on GPA (0.041 *SD*) and years of schooling (0.139 years) remained statistically significant, while effects on infant death and earnings are not. Birth length showed similar patterns, with significant effects on GPA (0.031 *SD*) and years of schooling (0.115 years). Head circumference effects were uniformly insignificant across all Swedish outcomes. In Norway, a strikingly different pattern emerged: birth weight was not significantly associated with any outcome, whereas birth length showed a strong significant effect on infant mortality (−0.024) and general ability (0.30 *SD*). Head circumference remained insignificant throughout. These results suggest that birth-length effects are more robust to genetic confounding than birth-weight effects, particularly for cognitive outcomes in Norway.

[Table 3 about here]

Body Proportionality and IUGR Type

Table 4 presents twin fixed-effects estimates for IUGR type. In Sweden, 9.85% of twin pairs showed within-pair variation in symmetric IUGR, and 17.58% in asymmetric IUGR. Symmetric IUGR was associated with larger reductions in height (−2.13 cm vs. −1.09 cm for asymmetric), GPA (−0.12 *SD* vs. A nonsignificant −0.04 SD), and years of schooling (−0.19 vs. −0.15 years). In Norway, the pattern was sharper: symmetric IUGR was associated with a 3.99 cm reduction in height, 0.62 *SD* reduction in general ability, and 0.68 reduction in years of schooling, all significantly larger than asymmetric IUGR effects.

[Table 4 about here]

Intergenerational Transmission

Table 5 examines intergenerational correlations in birth anthropometrics, estimated separately for Sweden and Norway. In Sweden, the intergenerational elasticity for log birth weight was 0.152 (column 1), meaning that a 10% increase in the mother's birth weight (a log-point increase ≈ 10% change in the birth measure) was associated with a 1.5% increase in her child's birth weight. This elasticity fell to 0.091 with grandmother fixed effects (column 2). Because the mothers are sisters — so the children are cousins — this specification compares the children of different sisters and nets out factors shared by sisters raised together: the portion of maternal-grandparental genotype common to siblings, and the shared rearing environment (grandparental socioeconomic status, neighborhood, and health behaviors). It does not difference out genetic or environmental factors that differ between sisters. To control more fully for shared genetic background, we further restricted the Swedish sample to twin mothers and add mother fixed effects (column 3); the elasticity then fell to 0.018 and was no longer statistically significant, indicating that once we compare the children of twin sisters — who are more genetically similar and share a common upbringing — the within-family intergenerational correlation in birth weight largely disappeared. Corresponding estimates for Norway were 0.138 (column 4), falling to 0.082 with grandmother fixed effects (column 5), and remaining significant at 0.085 among twin mothers (column 6). Similar patterns held for log birth length (Sweden: 0.148, falling to 0.088 with grandmother fixed effects and 0.046 among twin mothers; Norway:

0.141, falling to 0.099) and log head circumference (Sweden: 0.145, 0.082, and 0.001 respectively; Norway: 0.130, falling to 0.049). Across both countries, coefficients remained positive and significant after grandmother fixed effects, pointing to environmental or epigenetic mechanisms of transmission beyond shared genetics; in Sweden, the further attenuation to insignificance among twin mothers underscored the contribution of shared family factors.

Discussion

Our within-twin-pair analyses demonstrate that birth anthropometrics predict a range of outcomes from infant mortality through adult educational attainment, with effects persisting after controlling for shared genetic and family environmental factors. We interpret these findings in light of the developmental-origins literature, considering for each birth measure what aspect of fetal development it plausibly captures, how our estimates compare with prior twin and register-based studies, and what mechanisms could account for the observed patterns. There are substantial differences in birth measures between singletons and twins, with twins coming to a larger extent from the bottom of the distribution (Figure A1). The difference partly stems from differences in gestational length, with 2.5 weeks longer gestation for singletons, on average. Hence, we should be cautious in generalizing from within-twin-pair results to the general population.

Birth length emerges as the strongest predictor of health outcomes — infant mortality and adult height — consistent with its role as a cumulative indicator of skeletal growth throughout gestation. The large effect sizes (18.9 cm for Sweden and 24.4 for cm Norway are the coefficients for height in conditional twin FE models) and robustness across specifications support the interpretation that length captures environmental insults affecting early fetal development, when skeletal growth is most rapid. This accords with the classic developmental-origins account, in which linear skeletal growth indexes cumulative conditions across gestation (Barker et al., 1989; Gluckman et al., 2008), and with prior register-based twin evidence on birth size and adult height (Black et al., 2007). Birth weight, by contrast, retains stronger associations with cognitive and educational outcomes in conditional models, possibly reflecting the importance of third-trimester nutrient transfer for brain development and myelination (Georgieff, 2007).

Head circumference at birth shows the weakest and least consistent associations across specifications. Its effects are largely attenuated to insignificance when controlling for weight and length, and it shows greater sensitivity to genetic confounding in same-sex twin analyses. This may reflect the high heritability of head circumference (Lunde et al., 2007) or its greater susceptibility to measurement error. Consistent with this, molecular studies have attributed a substantial genetic component to infant head circumference (Vogelezang et al., 2022), so that within-pair differences may carry a smaller environmentally driven signal than for weight or length.

Our IUGR analyses provide compelling evidence for the brain-sparing hypothesis. Symmetrically growth-restricted infants — whose head circumference is proportionally reduced along with weight — experience substantially worse long-term outcomes than asymmetrically restricted infants whose head growth is relatively preserved. The magnitude differences are substantial: in Norwegian twins, symmetric IUGR is associated with more than double the reduction in general ability compared to asymmetric IUGR (−0.62 vs. −0.27 SD). These findings align with the fetal programming literature suggesting that early insults produce symmetric restriction affecting cellular proliferation across all organ systems, while later placental insufficiency triggers compensatory redistribution of cardiac output to preserve cerebral perfusion. The stronger cognitive penalty of symmetric restriction is consistent with the role of third-trimester nutrient transfer in brain development and myelination (Georgieff, 2007).

Our birth-weight results are consistent with prior twin studies. Using Norwegian administrative data and the same log-linear specification, Black et al. (2007) found effects on height and IQ among singletons closely matching our estimates. Figlio et al. (2014) reported that a 10% increase in birth weight is associated with 0.03 *SD* higher test scores, consistent with our (unconditional) GPA findings. Royer (2009) found that a 1000g increase in birth weight corresponds to 0.16 additional years of education — again comparable to our estimates. Our contribution extends this literature by demonstrating that birth-weight effects on height are largely mediated by birth length, that head circumference adds little predictive information beyond weight and length, and that the relative predictive value of different measures varies systematically across outcome domains.

The intergenerational transmission estimates (0.15 and 0.14 for log birth weight in Sweden and Norway respectively) are broadly consistent with prior studies using Scandinavian register data (Currie & Moretti, 2007; Lunde et al., 2007), though our inclusion of grandmother fixed effects, and — for Sweden — a specification restricted to twin mothers, provides stronger evidence on the roles of environment and genetics. In Sweden the mother–child correlation attenuates by roughly 40% under grandmother fixed effects and falls to insignificance among twin mothers, indicating a substantial contribution of shared family factors. The Swedish and Norwegian baseline elasticities are now similar (0.15 vs. 0.14 for log birth weight), but the two countries permit different specifications — the twin-mother comparison is available only in Sweden — so we interpret the cross-country estimates with caution while emphasizing the common qualitative pattern.

Implications

Our findings have implications for both research and clinical practice. For researchers studying developmental origins of health and disease, our results suggest that exclusive reliance on birth weight may obscure important information captured by birth length about early-gestation insults. For clinicians, the finding that symmetric IUGR predicts substantially worse long-term outcomes than asymmetric IUGR reinforces the importance of assessing body proportionality, not just absolute size, in growth-restricted neonates. While brain-sparing may provide partial protection for cognitive outcomes, asymmetric IUGR nonetheless carries significant long-term risk relative to normal growth. The intergenerational transmission of birth anthropometrics — persisting after grandmother fixed effects — suggests that interventions improving fetal growth may have benefits extending beyond the immediate generation.

Limitations

Several limitations warrant consideration. First, our twin sample includes both MZ and DZ pairs, as zygosity is not recorded in the Swedish or Norwegian birth registers for our cohorts. Based on the existing literature on twin births in Nordic populations, approximately two-thirds of all twin births are typically dizygotic. However, an exact proportion cannot be determined in our data. While same-sex twin analyses partially address this concern, residual genetic confounding cannot be excluded. This limitation could, in principle, be overcome by linking the birth registry to a dedicated medical twin registry containing zygosity information (e.g., the Swedish Twin Registry Study [STR]). Such linkages have been used in previous research for very limited samples of twins in previous articles (see e.g., Black et al., 2007), but access to these data is highly restricted and was not available for the present study.

Second, birth length and head circumference are measured with greater error than birth weight; classical measurement error would bias estimates toward zero, suggesting our length effects may be conservative. Third, our cohorts were born in the 1970s and 1980s, and changes in obstetric care may limit generalizability to contemporary births, though consistency across Sweden and Norway supports broader relevance. Fourth, the within-pair design may not generalize to singletons given twins' unique circumstances. Fifth, the within-pair estimator assumes linearity and additivity and, for a causal reading, that within-pair differences in birth measures are as good as random conditional on shared family factors; where they instead reflect processes such as unequal placental sharing, the estimates are better interpreted as quasi-causal.

Conclusions

This study examined the usefulness of birth length and head circumference as indicators of neonatal health beyond birth weight, using linked population registers from Sweden and Norway that provide comparable anthropometric measures alongside health and socioeconomic data across the life course. Our findings demonstrate that these additional measures capture distinct aspects of fetal development and improve understanding of the mechanisms through which early health shapes later outcomes. We document persistent effects of neonatal health on human capital from adolescence into adulthood, confirming and extending previous findings from both economics (Black et al., 2007; Figlio et al., 2014) and epidemiology (Bhutta et al., 2002; Shenkin et al., 2004).

Four key findings emerge from our analysis. First, in cross-sectional analyses, all three birth measures are independently associated with outcomes across the life course, even when included simultaneously in the same model. Second, when exploiting within-twin-pair variation (to control for shared genetic and family environmental factors) in conditional models, birth length emerges as the primary determinant of health outcomes (infant mortality and adult height), while birth weight retains stronger predictive power for human capital outcomes (GPA, cognitive skills, years of schooling). This pattern suggests that birth weight partly proxies for birth length when examining health consequences, and that the two measures capture insults occurring at different stages of fetal development. Third, head circumference proves useful for distinguishing symmetric from asymmetric intrauterine growth restriction, with symmetrically restricted infants — those not protected by brain sparing — experiencing substantially worse cognitive outcomes. Fourth, we document significant intergenerational transmission of birth anthropometrics that persists after grandmother fixed effects. The roughly 40% attenuation with grandmother fixed effects suggests substantial environmental transmission channels beyond shared genetics, consistent with epigenetic mechanisms or shared family environments affecting fetal growth across generations.

In sum, our work demonstrates the value of collecting multiple birth anthropometrics. Relying exclusively on birth weight may obscure important information about early-gestation developmental insults captured by birth length, and about the pattern of growth restriction revealed by head circumference relative to body size.

Endnotes

[1]More specifically, due to data protection regulations, the Swedish and Norwegian administrative register data are stored on separate secure servers and cannot be pooled or jointly analyzed.

[2]Birth length and head circumference are rounded to the nearest centimeter while birth weight is measured in grams. Measuring birth length and head circumference at birth is more difficult than measuring birth weight. Varying muscle tonus and how much the child is stretched during measuring affects recorded birth length. Head size may be affected by positioning during birth and late pregnancy, as well as delivery duration (Lunde et al., 2007). However, we have no reason to believe measurement quality varies systematically; potential measurement error should be classical and cause attenuation bias.

[3]In Sweden, ultrasounds were introduced in the 1970s but were not routinely used until the 1980s. Hence, gestational age is based on last menstrual period, which usually leads to underestimation. This error is not a concern as it should affect our three measures similarly. To handle implausible combinations, we exclude children with birth weight more (or less) than four standard deviations above (or below) the average birth weight by gestational week, using Swedish reference curves (Marsál et al., 1996). This restriction excludes 2,026 observations (0.3%).

[4]We follow the previous literature using the natural log of birth measures for our main specification. Nonparametric estimates (Figures 1 and A3) show a concave or linear relationship between health measures at birth and long-term outcomes, justifying our parameterization.

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Conflict of interest. None.

Ethical standards. This study uses anonymized administrative register data from Sweden and Norway. Data access was granted under agreements with Statistics Sweden and Statistics Norway. The study complies with the Declaration of Helsinki. Informed consent was waived due to the register-based nature of the study.

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Table 1. Descriptive statistics (Sweden and Norway, singletons and twins)

	Mean (*SD*)			
	Singletons		Twins	
	Sweden	Norway	Sweden	Norway
Female	0.486	0.486	0.500	0.495
	(0.50)	(0.50)	(0.50)	(0.50)
Birth weight, grams	3498.479	3528.954	2619.755	2600.837
	(527.80)	(550.55)	(544.18)	(611.23)
Head circumference, cm	34.585	35.186	33.000	33.505
	(1.64)	(1.59)	(1.97)	(2.04)
Birth length, cm	50.450	50.251	46.958	46.814
	(2.35)	(2.38)	(2.99)	(3.21)
Gestational age, weeks	39.769	40.021	37.232	37.324
	(1.77)	(2.00)	(2.63)	(3.09)
Infant mortality	0.005	0.008	0.023	0.033
	(0.07)	(0.09)	(0.15)	(0.18)
Height, cm	179.550	179.992	178.994	179.364
	(6.56)	(6.60)	(6.64)	(6.69)
Grade point average (standardized)	0.024	NA	0.085	NA
	(0.99)		(0.97)	
Cognitive skills (Stanine)	5.083	5.163	4.938	5.046
	(1.91)	(1.74)	(1.90)	(1.76)
Years of schooling, child	13.109	13.777	13.189	13.888
	(2.20)	(3.89)	(2.22)	(3.93)
Earnings age 31–35, 1000 SEK/NOK	253.691	424.545	254.145	420.214
	(140.01)	(246.157)	(134.73)	(250.100)
Intrauterine growth restriction	0.096	0.095	0.371	0.365
	(0.29)	(0.29)	(0.48)	(0.48)
Asymmetric IUGR	0.064	0.057	0.256	0.210
	(0.24)	(0.23)	(0.44)	(0.41)
Symmetric IUGR	0.032	0.038	0.115	0.155
	(0.18)	(0.19)	(0.32)	(0.36)
Mother's age at birth	26.959	26.353	27.873	27.417
	(4.89)	(5.00)	(4.85)	(4.85)
Years of schooling, mother	11.010	10.712	11.005	10.746
	(2.72)	(1.74)	(2.84)	(1.82)

Note: For Sweden, the sample size is 276,572 for height (men only) and 277,266 for cognitive skills (men only) and varies between 633,706 and 678,848 for singletons; and is 4022 for height (men only) and 4029 for cognitive skills (men only) and varies between 9,564 and 10,400 for twins. For Norway, the sample size is 348,522 for singletons (only 167,884 for height and 156,053 for cognitive ability) and 6,786 for twins. IUGR, intrauterine growth restriction.

Table 2: Within-twin estimates — birth measures (in logs) on outcomes (unconditional and conditional)

	(1) Sweden	(2) Norway	(3) Sweden	(4) Norway
Infant mortality				
ln(Birth weight)	-0.035**	-0.065*	0.016	0.020
	(0.016)	(0.036)	(0.029)	(0.056)
ln(Birth length)	-0.199***	-0.357**	-0.239**	-0.359
	(0.072)	(0.181)	(0.113)	(0.281)
ln(Head circ)	-0.092	-0.044	-0.009	0.021
	(0.062)	(0.061)	(0.077)	(0.048)
Height, cm				
ln(Birth weight)	6.632***	7.999***	1.800	3.031
	(0.799)	(1.530)	(1.491)	(2.768)
ln(Birth length)	27.001***	33.296***	18.910***	24.430**
	(3.187)	(6.696)	(5.157)	(11.671)
ln(Head circ)	20.083***	2.947	6.067	-1.236
	(3.261)	(7.018)	(4.125)	(1.753)
Grade point average				
ln(Birth weight)	0.298***	NA	0.201*	NA
	(0.068)		(0.114)	
ln(Birth length)	0.950***		0.287	
	(0.242)		(0.356)	
ln(Head circ)	0.826***		0.220	
	(0.240)		(0.295)	
Cognitive skills				
ln(Birth weight)	0.701***	1.498***	0.253	0.179
	(0.256)	(0.571)	(0.464)	(0.835)
ln(Birth length)	2.693***	6.148***	1.563	5.492
	(0.949)	(2.277)	(1.601)	(3.503)
ln(Head circ)	2.225**	0.905	0.816	0.250
	(1.036)	(1.368)	(1.219)	(0.552)
Years of schooling				
ln(Birth weight)	0.767***	1.201*	0.826***	1.377
	(0.179)	(0.708)	(0.317)	(1.161)
ln(Birth length)	2.410**	6.529*	0.709	-2.965
	(0.936)	(3.456)	(1.017)	(4.346)
ln(Head circ)	1.041	1.373	-1.201	1.233
	(0.701)	(1.681)	(0.943)	(1.957)
ln(Earnings)				
ln(Birth weight)	0.160**	1.692**	0.132	1.160
	(0.068)	(0.730)	(0.127)	(1.373)
ln(Birth length)	0.501	6.529*	0.131	2.789
	(0.368)	(3.456)	(0.420)	(5.715)
ln(Head circ)	0.368	1.373	0.000	-0.786
	(0.280)	(1.681)	(0.353)	(1.562)

Note: Each cell represents results from one regression in columns 1 and 3. The unconditional estimates include indicators for child gender and within-pair birth order. The conditional estimates (columns 3 and 4) add controls for the other two measures of health at birth. Height (cm) and cognitive skills (stanine scale) are only available for men age 18. Years of schooling is measured as highest observed educational attainment by age 35. Standard errors are clustered on twin pair, *$p < .10$, **$p < .05$, ***$p < .01$.

Table 3. Same-sex within-twin estimates — birth measures (standardized) on outcomes

	(1) Infant mortality	(2) Grade point average	(3) Years of schooling	(4) ln(Earnings)
Sweden				
Birth weight	-0.003	0.041**	0.139***	0.025
	(0.004)	(0.018)	(0.053)	(0.018)
Birth length	-0.006	0.031*	0.115**	0.019
	(0.005)	(0.017)	(0.051)	(0.018)
Head circumference	-0.004	0.021	-0.005	0.004
	(0.005)	(0.017)	(0.058)	(0.020)
Observations	7,436	6,891	6,823	6,764
Norway				
	(1) Infant mortality	(2) General ability	(3) Years of schooling	(4) ln(Earnings)
Birth weight	0.008	-0.012	-0.006	0.196
	(0.007)	(0.109)	(0.012)	(0.195)
Birth length	-0.024***	0.300***	0.017	0.221
	(0.006)	(0.102)	(0.010)	(0.164)
Head circumference	0.002	0.053	-0.010	-0.021
	(0.004)	(0.051)	(0.007)	(0.110)
Observations	4,316	1,889	4,133	4,316

Note: Each cell represents results from one regression, controlling for indicators for child gender and within-pair birth order. Grade point average is standardized by cohort (mean 0, standard deviation 1). Height (cm) and cognitive skills (stanine scale) are only available for men age 18. Years of schooling is measured as highest observed educational attainment by age 35. Standard errors are clustered on twin pair, *$p < .10$, **$p < .05$, ***$p < .01$.

Table 4. Within-twin estimates — symmetric and asymmetric IUGR on outcomes

	Sweden					
	(1) Infant mortality	(2) Height, cm	(3) Grade point average	(4) Cognitive skills	(5) Years of schooling	(6) ln(Earnings)
Symmetric	0.004	-2.129***	-0.120***	-0.277	-0.190*	0.006
	(0.010)	(0.619)	(0.042)	(0.212)	(0.113)	(0.048)
Asymmetric	-0.000	-1.085***	-0.042	-0.061	-0.149*	-0.041
	(0.005)	(0.396)	(0.029)	(0.142)	(0.086)	(0.032)
Adj. R-Sq.	0.425	0.788	0.739	0.695	0.599	0.369
Observations	10,400	4,022	9,653	4,029	9,564	9,485
	Norway					
	(1) Infant mortality	(2) Height, cm	(3) Grade point average	(4) General ability	(5) Years of schooling	(6) ln(Earnings)
Symmetric	0.024***	-3.982***	NA	-0.622***	-0.676***	-0.522***
	(0.006)	(0.365)		(0.097)	(0.143)	(0.141)
Asymmetric	0.034***	-2.651***		-0.271**	-0.425***	-0.664***
	(0.005)	(0.310)		(0.089)	(0.133)	(0.122)
Adj. R-Sq.	0.329	0.114		0.130	0.027	0.181
Observations	6,786	3,126		2,887	6,416	6,786

Note: Each column represents results from one regression. Reference category is non-IUGR children. All specifications include indicators for child gender and within-pair birth order. Grade point average is standardized by cohort (mean 0, standard deviation 1). Height (cm) and cognitive skills (stanine scale) are only available for men age 18. For Sweden, years of schooling is measured as highest observed educational attainment by age 35. For Norway, General ability has levels 1-9, or assumed: A = high, B = medium and C = low. Standard errors are clustered on twin pair, *p < .10, **p < .05, ***p < .01. IUGR, intrauterine growth restriction.

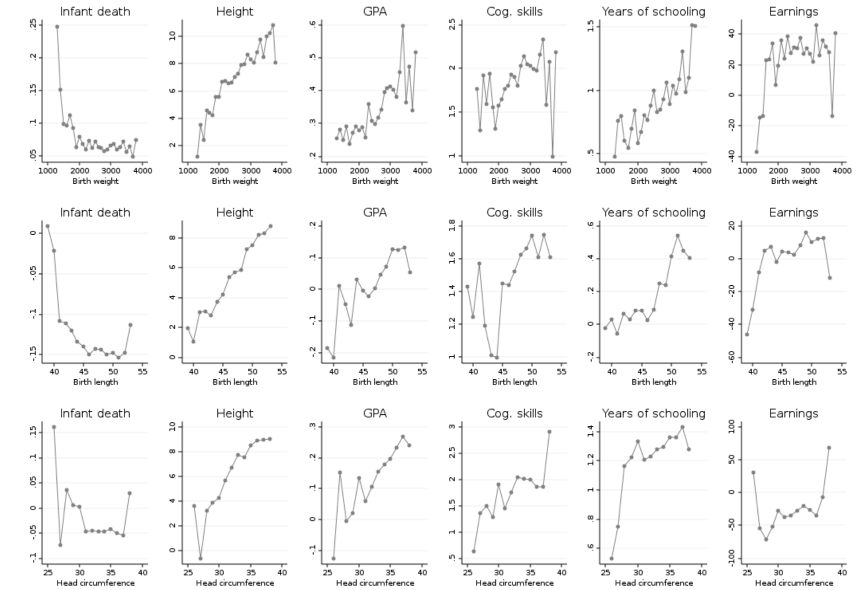
Table 5. Intergenerational correlations

	Sweden			Norway		
	(1)	(2)	(3)	(4)	(5)	(6)
			Low child birth weight			
Birth weight <2500 g	0.014***	0.004	0.001	0.006**	0.003	n/a
	(0.001)	(0.004)	(0.008)	(0.003)	(0.011)	
Adj. R-Square	0.525	0.571	0.584	0.503	0.110	
			Child birth weight, g			
Birth weight, g	0.182***	0.115***	0.020	0.173***	0.107***	0.110*
	(0.001)	(0.005)	(0.036)	(0.003)	(0.011)	(0.064)
Adj. R-Square	0.473	0.662	0.661	0.441	0.562	0.608
			Child ln(Birth weight)			
ln(Birth weight)	0.152***	0.091***	0.018	0.138***	0.082***	0.085*
	(0.001)	(0.005)	(0.026)	(0.003)	(0.010)	(0.046)
Adj. R-Square	0.592	0.773	0.737	0.556	0.629	0.674
			Child birth length, cm			
Birth length, cm	0.156***	0.094***	0.049	0.151***	0.108***	0.169**
	(0.001)	(0.004)	(0.031)	(0.003)	(0.013)	(0.072)
Adj. R-Square	0.491	0.625	0.625	0.427	0.463	0.578
			Child ln(birth length)			
ln(Birth length)	0.148***	0.088***	0.046	0.141***	0.099***	0.160**
	(0.001)	(0.004)	(0.028)	(0.004)	(0.021)	(0.069)
Adj. R-Square	0.526	0.649	0.652	0.342	0.026	0.593
			Child head circumference, cm			
Head circ, cm	0.152***	0.087***	-0.000	0.158***	0.077***	0.115
	(0.001)	(0.005)	(0.030)	(0.004)	(0.013)	(0.085)
Adj. R-Square	0.398	0.552	0.533	0.310	0.437	0.828
			Child ln(Child head circumference)			
ln(Head circ)	0.145***	0.082***	0.001	0.130***	0.049***	0.302**
	(0.001)	(0.004)	(0.027)	(0.008)	(0.015)	(0.136)
Adj. R-Square	0.433	0.577	0.583	0.207	0.376	0.723

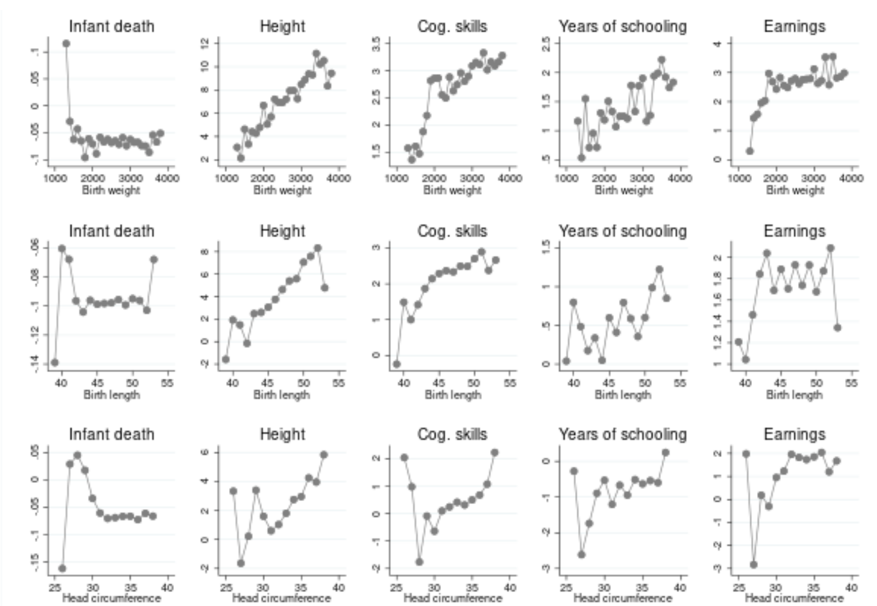
Note: Each cell reports the coefficient from a regression of the child's birth outcome on the corresponding maternal measure. Columns (1) and (4) control for child gender, gestational age, birth year, birth month, and maternal age. Columns (2) and (5) additionally include grandmother fixed effects. Columns (3) and (6) only contain first-generation twins and also include grandmother fixed effects. Note there is no sufficient variation to estimate the model for the intergenerational transmission of low birth weight in column (6). Standard errors are clustered on twin pair, $*p < .10$, $**p < .05$, $***p < .01$. Adj. R-Square, adjusted R-Square; circ, circumference.

Figure 1. Nonparametric twins estimates.

(a) Sweden



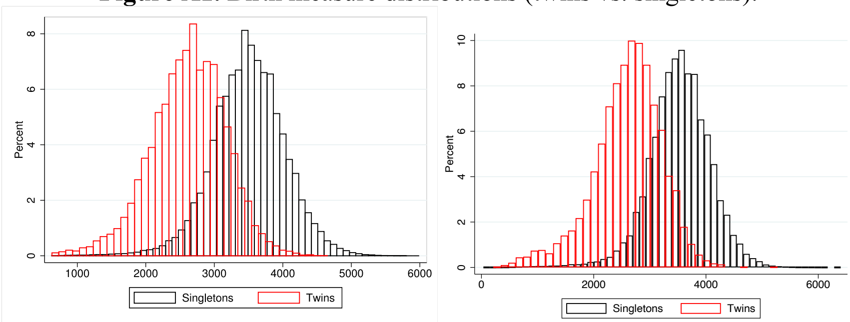
(b) Norway



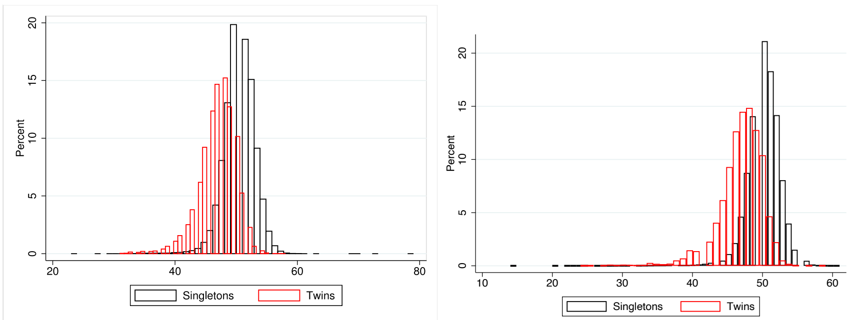
Note: Twin fixed-effects estimates for different measures of health at birth and child outcomes, controlling for gender, within-pair birth order and twin fixed effects. For birth weight the reference category is <1000 grams, for birth length it is <38 cm, and for head circumference it is <26 cm. To deal with extreme values we winsorize the data at 3800 g for birth weight (0.3% of the sample), at 53 cm for birth length (0.1% of the sample), and at 38 cm for head circumference (0.1% of the sample). Grade point average is standardized by cohort (mean 0, *SD* 1). Height (cm) and cognitive skills (stanine scale) are only available for men age 18. Years of schooling is measured as highest observed educational attainment by age 35.

Appendix

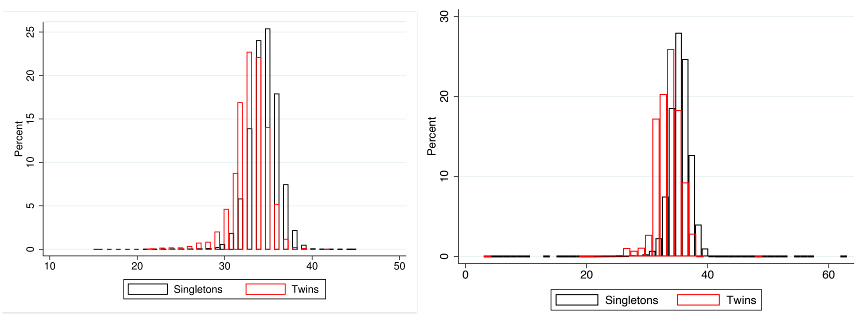
Figure A1. Birth measure distributions (twins vs. singletons).



(a) Distributions of Birth Weight – Sweden (left) and Norway (right)



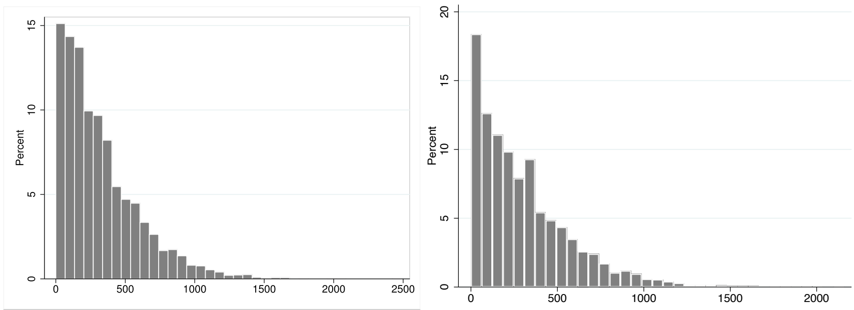
(b) Distributions of Birth Length – Sweden (left) and Norway (right)



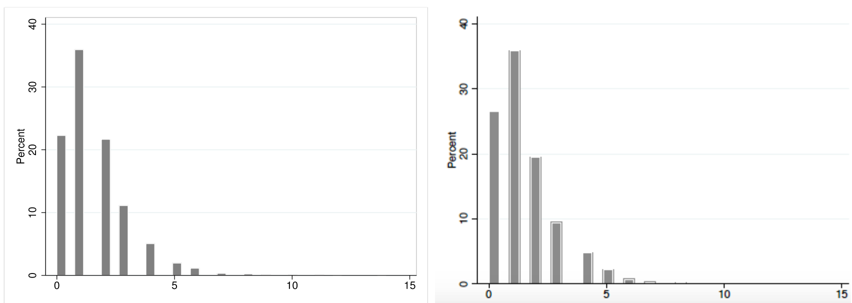
(c) Distributions of Birth Head Circumference – Sweden (left) and Norway (right)

Note: Figure A1 plots histograms of birth weight, birth length and birth head circumference for all twins (red line) and singletons (black line).

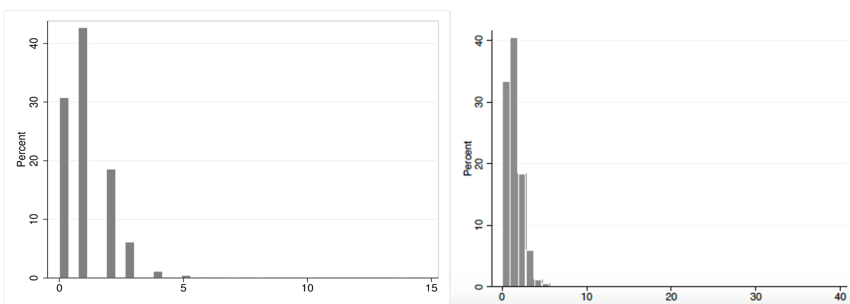
Figure A2. Within-twin-pair differences in birth measures.



(a) Differences in Birth Weight – Sweden (left) and Norway (right)



(b) Differences in Birth Length – Sweden (left) and Norway (right)

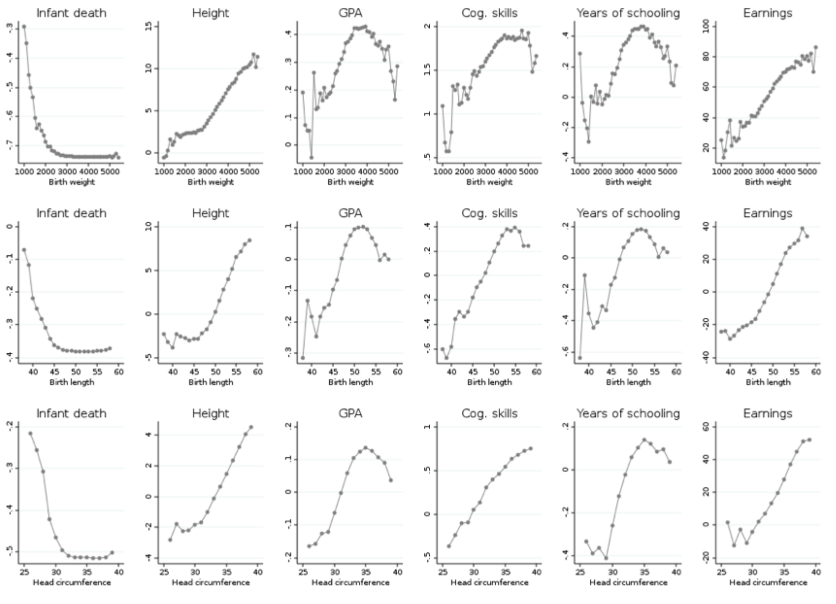


(c) Differences in Birth Head Circumference – Sweden (left) and Norway (right)

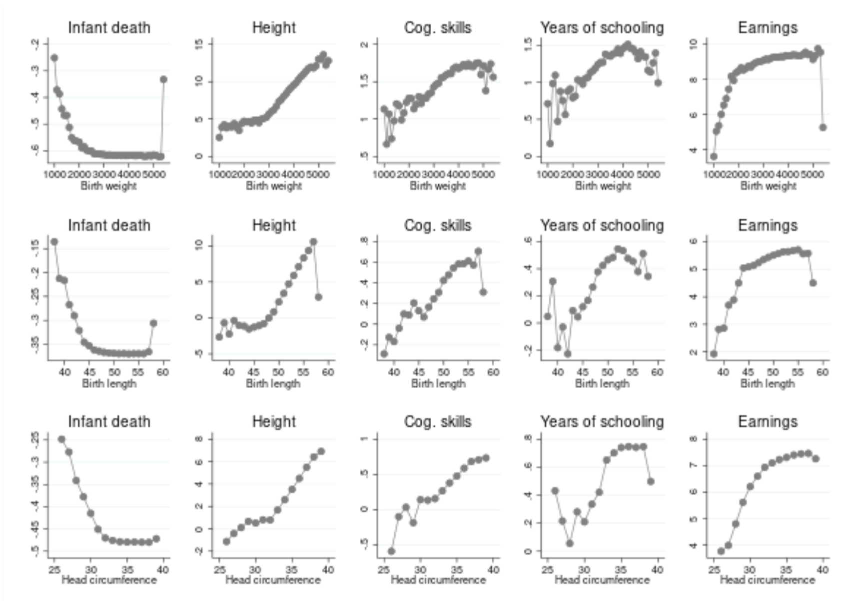
Note: Figure 2 plots histograms of within-twin-pair difference in birth weight, birth length and head circumference for all twin births. Differences in birth weight are measured in grams, differences in birth length and head circumference in centimeters.

Figure A3. Nonparametric singleton estimates.

(a) Sweden



(b) Norway



Note: For birth weight the reference category is <1,000 g, for birth length it is <38 cm, and for head circumference it is <26 cm. To deal with extreme values we winsorize the data at 5,400 g for birth weight (0.01% of the sample), 50 cm for birth length (0.02% of the sample), and 39 cm for head circumference (0.1% of the sample). Grade point average is standardized by cohort (mean 0, *SD* 1). Height (cm) and cognitive skills (stanine scale) are only available for men age 18. Years of schooling is measured as highest observed educational attainment by age 35.

Table A1. Singleton OLS estimates — birth measures on outcomes

	Unconditional		Conditional	
	(1) Sweden	(2) Norway	(3) Sweden	(4) Norway
Infant mortality				
ln(Birth weight)	-0.029***	-0.107***	-0.023***	-0.028***
	(0.001)	(0.003)	(0.001)	(0.003)
ln(Birth length)	-0.082***	-0.271***	-0.026***	-0.105***
	(0.002)	(0.010)	(0.003)	(0.009)
ln(Head circ)	-0.051***	-0.171***	-0.002	-0.045***
	(0.002)	(0.010)	(0.002)	(0.007)
Height, cm				
ln(Birth weight)	15.510***	10.755***	3.111***	-0.744***
	(0.094)	(0.119)	(0.190)	(0.286)
ln(Birth length)	61.561***	47.256***	52.466***	51.285***
	(0.408)	(0.535)	(0.672)	(1.117)
ln(Head circ)	29.865***	26.142***	3.856***	-0.145
	(0.304)	(1.140)	(0.339)	(0.437)
Grade point average				
ln(Birth weight)	0.424***	NA	0.222***	NA
	(0.009)		(0.014)	
ln(Birth length)	1.307***		0.606***	
	(0.029)		(0.042)	
ln(Head circ)	1.000***		0.385***	
	(0.027)		(0.032)	
Cognitive skills				
ln(Birth weight)	0.951***	0.848***	0.549***	0.395***
	(0.026)	(0.027)	(0.041)	(0.058)
ln(Birth length)	2.687***	2.675***	0.847***	0.842***
	(0.086)	(0.095)	(0.123)	(0.167)
ln(Head circ)	2.438***	2.735***	1.197***	1.397***
	(0.081)	(0.161)	(0.095)	(0.185)
Years of schooling				
ln(Birth weight)	0.668***	1.108***	0.321***	0.456***
	(0.019)	(0.045)	(0.031)	(0.080)
ln(Birth length)	2.151***	3.690***	1.152***	2.354***
	(0.064)	(0.158)	(0.093)	(0.293)
ln(Head circ)	1.524***	2.529***	0.521***	0.644***
	(0.060)	(0.185)	(0.072)	(0.203)
ln(Earnings)				
ln(Birth weight)	0.154***	2.038***	0.079***	0.547***
	(0.007)	(0.051)	(0.011)	(0.074)
ln(Birth length)	0.481***	5.613***	0.231***	2.645***
	(0.022)	(0.174)	(0.032)	(0.238)
ln(Head circ)	0.364***	3.851***	0.138***	1.080***
	(0.021)	(0.197)	(0.025)	(0.188)

Note: Each cell in columns 1 and 2 (unconditional estimates) represents results from one regression, where the respective outcome is regressed on each birth measure in turn, and indicators for child gender, gestational age (weeks), year by month of birth, birth order, mother's age at childbirth and mother's educational attainment (years). The conditional estimates in columns 3 and 4, instead, include among the regressors all the three measures of health at birth. Grade point average (for Sweden only) is standardized by cohort (mean 0, *SD* 1). Height (cm) and cognitive skills (stanine scale) are only available for men age 18. Years of schooling is measured as highest observed educational attainment by age 35. Robust standard errors in parenthesis, *$p < .10$, **$p < .05$, ***$p < 0.01$.

External Validity

We examined the external validity of our findings by comparing estimates across singletons and twins for Sweden and Norway, assessing whether the within-pair variation used for identification generates results that generalize to the broader population of births.

In the Swedish sample, estimates from singleton regressions and twin regressions without fixed effects are highly consistent across outcomes. For example, the effect of birth weight on grade point average (GPA) is 0.080 *SD* among singletons and 0.062 *SD* among twins; for years of schooling, the respective estimates are 0.124 and 0.153 years. Once twin fixed effects are included, the magnitudes attenuate somewhat but remain substantial—especially for cognitive and educational outcomes (e.g., 0.056 *SD* for GPA, 0.137 years for schooling).

The largest differences between singletons and twins emerge for height and infant death. The birth-length coefficient on height is halved when moving from singletons to the twin FE model (from 2.4 to 1.25 cm), consistent with the high heritability of height (Yang et al., 2010). For infant mortality, estimates vary more substantially, reflecting both compositional and measurement differences between twins and singletons. These differences are expected and do not undermine the validity of the main results.

Taken together, these comparisons offer supportive, though not definitive, evidence that the within-pair estimates we present are externally valid and likely to generalize to broader birth cohorts.

Table A2. External validity, Sweden (standardized measures of health at birth)

	(1) Infant mortality	(2) Height, cm	(3) Grade point average	(4) Cog. skills	(5) Years of schooling	(6) ln(Earnings)
Singletons (overlapping distributions)						
Birth weight	-0.005***	1.905***	0.080***	0.169***	0.124***	0.030***
	(0.000)	(0.022)	(0.002)	(0.006)	(0.004)	(0.001)
Birth length	-0.004***	2.427***	0.067***	0.132***	0.110***	0.026***
	(0.000)	(0.024)	(0.002)	(0.006)	(0.004)	(0.001)
Head circ	-0.003***	0.965***	0.052***	0.124***	0.079***	0.018***
	(0.000)	(0.019)	(0.002)	(0.005)	(0.004)	(0.001)
Observations	442,059	164,392	423,194	164,894	418,036	415,391
Twins						
Birth weight	-0.012***	2.321***	0.062***	0.145***	0.153***	0.027***
	(0.002)	(0.138)	(0.010)	(0.038)	(0.023)	(0.008)
Birth length	-0.011***	2.375***	0.060***	0.118***	0.152***	0.030***
	(0.002)	(0.119)	(0.009)	(0.032)	(0.021)	(0.007)
Head circ	-0.009***	1.399***	0.065***	0.183***	0.103***	0.030***
	(0.002)	(0.146)	(0.010)	(0.036)	(0.022)	(0.007)
Observations	10,192	2,853	9,597	2,852	9,496	9,418
Twin FE						
Birth weight	-0.004	1.112***	0.056***	0.111*	0.137***	0.023
	(0.004)	(0.201)	(0.017)	(0.065)	(0.045)	(0.017)
Birth length	-0.008*	1.251***	0.045***	0.122*	0.116***	0.021
	(0.004)	(0.209)	(0.016)	(0.063)	(0.044)	(0.017)
Head circ	-0.003	0.935***	0.040**	0.096	0.045	0.015
	(0.004)	(0.228)	(0.016)	(0.071)	(0.048)	(0.019)
Observations	10,192	2,853	9,597	2,852	9,496	9,418

Note: Each cell represents results from one regression. The first panel (Singletons) contains a sample of singletons born with health at birth measures within the 1st–99th percentile of the twin birth distribution. The second (Twins) and third panel (Twins FE) contains a sample of twins. Number of observations for twins differs from Table 3 since in the second panel we control for mother's years of schooling which contains some missing information. To make to results comparable, we include only the nonmissing observations also in the third panel. The regressions in the first and second panel include indicators for child gender, gestational age (weeks), year by month of birth, birth order, mother's age at childbirth and mother's educational attainment (years). The third panel controls for twin fixed effects, indicators of gender and within-pair birth order. Grade point average is standardized by cohort (mean 0, *SD* 1). Height (cm) and cognitive skills (stanine scale) are only available for men age 18. Years of schooling is measured as highest observed educational attainment by age 35. Robust standard errors in parenthesis, standard errors are clustered on twin pair in the third panel, $^{*}p < .10$, $^{**}p < .05$, $^{***}p < .01$. circ, circumference;

Table A3. External validity, Norway (standardized measures of health at birth)

	(1) Infant mortality	(2) Height, cm	(4) Cog. skills	(5) Years of schooling	(6) ln(Earnings)
Singletons (overlapping distributions)					
Birth weight	-0.002***	0.049	0.064***	0.071***	0.033**
	(0.001)	(0.035)	(0.010)	(0.015)	(0.013)
Birth length	-0.002***	2.682***	0.070***	0.128***	0.107***
	(0.001)	(0.031)	(0.009)	(0.014)	(0.012)
Head circ	-0.0004**	0.150***	0.108***	0.058***	0.057***
	(0.0002)	(0.025)	(0.007)	(0.011)	(0.010)
Adj. R-Sq.	0.068	0.119	0.063	0.031	0.013
Observations	260,726	126,101	117,199	255,235	260,726
Twins					
Birth weight	-0.004	0.340	0.036	0.089	0.096
	(0.003)	(0.304)	(0.081)	(0.127)	(0.099)
Birth length	-0.004	2.154***	0.097	0.168*	0.145*
	(0.003)	(0.242)	(0.063)	(0.095)	(0.081)
Head circ	-0.003	0.247	0.240	0.125	0.074
	(0.003)	(0.203)	(0.056)	(0.086)	(0.073)
Adj. R-Sq.	0.167	0.169	0.146	0.061	0.083
Observations	5,804	2,736	2,531	5,618	5,804
Twin FE					
Birth weight	-0.001	0.471	-0.111	0.234	0.182
	(0.006)	(0.348)	(0.119)	(0.203)	(0.172)
Birth length	-0.005	1.258***	0.284***	-0.179	0.003
	(0.005)	(0.294)	(0.101)	(0.167)	(0.141)
Head circ	-0.002	0.022	0.125	0.175	0.003
	(0.004)	(0.235)	(0.082)	(0139)	(0.116)
Adj. R-Sq.	0.413	0.782	0.664	0.322	0.353
Observations	5,804	2,736	2,531	5,618	5,804

Note: Each cell represents results from one regression. The first panel (Singletons) contains a sample of singletons born with health at birth measures within the 1^{st}-99^{th} percentile of the twin birth distribution. The second (Twins) and third panel (Twins FE) contains a sample of twins. Number of observations for twins differs from Table 3 since in the second panel we control for mother's years of schooling which contains some missing information. To make to results comparable, we include only the non-missing observations also in the third panel. The regressions in the first and second panel include indicators for child gender, gestational age (weeks), year by month of birth, birth order, mother's age at childbirth and mother's educational attainment (years). The third panel controls for twin fixed effects, indicators of gender and within-pair birth order. Grade point average is standardized by cohort (mean 0, standard deviation 1). Height (cm) and cognitive skills (stanine scale) are only available for men age 18. Years of schooling is measured as highest observed educational attainment by age 35. Robust standard errors in parenthesis, standard errors are clustered on twin pair in the third panel, * p<0.10, ** p<0.05, *** p<0.01.

Table A4. Singleton OLS estimates — IUGR type on outcomes

	(1) Infant mortality	(2) Height, cm	(3) Grade point average	(4) Cog. skills	(5) Years of schooling	(6) ln (Earnings)
Sweden						
Symmetric	0.016***	-4.605***	-0.210***	-0.446***	-0.321***	-0.079***
	(0.001)	(0.066)	(0.007)	(0.019)	(0.014)	(0.005)
Asymmetric	0.007***	-3.644***	-0.121***	-0.250***	-0.190***	-0.047***
	(0.000)	(0.051)	(0.005)	(0.014)	(0.010)	(0.004)
Adj. R-Sq.	0.083	0.041	0.189	0.144	0.180	0.051
Observations	665,344	275,438	638,428	276,138	630,119	626,059

	(1) Infant mortality	(2) Height, cm	(3) Grade point average	(4) General ability	(5) Years of schooling	(6) Ln (Earnings)
Norway						
Symmetric	0.016***	-4.563***	NA	-0.507***	-0.518***	-0.484***
	(0.001)	(0.088)		(0.023)	(0.033)	(0.035)
Asymmetric	0.016***	-3.657***		-0.275***	-0.377***	-0.445***
	(0.001)	(0.069)		(0.019)	(0.028)	(0.028)
Adj. R-Sq.	0.015	0.029		0.058	0.030	0.017
	348,522	167,884		156,053	340,607	348,522

Note: Each column represents results from one regression. Reference category is non-IUGR children. All specifications include indicators for child gender, gestational age (weeks), year by month of birth, birth order, mother's age at childbirth and mother's educational attainment (years). For Sweden, Grade point average is standardized by cohort (mean 0, standard deviation 1). Height (cm) and cognitive skills (stanine scale) are only available for men age 18. Years of schooling is measured as highest observed educational attainment by age 35. Robust standard errors in parenthesis, *$p < .10$, **$p < .05$, ***$p < .01$. IUGR, intrauterine growth restriction.