Social inequalities in birthweight in times of crisis. A population-level analysis of social inequalities in birthweight before and during COVID-19 pandemic using data from 11 countries.

Authors: Moritz Oberndorfer[1,2,3,4], Eugenio Paglino[1,2], Hanna Remes[1,2], Juha MO Luukkonen[1,2], Pekka T Martikainen[1,2,5]

[1] Helsinki Institute for Demography and Population Health, University of Helsinki, Helsinki, Finland

[2] Max Planck | University of Helsinki Center for Social Inequalities in Population Health, Helsinki, Finland and Rostock, Germany

[3] Public Health, School of Health and Wellbeing, University of Glasgow, Glasgow, Scotland

[4] Department of Public Health Sciences, Stockholm University, Stockholm, Sweden

[5] Max Planck Institute for Demographic Research, Rostock, Germany

Short abstract 250 words

Crises like the COVID-19 pandemic hit populations with new potentially harmful and protective exposures that may be distributed unequally in a population. Counterintuitively, even stark social inequalities in the distribution of crisis-related exposures may not lead to an observed increase in social inequalities in perinatal health. This is because crises-related exposures may change the composition of live births through selection in utero and/or selective fertility.

To analyse how social inequalities in birthweight change during crises, we used individual-level data from 5 countries (Brazil, Ecuador, Finland, Spain, United States) and 6 more until June 2026 (Austria, Denmark, Netherlands, Scotland, South Australia, Sweden) covering births from 2015 to 2021. Births were nested within social strata consisting of the combination of parental socioeconomic circumstances, maternal age, maternal partnership status, and first-time/already mother. We used Bayesian linear multilevel modelling.

Results suggest between-country differences in grand mean birthweight of up to 400g among unexposed live births. Within-country differences in birthweight between social strata were similarly large but their extent varied across countries. Changes in mean birthweights differed by up to 40g between strata within countries. In Spain, babies conceived during the pandemic had smaller between- and within-strata variation in birthweight compared to unexposed cohorts. we find weak evidence for changes in social inequalities in birthweight across countries during the pandemic.

A lack of changes in social inequalities in birthweight may be explained by the simultaneous effects of crisis-related exposures widening inequalities and selection in utero and at conception decreasing variation in birthweight between social strata.

Extended abstract (2-4 pages)

Topic

Birthweight is associated with health and socioeconomic outcomes across the life course. Previous studies have reported associations between birthweight and infant mortality[1] (even above the low-birthweight threshold of 2500 g[2]), chronic conditions during childhood and adulthood, and associations with lower educational attainment, unemployment, and likelihood of receiving social benefits.[3] Birthweights at both ends of the distribution – low birthweight (<2500 grams) and macrosomia (>4000 grams) – are associated with infant morbidity and mortality and macrosomia being additionally associated with birth injuries and maternal morbidity.[4] Importantly, birthweight and other markers of infant health are associated with social determinants – parental socioeconomic circumstances, maternal partnership status, maternal age, and parity[5,6] – contributing to the intergenerational transmission of social inequalities[5].

In this study, we aimed to contribute to a generalisable understanding of how existing social inequalities in birthweight among live births respond to crises by connecting population health theory, insights from perinatal epidemiology (in utero selection) and demography (selective fertility). Following these theoretical considerations, we studied changes in population-average and group-specific mean birthweight, and variation in birthweight between and within population groups at the intersection of multiple social and demographic determinants of birthweight during the COVID-19 pandemic. To learn more convincingly about responses of social inequalities in birthweight to crises, we conducted a comparative analysis across 5 countries for this abstract (Brazil, Ecuador, Finland, Spain, United States) and will extend our study with results from 6 other countries (Austria, Denmark, Netherlands, Scotland, South Australia, Sweden) until June 2026. Thus, we study the response to crisis across varying syndemic configurations of pandemic experiences and pre-existing social inequalities in the social and demographic determinants of birthweight.

Theoretical focus

Crises like the COVID-19 pandemic hit populations with an emerging array of potentially harmful or protective exposures and collide with pre-existing social inequalities in perinatal health[6–8] and its social and demographic determinants.[9]

Syndemic theory and Fundamental Cause Theory (FCT) help us predict how this collision may affect the population-level and social distribution of perinatal health. Fundamental Cause Theory puts emphasis on the unequal distribution of flexible resources (money, power, prestige, social connections) across social positions used to prevent or mitigate harm and to improve health.[10,11] Inequalities in flexible resources may lead to unequal distributions of emerging crisis-related harmful and protective exposures for perinatal health within the population. During the COVID-19 pandemic, examples for crisis-related exposures potentially harmful for birth outcomes were risk of COVID-19 infection and severe disease, increased exposure to prenatal stress through crisis-related economic uncertainty, social isolation due to lockdown measures, barriers in access to health care services, and crises-related increase in harmful behavioural exposures. Examples for potentially protective exposures were reduced exposure to non-COVID-19 infections, reduced exposure to air pollution, reduced work-related travel, and heightened awareness about health behaviour.

The theory of syndemics states that epidemics co-occur in time and space (e.g., COVID-19 and the epidemic of non-communicable diseases) due to large-scale social forces (like social inequalities) and that these co-occurring epidemics interact to adversely affect health among disadvantaged population groups.[12,13]

Thus, both FCT and syndemic theory arrive at the prediction that crisis-related harmful exposures are more likely to affect disadvantaged population groups than advantaged groups and that advantaged groups are more likely to benefit from potential protective exposures. Consequently, the crisis-related health burden will be unequally shared across population groups at different intersections of social disadvantage and exacerbate pre-existing health inequalities.

Counterintuitively, we may not observe widening social inequalities in perinatal health outcomes during periods of crises, even if there are stark social inequalities in the distribution of crisis-related harmful and protective exposures within a population. This is because the unequal distribution of crisis-related exposures may change the composition of live births through exposure-related selection in utero[14,15] and/or selective conception[16–20] – a consequence of "live birth bias" in perinatal epidemiology[21,22]. Put differently, evidently harmful (crisis-related) in utero exposures can seem to have no or even protective effects on health outcomes[15,21,22] because harmful exposures may cause a stronger selection for "healthy" foetuses in utero[14,23–25] with male foetuses more potentially affected[23,25–27]. Further, the magnitude of such live birth bias can be larger for disadvantaged population groups that share a higher burden of the harmful (crises-related) exposures and the adverse outcome.[28] Therefore, stronger selection for healthy foetuses in utero, if uniform across the population or concentrated among disadvantaged population groups with more vulnerable foetuses, will lead to higher population-average birthweight and smaller variation in birthweight between disadvantaged and advantaged population groups.

Similarly, for cohorts conceived during the pandemic, compositional change towards parents in advantaged social circumstances due to selective conception – as observed for European countries and the United States[16] – may lead to higher population-average birthweight and smaller variation in birthweight. Conversely, where crises select for parents in more disadvantaged positions[16,29,30], population-average birthweight may decrease and its variation increase.

Previous literature on the effect of in utero exposure to stressful environments and crises[14,23–25,27,31] and literature on changes in parental socioeconomic and demographic compositions of birth cohorts[16,18,29,30,32–34] suggest that both selection in utero and selective conception occurs in response to crises, and recently during the COVID-19 pandemic. It follows that social inequalities in the distribution of harmful and protective crisis-related pre-conception and prenatal exposures can lead to several plausible contradicting impact scenarios[35,36] concerning combinations of effects on population-average birthweight and variation in birthweight. How social inequalities in birthweight respond to crises is thus an empirical question. Given the potentially counteracting forces on social inequalities in birthweight through an unequal distribution of emerging crisis-related exposures – a widening due to the direct effects harmful and protective effects and a narrowing due to a positive selection for foetuses and/or parents – it may appear that social inequalities in birthweight do not change during crises like the pandemic.

Data

We used individual-level population-wide birth data from 5 countries (Brazil, Ecuador, Finland, Spain, United States) and 6 more until June 2026 (Austria, Denmark, Netherlands, Scotland, South Australia, Sweden) covering registered births from 2015 to 2021 for this observational study. Due to computational constrains we used a 5% random sample of births in Brazil and a 10% random sample for the United States for this abstract.

Methods

We follow a conception cohort approach because the pandemic had (country-specific) time-varying effects on the number of conceptions[16] which will affect the gestational age composition of (monthly

or weekly) birth cohorts and thus affect preterm birth rates and birthweight[18,19,37]. We focus on three conception cohorts observed as live births. Unexposed cohorts: births conceived before the pandemic and not exposed to the pandemic in-utero (born before March 2020) (C1). Second, births conceived before the pandemic but exposed to the pandemic in-utero (born during or after March 2020) (C2). Third, the births conceived during the pandemic and exposed to the pandemic in-utero (C3) which was previously called "Lockdown Cohort"[17]. Our included and excluded conception cohorts are presented in Figure 1.

Variables

Our outcome is birthweight measured in grams. We used parental socioeconomic circumstances, maternal age, maternal partnership status, and parity as axes along which crisis-related harmful and protective exposures may have been unequally distributed during the pandemic. These variables have been associated with birthweight in previous research[6,8] and infant health more generally, and are widely available and comparable across countries with few missing values.

Depending on availability, we used equivalised household income, pre-existing measures of (small) area-level deprivation of maternal area of residence, and maternal level educational attainment as available in population registers or on birth certificates as indicators of parental socioeconomic circumstances. When household income or area deprivation measures were available, we assigned births to quintiles of equivalised household income / deprivation index. Maternal age was divided into 5 groups: below 20, 20-24, 25-29, 30-34, and 35 and above. Maternal partnership status was indicated by a binary variable. Parity was divided into two groups: no previous live births ("first time mothers") and at least one previous live birth ("already mothers"). Together, these variables lead to 5*5*2*2= 100 unique social strata. Some of these strata had very few observations as, for example, there are few births among women aged below 20 who already had a live birth and / or completed tertiary education. Where the strata size was too low, we collapsed these strata to their closest neighbouring strata.

Data analysis

We estimated four Bayesian linear multilevel models per country with live births nested in social strata. The models are specified with two intercepts – one for the unexposed and one for the exposed group – with their respective random effects, no common intercept, and adjusted for month of conception indicators and a linear term for monthly data of conception to account for seasonality and secular trends in birthweight respectively. For Brazil and Ecuador, we additionally adjusted for the effects of the ZIKV-epidemic by including a binary variable indicating babies born during the epidemic as done previously.[16] In the first model, we estimated differences in birthweight between the unexposed (C1) and the cohort exposed and conceived before the pandemic among male babies (C2). Then we estimated the same model for the unexposed (C1) and cohort exposed and conceived during the pandemic (C3). Second, we estimated these two models (per country) again for female babies. From the posterior distribution of these models, we obtained the following estimates to study how social inequalities in birthweight changed during the pandemic. First, we estimated the differences between the conditional grand mean of birthweight of exposed and unexposed conception cohorts and the differences in the conditional stratum-specific means. These estimands answer to what extent population grand mean birthweight changed during the pandemic and the extent to which these changes were unequal across strata. Next, we estimated how the between-stratum variation (inequalities) in birthweight changed during the pandemic. Lastly, we estimated differences in the within-stratum standard deviation across all strata and within each stratum. This answers to what extent within-strata deviations from stratum-specific (conditional and precision-weighted) means

changed during the pandemic and thus if variance changed within population groups. Point estimates are the means and 95% credible intervals are the 2.5th and 97.5th percentiles of the posterior distribution. Models were estimated using the specialised multilevel modelling software MLwiN[38] and the R package "brms"[39]. We conducted a complete case analysis and thus only included births with non-missing information on birthweight, gestational age, birth date, sex of the baby, and the strata covariates. Missing values were generally below 2% except for maternal education in Spain and marital status in the US due to changes in data collection in California from 2017 onwards.

(Expected) findings

The results presented are based on about 5 500 000 live births from Brazil, Ecuador, Finland, Spain, and the United States. The analysis presented at the EPC conference will be based on about 35 500 000 live births from Austria, Brazil, Denmark, Ecuador, Finland, Netherlands, Scotland, South Australia, Spain, Sweden, and the United States.

We found between-country differences in grand mean birthweight of more than 400g among both unexposed male live births (Brazil: 3241g, Ecuador: 3118g, Finland: 3565g, Spain: 3269g, United States: 3297g) and female babies (Brazil: 3135g, Ecuador: 2990g, Finland: 3444g, Spain: 3149g, United States: 3213g). Within-country differences in birthweight between social strata were similarly large but their extent varied across countries. Among unexposed male babies, the stratum-specific means were up to 150g higher/lower than the population grand mean in Finland (min: 3367g; max: 3706g), Spain (min: 3112g; max: 3387g), and the United States (min: 3080g; max: 3491g). The largest within country differences were among unexposed births were among female babies in the United States with about 400g differences in the means of strata with the lowest mean birthweight compared with means of strata with the highest mean birthweights (min: 2974g; max: 3405g). Within-country differences were the smallest in Ecuador with strata-specific means ranging from 2844g to 3090g among unexposed female babies and from 2988g to 3231g among unexposed male babies. (See Figure 2).

We find small positive effects (most between +10g and +20g) on grand mean birthweight among Ecuador, Finland, and the US for both male and female babies and both exposed cohorts. However, for some social strata in the countries with increases in grand mean birthweight, we also find potential negative effects on mean birthweight among male babies in Finland and female babies in the US. In many cases, differences in mean birthweight showed high heterogeneity across social strata with up to 35g difference in the effect within a cohort (Figure 2). An equal distribution of mean differences across social strata was the exception in our results so far. Male babies exposed and conceived during the pandemic had a lower between-stratum variation than unexposed male babies in Spain and exposed male babies conceived before the pandemic had higher between-stratum variation than unexposed male babies in Brazil (Figure 4). Results for Spain are not compatible with the theoretical prediction that a selection for a more advantaged parental composition led to higher mean birthweights (Figure 3) but with the prediction that this selection led to lower inequalities between strata (Figure 4). In further analysis, we find that this is due to positive effects on birthweight being concentrated among strata with low mean birthweights and negative effects on birthweight being concentrated among strata with high mean birthweights. For Brazil, we find increases in the between and within-stratum variation among male babies comparing unexposed with cohorts exposed and conceived before the pandemic. Here, negative effects were concentrated among strata with low mean birthweights and positive effects concentrated among social strata with high birthweights.

In summary, social inequalities in birthweight varied substantially between countries but there is weak cross-country evidence for changes in inequalities in birthweight between social strata during the pandemic. The patterns we found are inconsistent across countries. A lack of changes in social

inequalities in birthweight may be explained by the simultaneous effects of crisis-related exposures widening inequalities and selection in utero and at conception decreasing variation in birthweight. The results for further countries that will be included in the paper before the EPC conference may impact our preliminary conclusions.

Figures

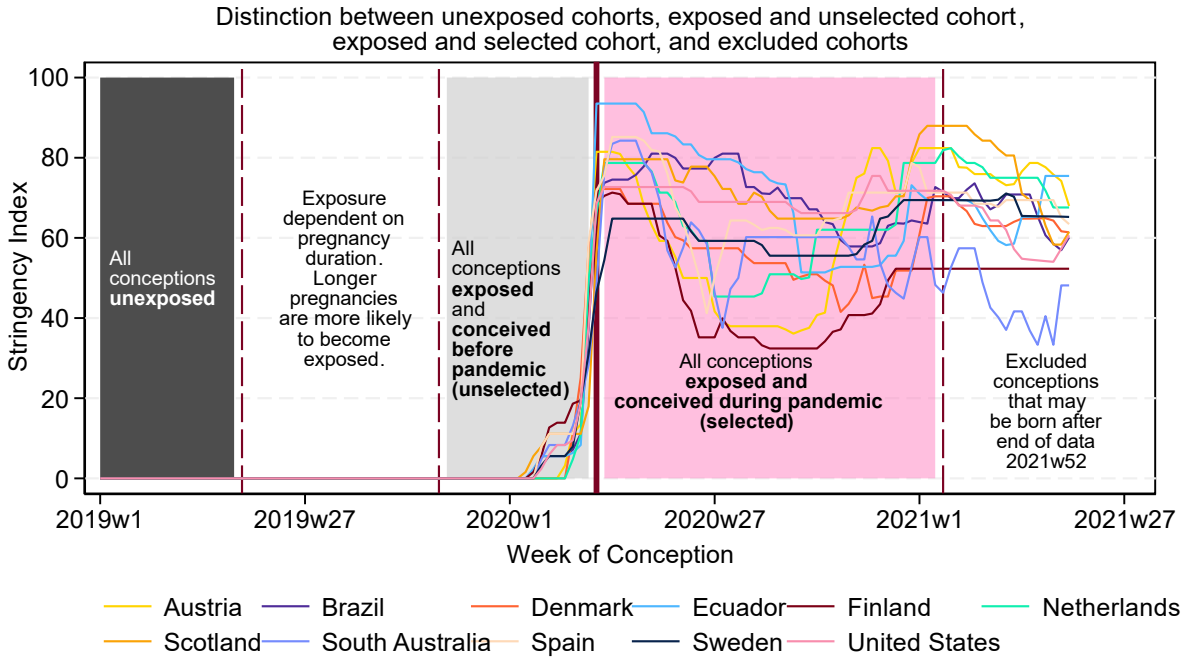

Figure 1: Included and excluded live births by estimated date of conception with country-specific weekly average Stringency Index in the background. Live births conceived from January 2015 to and including 18th week of 2019 are unexposed to the COVID-19 pandemic. Live births conceived from 19th week of 2019 to 44th week of 2019 and from 5th week of 2021 onwards are excluded as they likely bias our analysis. Live births conceived between (and including) 45th week of 2019 and 11th week of 2020 are treated as exposed to the pandemic and not affected by selective conception ("exposed and unselected"). Live births conceived between 12th week of 2020 and 4th week of 2021 are treated as exposed and affected by selective conception ("exposed and selected")

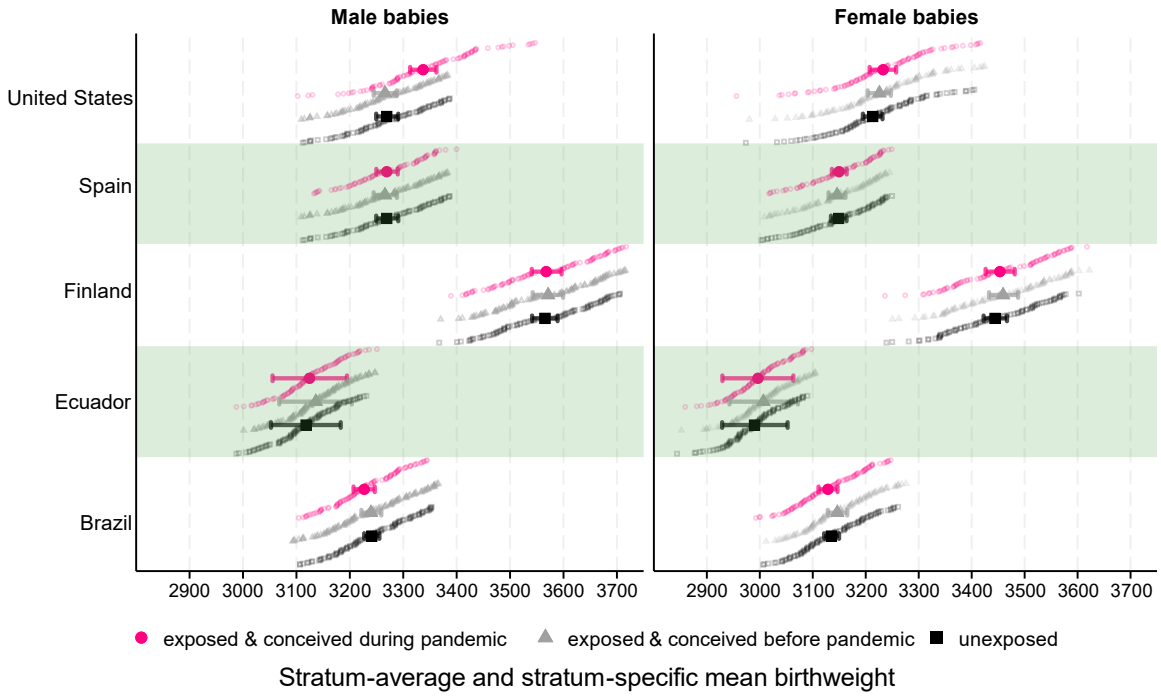

Figure 2: Population grand means of birthweight and stratum-specific mean birthweights for each conception cohort, country and for male and female babies separately. Filled black squares and surrounding bars present the estimates of the grand mean birthweight and respective 95% credible intervals for the unexposed cohorts. Hollow black squares present the point estimates for stratum-specific mean birthweights. Stratum-specific means are sorted by rank of stratum-specific birthweight within each cohort. Strata are created by the unique combination of parental socioeconomic circumstances (five categories of household income, education or area deprivation), maternal age (five categories: <20, 20-24, 25-29, 30-34, 35 and above), maternal partnership status (two categories), parity (two categories: first time mother, already mother). Strata with too few observations were collapsed with similar categories (see suppl. material). Grand mean and stratum-specific differences in mean birthweight were estimated by Bayesian linear multilevel models with births nested within social strata. Models were separately estimated by sex of the baby and for the comparison between unexposed and unselected and unexposed and selected cohorts. All models were estimated with a fixed intercept for both unexposed and exposed cohorts, random intercepts for both fixed intercepts, residual error terms for both fixed intercepts, and were adjusted for secular linear trends in birthweight and seasonality in birthweight by month of conception, and a variable indicating the ZIKV epidemic in Brazil, and Ecuador.

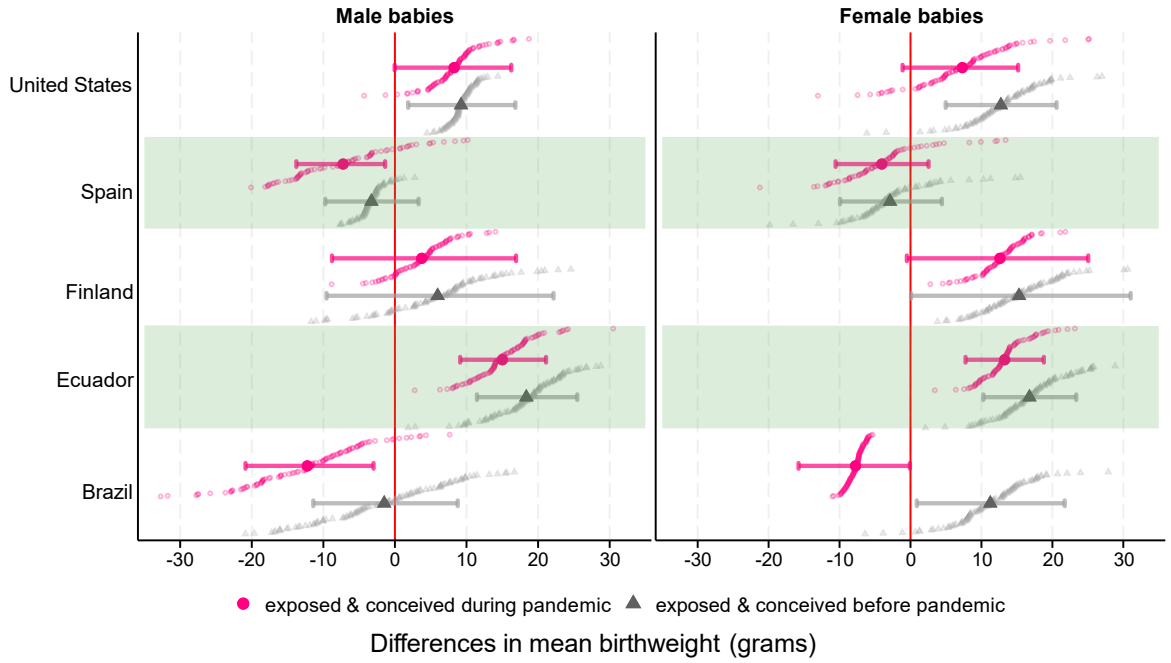

Figure 3: Differences in grand mean birthweight and their 95% credible intervals comparing unexposed with babies exposed in utero and conceived before the pandemic (triangles) and unexposed with babies exposed in utero and conceived during the pandemic (dots). Smaller hollow triangles and dots around the stratum-average difference are stratum-specific point estimates. The vertical position of stratum-specific estimates around the stratum-average estimates is based on the rank of stratum-specific differences. Strata are created by the unique combination of parental socioeconomic circumstances (five categories of household income, education or area deprivation), maternal age (five categories: <20, 20-24, 25-29, 30-34, 35 and above), maternal partnership status (two categories), parity (two categories: first time mother, already mother). Strata with too few observations were collapsed with similar categories (see suppl. material). Grand mean and stratum-specific differences in mean birthweight were estimated by Bayesian linear multilevel models with births nested within social strata. Models were separately estimated by sex of the baby and for the comparison between unexposed and unselected and unexposed and selected cohorts. All models were estimated with a fixed intercept for both unexposed and exposed cohorts, random intercepts for both fixed intercepts, residual error terms for both fixed intercepts, and were adjusted for secular linear trends in birthweight and seasonality in birthweight by month of conception, and a variable indicating the ZIKV epidemic in Brazil, and Ecuador.

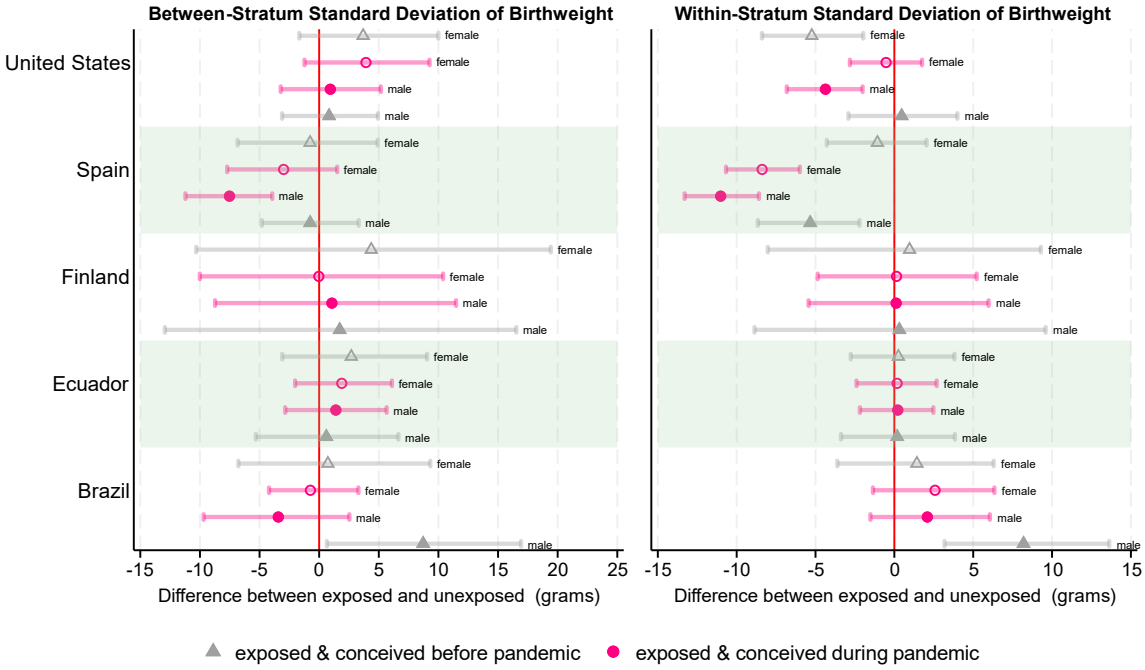

Figure 4: Difference in between-stratum and within-stratum standard deviation of birthweight between unexposed cohorts and cohorts exposed and conceived before the pandemic (triangles), and between unexposed cohorts and cohorts exposed and conceived during the pandemic (circles). Point estimates (symbols) and 95% credible intervals (error bars) were derived from estimated by Bayesian linear multilevel models with births nested within social strata. All models were estimated with a fixed intercept for both unexposed and exposed cohorts, random intercepts for both fixed intercepts, residual error terms for both fixed intercepts, and were adjusted for secular linear trends in birthweight and seasonality in birthweight by month of conception. Differences in between-stratum and within-stratum standard deviations were estimated using the posterior distributions of the variance components estimates of unexposed and exposed cohorts. Strata are created by the unique combination of parental socioeconomic circumstances (five categories of education or area deprivation), maternal age (five categories: <20, 20-24, 25-29, 30-34, 35 and above), maternal partnership status (two categories), parity (two categories: first time mother, already mother). Strata with too few observations were collapsed with similar categories.

References

1. Wilcox AJ, Skjaerven R. Birth weight and perinatal mortality: the effect of gestational age. *Am J Public Health*. 1992;82(3):378-382. doi:10.2105/AJPH.82.3.378
2. Alexander GR, Kogan M, Bader D, Carlo W, Allen M, Mor J. US birth weight/gestational age-specific neonatal mortality: 1995-1997 rates for whites, hispanics, and blacks. *Pediatrics*. 2003;111(1):e61-66. doi:10.1542/peds.111.1.e61
3. Bilgin A, Mendonca M, Wolke D. Preterm Birth/Low Birth Weight and Markers Reflective of Wealth in Adulthood: A Meta-analysis. *Pediatrics*. 2018;142(1):e20173625. doi:10.1542/peds.2017-3625
4. Ro A, Goldberg RE, Kane JB. Racial and Ethnic Patterning of Low Birth Weight, Normal Birth Weight, and Macrosomia. *Preventive Medicine*. 2019;118:196-204. doi:10.1016/j.ypmed.2018.10.012
5. Aizer A, Currie J. The intergenerational transmission of inequality: Maternal disadvantage and health at birth. *Science*. 2014;344(6186):856-861. doi:10.1126/science.1251872
6. Currie J. Inequality at Birth: Some Causes and Consequences. *American Economic Review*. 2011;101(3):1-22. doi:10.1257/aer.101.3.1
7. Martinson ML, Reichman NE. Socioeconomic Inequalities in Low Birth Weight in the United States, the United Kingdom, Canada, and Australia. *Am J Public Health*. 2016;106(4):748-754. doi:10.2105/AJPH.2015.303007
8. Cozzani M. Inequalities at birth: stable socioeconomic differences in birth outcomes in three British cohorts. *Genus*. 2023;79(1):18. doi:10.1186/s41118-023-00191-z
9. Torche F, Nobles J. The Unequal Impact of the COVID-19 Pandemic on Infant Health. *Demography*. 2022;59(6):2025-2051. doi:10.1215/00703370-10311128
10. Link BG, Phelan J. Social Conditions As Fundamental Causes of Disease. *Journal of Health and Social Behavior*. Published online 1995:80-94. doi:10.2307/2626958
11. Clouston SAP, Link BG. A Retrospective on Fundamental Cause Theory: State of the Literature and Goals for the Future. *Annual Review of Sociology*. 2021;47(1):131-156. doi:10.1146/annurev-soc-090320-094912
12. Bambra C, Riordan R, Ford J, Matthews F. The COVID-19 pandemic and health inequalities. *J Epidemiol Community Health*. 2020;74(11):964-968. doi:10.1136/jech-2020-214401
13. Tsai AC, Mendenhall E, Trostle JA, Kawachi I. Co-occurring epidemics, syndemics, and population health. *The Lancet*. 2017;389(10072):978-982. doi:10.1016/S0140-6736(17)30403-8
14. Catalano RA, Bruckner TA, Gemmill A, Margerison CE. The pandemic preterm paradox: a test of competing explanations. *American Journal of Epidemiology*. 2024;193(12):1823-1831. doi:10.1093/aje/kwae128
15. Nobles J, Hamoudi A. Detecting the Effects of Early-Life Exposures: Why Fecundity Matters. *Popul Res Policy Rev*. 2019;38(6):783-809. doi:10.1007/s11113-019-09562-x
16. Oberndorfer M, Luukkonen J, Remes HM, et al. *The COVID-19 Pandemic Changed the Socioeconomic Composition of Parents: A Register-Based Study of 76.5 Million Live Births in 12 Countries*. 0 ed. Max Planck Institute for Demographic Research; 2024:WP-2024-039. doi:10.4054/MPIDR-WP-2024-039
17. Oberndorfer M, Dundas R, Leyland AH, Pearce A. The LoCo (Lockdown Cohort)-effect: why the LoCo may have better life prospects than previous and subsequent birth cohorts. *European Journal of Public Health*. Published online May 5, 2022:ckac049. doi:10.1093/eurpub/ckac049
18. Cozzani M, Fallesen P, Passaretta G, Härkönen J, Bernardi F. The Consequences of the COVID-19 Pandemic for Fertility and Birth Outcomes: Evidence from Spanish Birth Registers. *Population and Development Review*. 2023;n/a(n/a). doi:10.1111/padr.12536
19. Fallesen P, Oberndorfer M, Cozzani M. Changes in conception rates, not in pregnancy-related behaviour, likely caused decline in preterm births during the first year of the COVID-19 pandemic. *BJOG*. 2023;130(10):1153-1155. doi:10.1111/1471-0528.17568
20. Oberndorfer M, Henery PM, Dundas R, et al. Study protocol: examining the impacts of COVID-19 mitigation measures on pregnancy and birth outcomes in Scotland—a linked administrative data study. *BMJ Open*. 2023;13(2):e066293. doi:10.1136/bmjopen-2022-066293
21. Snowden JM, Bovbjerg ML, Dissanayake M, Basso O. The curse of the perinatal epidemiologist: inferring causation amidst selection. *Curr Epidemiol Rep*. 2018;5(4):379-387. doi:10.1007/s40471-018-0172-x
22. Liew Z, Olsen J, Cui X, Ritz B, Arah OA. Bias from conditioning on live birth in pregnancy cohorts: an illustration based on neurodevelopment in children after prenatal exposure to organic pollutants. *International Journal of Epidemiology*. 2015;44(1):345-354. doi:10.1093/ije/dyu249
23. Bruckner TA, Bustos B, Margerison C, Gemmill A, Casey J, Catalano R. Selection in utero against male twins in the United States early in the COVID-19 pandemic. *American Journal of Human Biology*. 2023;35(3):e23830. doi:10.1002/ajhb.23830

24. Bruckner TA, Catalano R. Selection in utero and population health: Theory and typology of research. *SSM - Population Health*. 2018;5:101-113. doi:10.1016/j.ssmph.2018.05.010
25. Bruckner TA, Nobles J. Intrauterine stress and male cohort quality: The case of September 11, 2001. *Social Science & Medicine*. 2013;76:107-114. doi:10.1016/j.socscimed.2012.10.012
26. Kraemer S. The fragile male. *BMJ*. 2000;321(7276):1609-1612. doi:10.1136/bmj.321.7276.1609
27. Torche F, Kleinhaus K. Prenatal stress, gestational age and secondary sex ratio: the sex-specific effects of exposure to a natural disaster in early pregnancy. *Human Reproduction*. 2012;27(2):558-567. doi:10.1093/humrep/der390
28. Goin DE, Casey JA, Kioumourtzoglou MA, Cushing LJ, Morello-Frosch R. Environmental hazards, social inequality, and fetal loss: Implications of live-birth bias for estimation of disparities in birth outcomes. *Environmental Epidemiology*. 2021;5(2):e131. doi:10.1097/EE9.0000000000000131
29. Marteleto LJ, Dondero M. Navigating women's reproductive health and childbearing during public health crises: Covid-19 and Zika in Brazil. *World Dev*. 2021;139:105305. doi:10.1016/j.worlddev.2020.105305
30. Rangel MA, Nobles J, Hamoudi A. Brazil's Missing Infants: Zika Risk Changes Reproductive Behavior. *Demography*. 2020;57(5):1647-1680. doi:10.1007/s13524-020-00900-9
31. Cozzani M, Triventi M, Bernardi F. Maternal Stress and Pregnancy Outcomes Evidence from a Natural Experiment: The 2004 Madrid Train Bombings. *European Sociological Review*. 2022;38(3):390-407. doi:10.1093/esr/jcab045
32. Lappegård T, Kornstad T, Dommermuth L, Kristensen AP. *Understanding the Positive Effects of the COVID-19 Pandemic on Women's Fertility in Norway*. Statistisk sentralbyrå; 2022. Accessed January 31, 2023. https://ssb.brage.unit.no/ssb-xmlui/handle/11250/2995390
33. Beach B, Brown R, Ferrie J, Saavedra M, Thomas D. Reevaluating the Long-Term Impact of In Utero Exposure to the 1918 Influenza Pandemic. *Journal of Political Economy*. 2022;130(7):1963-1990. doi:10.1086/719757
34. Marteleto LJ, Guedes G, Coutinho RZ, Weitzman A. Live Births and Fertility Amid the Zika Epidemic in Brazil. *Demography*. 2020;57(3):843-872. doi:10.1007/s13524-020-00871-x
35. Benach J, Malmusi D, Yasui Y, Martínez JM, Muntaner C. Beyond Rose's Strategies: A Typology of Scenarios of Policy Impact on Population Health and Health Inequalities. *Int J Health Serv*. 2011;41(1):1-9. doi:10.2190/HS.41.1.a
36. Subramanian SV, Kim R, Christakis NA. The "average" treatment effect: A construct ripe for retirement. A commentary on Deaton and Cartwright. *Social Science & Medicine*. 2018;210:77-82. doi:10.1016/j.socscimed.2018.04.027
37. Cozzani M, Fallesen P, Härkönen J. Temporal Changes in the Quantity of Conceptions Influence Preterm Births Rates at the Population Level. *DISIA WORKING PAPER*. Published online 2025.
38. Leckie G, Charlton C. runmlwin : A Program to Run the **MLwiN** Multilevel Modeling Software from within *Stata*. *J Stat Soft*. 2012;52(11). doi:10.18637/jss.v052.i11
39. Bürkner PC. brms: An R Package for Bayesian Multilevel Models Using Stan. *Journal of Statistical Software*. 2017;80:1-28. doi:10.18637/jss.v080.i01