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Interpregnancy intervals and perinatal and child health in Sweden: A comparison within families and across social groups

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A large body of research has shown that children born after especially short or long birth intervals experience an elevated risk of poor perinatal outcomes, but recent work suggests this may be explained by confounding by unobserved family characteristics. We use Swedish population data on cohorts born 1981–2010 and sibling fixed effects to examine whether the length of the birth interval preceding the index child influences the risk of preterm birth, low birth weight, and hospitalization during childhood. We also present analyses stratified by salient social characteristics, such as maternal educational level and maternal country of birth. We find few effects of birth intervals on our outcomes, except for very short intervals (less than seven months) and very long intervals (>60 months). We find few differences in the patterns by maternal educational level or maternal country of origin after stratifying by the mother's highest educational attainment.

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Keywords: interpregnancy intervals; perinatal health; child health; low birth weight; preterm birth; childhood hospitalization; population register data; sibling fixed effects; Sweden

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Introduction

A large body of work has examined how the length of intervals between births is related to birth outcomes and the health of the child. For the most part, this literature has consistently shown that interpregnancy intervals (IPIs) that are particularly short (e.g. less than 18 months) or particularly long (e.g. 60+ months) increase the risk of a range of poor outcomes (Conde-Agudelo et al. 2006). Past studies have also suggested that short birth intervals are associated with poor long-term outcomes, such as lower cognitive ability, achieving lower grades in school, and being less likely to make subsequent educational transitions (Powell and Steelman 1990, 1993), suggesting either that there are consequent effects of the poor perinatal outcomes or that the short spacing between siblings also has a negative effect on the development environment within the household. Recently, however, a series of studies

have attempted to control for the shared family environment by comparing siblings born to the same mother. Several studies in high-income countries have found that after adopting this approach, the association between particularly short or long birth intervals and poor perinatal outcomes is completely removed (Ball et al. 2014; Class et al. 2017; Hanley et al. 2017). In this study we use Swedish population data to examine whether IPI length—the time between the birth of the next oldest sibling and the conception of the index child—is associated with preterm birth and low birth weight (LBW), as well as hospitalization during various age windows of childhood. We also examine whether different patterns are observed among more vulnerable sections of the population, such as children born to mothers with low levels of education and children born to immigrant mothers. Potential differences across social groups have been ignored in the most recent body of literature that

has attempted to control for unobserved shared frailty in the sibling group.

The focus of our study—health outcomes of children beyond the first year of life, which we examine by studying child hospitalization—has not been examined in previous research. We would expect the risk of hospitalization during childhood to be related to birth interval length by a different set of mechanisms from those affecting the risk of preterm birth, LBW, and being small for gestational age (SGA) and, in addition to adverse effects very early in life, to also be related to the degree of parental investment and attention available to each child during childhood (Blake 1981). Having closely spaced children, and particularly a larger number of closely spaced children, would make it more difficult for the parents to monitor the wellbeing of each child, which might be related to the risk of hospitalization from accidents as well as other diseases and illnesses. Similarly, the focus on hospitalization allows us to examine if the eventual poor perinatal outcomes of closely spaced children have repercussions on health later in childhood, as well as to identify at what ages such effects are felt.

Previous empirical research

Until very recently, the overwhelming body of evidence has demonstrated convincingly that short IPIs are bad for the health of the child as well as the mother. For example, a meta-analysis of 67 studies by Conde-Agudelo et al. (2006) found that short and long intervals were associated with poor outcomes in high-income countries as well as low-income countries. In both high- and low-income settings, both short and long intervals were found to be associated with the risk of poor outcomes such as preterm birth, LBW, and SGA, while short birth intervals were also associated with even more severe outcomes, such as perinatal mortality, in low-income contexts (Conde-Agudelo et al. 2006). A further meta-analysis by Conde-Agudelo et al. (2007) showed that particularly short and long birth intervals were also associated with risks to maternal health. On the strength of this evidence, the World Health Organization (WHO) has issued universal recommendations that potential mothers should wait at least 24 months after the previous birth before conceiving again (WHO 2006).

In the past five years, however, a series of studies on the effects of birth spacing, comparing siblings who are discordant on birth interval length, have called these long-standing conclusions into question

(Klebanoff 2017). The logic behind this sibling comparison approach is that by controlling for otherwise unobserved shared factors within the family, it is possible to isolate the effects of interval length itself, net of risk factors shared among siblings that are potentially correlated with the length of birth intervals. The first known study to apply a sibling fixed effects analysis to this research question—Ball et al. (2014), using data from Australia—found that the association between short IPIs (defined as 0–5 months) and the risk of preterm birth, LBW, and SGA was almost entirely removed after applying sibling fixed effects. This result was replicated using data from Canada (Hanley et al. 2017). A study using data from Sweden also found that short IPIs, again defined as 0–5 months, were no longer associated with the risk of LBW or SGA when using a fixed effects analysis, though the shortest IPIs did increase the odds of preterm birth (Class et al. 2017). Similar analyses conducted using data from the United States (US) (Shachar et al. 2016; Mayo et al. 2017) have shown that IPIs of 0–5 months are associated with the risk of preterm birth, even after adjusting for shared maternal frailty. A study using data from the Netherlands (Koullali et al. 2017) also found that an IPI of 0–5 months was associated with an increased risk of LBW and preterm birth, though this study conditioned on the mother having had a preterm birth at parity one. Although several studies have found that the very shortest intervals, 0–5 months, increase the risk of preterm birth, Shachar et al. (2016) and Class et al. (2017) also found that IPIs of less than 18 months increased the risk of preterm birth, though not the risk of LBW or SGA. Research on infant mortality in less developed contexts using sibling comparison models has found that short birth intervals matter at lower levels of development but that the negative effects are substantially weaker at higher levels of development (Molitoris 2017; Molitoris et al. 2019).

These studies applying a within-mother comparison approach have also found varying patterns in regard to the very longest IPIs, usually defined as 60+ months. The Swedish study (Class et al. 2017) found that these longest IPIs increased the odds of LBW, preterm, and SGA births, while the Canadian study found that the longest IPIs increased the odds of LBW but not other outcomes, and the Australian study found that they increased the odds of SGA (Ball et al. 2014; Hanley et al. 2017). The Centers for Disease Control and Prevention in the US have suggested that more research is needed to fully understand the relationship between IPI length and health risks for both the mother and the child (Copen et al. 2015).

A related body of research focusing on adult health and mortality (Barclay and Kolk 2018) and the educational and socio-economic consequences of short birth intervals for outcomes later in life (Powell and Steelman 1990, 1993; Buckles and Munnich 2012; Barclay and Kolk 2017) has examined birth intervals with varying results. Typically, adverse effects, such as lower grades or lower educational attainment, are found in studies not adequately controlling for family background (Powell and Steelman 1990, 1993), but these negative effects disappear in studies applying sibling comparisons (Barclay and Kolk 2017, 2018). However, a study using sibling comparisons and data from Ethiopia, India, Peru, and Vietnam found that short spacing was associated with lower height at age one (Miller and Karra 2017). Our examination of childhood health and hospitalization bridges the divide between previous research on perinatal outcomes and previous research focusing on adult outcomes in high-income countries, by examining whether birth interval lengths lead to negative consequences in the sensitive years between birth and age ten, which themselves have been shown to be a critical period for later life health and socio-economic outcomes (Blackwell et al. 2001; Palloni 2006; Haas 2008).

Potential mechanisms linking interval length to poor outcomes

Although the focus of our study is not to identify or evaluate the mechanisms that may link IPI length to perinatal outcomes and child health, a brief review of these potential mechanisms is valuable, in order to contextualize the debate over whether the length of birth intervals should matter or not for child outcomes. Broadly speaking there are three groups of explanations that may account for an association between IPI length and child outcomes: (1) physiological mechanisms; (2) social and environmental mechanisms; and (3) selection and confounding (Conde-Agudelo et al. 2012; Barclay and Kolk 2018). First, physiological mechanisms that may be particularly important in the Swedish context include maternal nutrient depletion, folate depletion, and physiological regression. Maternal nutrient depletion and folate depletion essentially refer to a lack of recovery time between pregnancies, which may mean that the foetus does not have access to all of the resources needed to develop adequately (Smits and Essed 2001; Conde-Agudelo et al. 2012). The physiological regression theory is related to the risks associated with very long IPIs, and is

related to the physical adaptations that women undergo when they first become pregnant (Zhu et al. 1999). A long interval may lead to a physiological transformation for the mother back to the physical state of a woman who has not yet experienced a pregnancy, meaning that the mother is less physically primed for childbearing. This theory may explain why both firstborn children and children born after long intervals may be more likely to be born preterm or LBW, because in neither case is the mother physically primed for childbearing (Kramer 1987; Conde-Agudelo et al. 2006). Second, social and environmental mechanisms that are relevant to the risk of hospitalization essentially revolve around sibling competition for finite parental resources, where short birth intervals are expected to lead to less parental attention and supervision for each child.

Finally, selection and confounding mechanisms refer to the fact that IPI length is not randomly distributed in the population. For example, in the US, short birth intervals are particularly likely to be unintended and to be found among socio-economically and socio-demographically disadvantaged groups, such as teenage mothers and racial or ethnic minority groups (Gemmill and Lindberg 2013). However, short intervals are also common among socio-economically advantaged mothers who delay first childbearing to older ages and need to reduce birth interval length in order to achieve desired fertility (Gemmill and Lindberg 2013). Long birth intervals may also be a consequence of difficulty conceiving and therefore linked to lower underlying fecundity and maternal health. As a result, it is important to adjust for all factors that are shared among siblings in the sibling group, in order to try to isolate the effects of birth intervals net of confounding factors. As already discussed, when this approach is applied, the long-standing conclusions regarding the negative effects of short and long birth intervals are no longer so clear (Ball et al. 2014; Shachar et al. 2016; Barclay and Kolk 2017, 2018; Class et al. 2017; Hanley et al. 2017; Koullali et al. 2017; Molitoris et al. 2019).

Key contributions of this study

In this study, we aim to extend the literature on the association between IPI length and child outcomes in two key ways. First, the most recent studies on this topic applying a sibling comparison design have focused on identifying the main effects of birth intervals on perinatal outcomes, and have ignored the potential for differences across social groups, such as by maternal educational level or among children born to immigrant mothers. Our first key contribution

is to examine whether the association between IPI length and perinatal and child health outcomes varies between these salient social groups. Specifically, we examine whether the patterns differ between mothers with tertiary education and mothers with less than tertiary education, and also between children born to: (1) native-born Swedish mothers; (2) immigrant mothers who were born in the other EU-15 nations, Norway, Switzerland, and non-European OECD countries; (3) immigrant mothers born in Central and Eastern Europe; and (4) immigrant mothers born anywhere else in the world.

Given that immigrant groups make up only a small proportion of the population, negative effects of short birth intervals among this more vulnerable section of the population could be subsumed by the lack of an association in the native-born population in a pooled analysis of the full population. Furthermore, from previous research we know that immigrant mothers and those with low levels of education, even net of the overlap between the two groups, experience worse birth outcomes, with an increased risk of preterm birth and SGA (Rasmussen et al. 1995; Gissler et al. 2003; Luo et al. 2006); however, it should be noted that the differences observed between native-born Swedish mothers and immigrant mothers are smaller than the differences observed between native-borns and immigrants in many other countries (Bollini et al. 2009). For example, some earlier studies in Sweden have reported negligible differences between immigrants and Swedes for severe birth outcomes, such as perinatal death, though this might be explained by the relative rarity of such cases (Smedby and Ericson 1979; Oldenburg et al. 1997).

Better educated mothers and those born in Sweden may have more resources to monitor their own health as well as that of their child, both during pregnancy and afterwards, and to adopt compensatory behaviours that reduce any potential negative effects of short IPIs. Part of the explanation for these differences in birth outcomes is that mothers from immigrant groups and mothers with lower levels of education are more likely to suffer from general socio-economic disadvantage and the concomitant negative health effects (Westerling and Rosén 2002; Wiking et al. 2004; Torssander and Erikson 2009). Research has also suggested that mothers from immigrant groups or with lower levels of education face more barriers in taking full advantage of prenatal care opportunities (Essén et al. 2002; Heaman et al. 2013), and for some immigrant groups there are also socio-cultural differences in what are considered to be acceptable practices during pregnancy (Essén et al. 2002). For example,

research has indicated that East African immigrants in Sweden are more likely to experience longer delays in establishing contact with healthcare centres during pregnancy, as well as to face verbal miscommunication due to lack of interpreters at healthcare centres, among other suboptimal factors (Essén et al. 2002). Previous research has also documented differences in the risk of vitamin deficiencies, which can critically affect the development of the foetus (Sääf et al. 2011). Furthermore, potential incompatibility between the diet in the country of origin and the availability of food items in Sweden, as well as ethnocultural dietary norms and practices related to pregnancy, could potentially lead to food choices that have detrimental health effects (Ahlqvist and Wirfält 2000; Higginbottom et al. 2014). Given that short IPIs can lead to maternal nutrient depletion (Smits and Essed 2001), disparities of this kind may magnify potential differences in negative effects of birth spacing between the children of mothers originating from different countries.

We also know from previous research that educational attainment and country of origin are associated with health behaviours such as smoking and alcohol consumption (Cnattingius et al. 1992; Moussa et al. 2010; Urquia et al. 2013), which greatly increase the risks of poor perinatal outcomes (Cnattingius 2004) and health outcomes for children (Wisborg et al. 1999; Davidson et al. 2010). These differences in health behaviours also vary according to the region of origin of immigrants, which is part of the reason for stratifying our analyses.

Our second key contribution is that we examine a series of outcomes that have not been examined in the previous literature: whether the risks of hospitalization during several age windows of childhood are affected by the length of the birth interval between siblings. We expect the risk of hospitalization from different causes to vary by the age of the child, and therefore we examine the risk of hospitalization in relation to birth interval length in the first year of life and at ages 1–3, 4–6, and 7–10. We argue that this broader focus on health beyond the first year of life makes an important contribution to understanding whether and how birth intervals have long-term negative effects on individuals.

Data

In this study, we use data available at the Umeå SIMSAM Lab combining information from several administrative registers in Sweden (Lindgren et al. 2016), specifically, the Multigenerational Register,

the Medical Birth Register, and the National Patient Register. The Multigenerational Register and the Medical Birth Register include information on demographic events, most importantly the births of siblings and the social background of children and their parents. The National Patient Register provides measures on all in-hospital care with respect to the dates of admission and discharge. We select cohorts of children born in Sweden between 1981 and 2010. For these cohorts, we can access all the relevant maternal and child characteristics during pregnancy and birth. Our primary estimation strategy is based on implementing a sibling fixed effects approach, which requires variance within the sibling group: one-child families do not have an IPI, and there is only one IPI in a two-child family. Therefore, we exclude families with only one or two children. The distribution of sibling group size in our data can be seen in Figure S1. We also exclude firstborn children because the preceding IPI is undefined for firstborns. Finally, we exclude families with multiple births and children in blended families who have any half-siblings. We exclude blended families because we want to ensure that parents' attention and investment is focused on their own biological children rather than any other children they might have, as this could

otherwise confound our results. Overall, taking into account these various exclusion criteria, we estimate sibling fixed effects models based on 499,339 children from 243,906 families. The flow chart in Figure 1 illustrates our analytical sample selection process.

Independent variable: Interpregnancy intervals (IPIs)

We calculate the number of months between the date of birth of the earlier-born sibling and the date of conception of the next sibling. Date of conception is based on information on gestational age at birth available in the Medical Birth Register. It is assessed according to maternal reports on last menstrual period and clinical judgment by the attending paediatrician (Socialstyrelsen 2003). IPIs are categorized as 0–6 months, 7–12 months, 13–18 months, 19–24 months (the reference category), 25–30 months, 31–36 months, 37–42 months, 43–48 months, 49–54 months, 55–60 months, and >60 months.

Dependent variables

We consider a wide range of outcome variables measuring health at birth and during the first ten

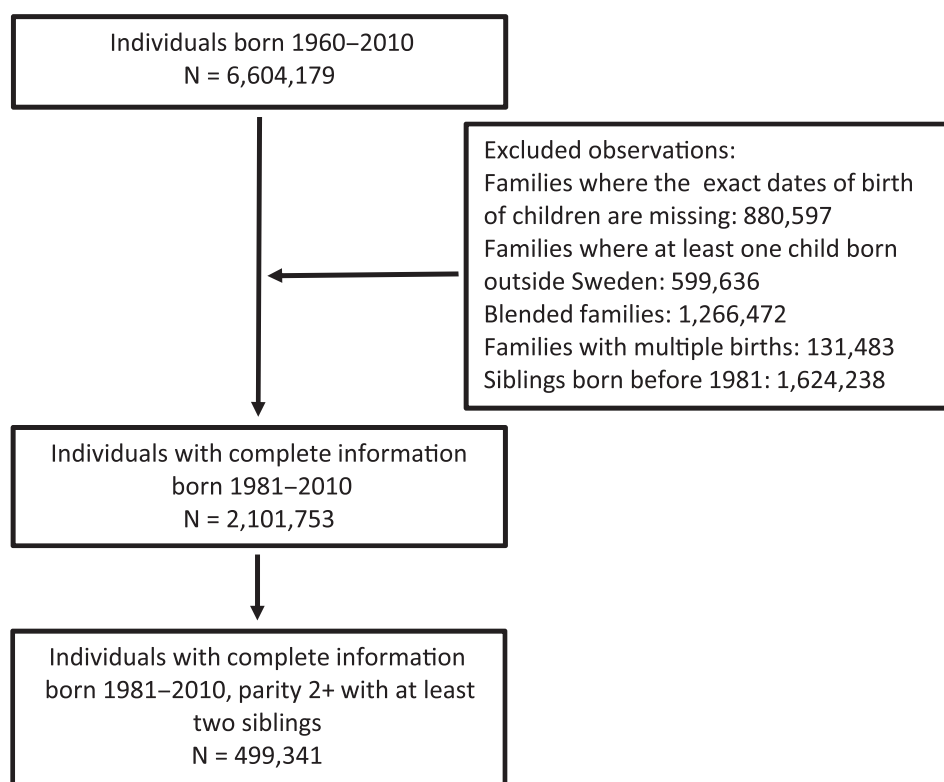


Figure 1 Flow chart illustrating the analytical sample selection process.

Note: Our analytical sample varies slightly between different analyses because of variation in the availability of complete data on each of the six outcome variables, but the total number of unique individuals studied across all six outcomes that we examine is 499,341.

years of a child's life: preterm birth, LBW, and hospitalization during the first ten years of life.

Preterm births. Based on gestational age, we distinguish the following categories of preterm birth: extremely preterm (less than 28 weeks), very preterm (28–31 weeks), and moderate preterm (32–36 weeks). Births after 37 completed weeks of pregnancy are considered as births at term.

Low birth weight. Infants with birth weight less than 2,500 g are classified as children with LBW.

Hospitalization. Based on data on the dates of admission and discharge from the National Patient Register, which includes all inpatient care in Sweden (Ludvigsson et al. 2011), we created four binary indicators of hospitalization, for the first year of life and ages 1–3, 4–6, and 7–10. These indicators take a value of zero if a child was not hospitalized for at least one day at a specific age or a value of one if a child was hospitalized at least once at that age.

Stratified analyses

In this study we also examine how patterns of perinatal outcomes and childhood hospitalization by interpregnancy intervals vary across children born to mothers with different levels of education and different countries of origin. Specifically, we first examine whether the patterns differ between mothers with tertiary education and mothers with less than tertiary education, as defined by the highest level of education achieved by 2010. Second, we examine whether the patterns differ between children born to: (1) native-born Swedish mothers (84 per cent of the analytical sample); (2) immigrant mothers from the other EU-15 nations (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and the United Kingdom), Norway, Switzerland, and non-European OECD countries (4 per cent of the analytical population); (3) immigrant mothers from Central and Eastern Europe (4 per cent of the analytical population); and (4) immigrant mothers from the rest of the world (8 per cent of the analytical population).

Methods

Our primary estimation strategy is based on sibling fixed effects models, where biological children

sharing the same mother and father are treated as repeated observations from the same family. The choice of methodological approach was motivated by the fact that biological siblings experience a similar childhood environment in a way that a randomly selected pair of individuals does not, and introducing the sibling fixed effect allows us to adjust for that shared environment. In addition, the same family-specific factors that determine IPI length may affect the risk of both adverse birth outcomes and children's health problems leading to hospitalization. By using fixed effects sibling models, we control for all shared family-specific factors, including unobserved factors, which might otherwise bias our estimates. This allows us to estimate the net effect of IPI length on the various outcome variables that we examine.

For our analysis of the pooled population, we contrast the results from the fixed effects models with the results from ordinary least squares (OLS) models on binary outcomes (i.e. linear probability models), with the standard errors adjusted for clustering at the sibling group level. For each of our six outcome variables, we estimate the following two models:

$$y_i = \alpha + \beta_1 \text{IPI}_i + \beta_2 \text{Sex}_i + \beta_3 \text{Birth Order}_i + \beta_4 \text{MatAge}_i + \beta_5 \text{Size} + \varepsilon \quad (1)$$

$$y_{ij} = \alpha_j + \beta_1 \text{IPI}_{ij} + \beta_2 \text{Sex}_{ij} + \beta_3 \text{Birth Order}_{ij} + \beta_4 \text{Mat Age}_{ij} + \varepsilon \quad (2)$$

where y_{ij} is the outcome for individual i in sibling group j for each of our six outcome variables. In Model (1) we use a linear regression model to examine how the IPI length experienced by individual i is associated with each outcome variable, adjusting for sex, birth order, maternal age at time of birth, and sibling group size, all of which covary with IPI length and the various outcomes that we study. IPI is entered into the model as a series of eleven dummy variables based on six-month categories for IPI length, from 0–6 months up to >60 months. In Model (1), our analysis population is second- and later-born children in sibling groups with at least three children; that is, we exclude firstborns because there is no value for the length of the preceding interval. In Model (2), we introduce the sibling fixed effect α_j and remove the control for sibling group size because that is adjusted for in the fixed effects approach. We use the same analysis sample for Model (2) as for Model (1).

For our analyses of children born to mothers by country of origin and educational level, we present the results from only our fixed effects models

(Model (2)). In these analyses we run separate models by mother country of origin and educational level.

Results

Descriptive statistics

Table 1 shows summary statistics for the six main outcomes that we focus on in this paper: LBW, preterm birth, SGA, and hospitalization before the first birthday and at ages 1–3, 4–6, and 7–10. Detailed descriptive tables can be seen in the supplementary material, in Tables S1–S6. As can be seen in Table 1, the incidence of LBW, preterm birth, hospitalization before the first birthday, and hospitalization at ages 4–6 and 7–10, is highest among children with IPIs of less than 13 months (particularly less than seven months). The incidence of LBW, preterm birth, and hospitalization before the first birthday is also elevated among children born after IPIs of >60 months. For hospitalizations at ages 1–3, the incidence is highest among children born after the shortest IPIs, but is not elevated for children born after the longest IPIs of more than five years.

Low birth weight

The estimates for the relationship between IPIs and the probability of LBW are shown in Figure 2. Please take care to note that the y-axis scale varies between panels (a), (b), and (c) across Figures 2–7. Full results tables with detailed output for the results underlying Figure 2 can be found in Tables S7–S9 in the supplementary material; these tables also include information from F-tests, where we test the joint significance of including the length of IPIs in our regression models.

Panel (a) in Figure 2 contrasts the results from the within-family sibling comparison (i.e. Model 2, the fixed effects model) with those from the regular OLS models (Model 1) that do not adjust for unobserved factors that are correlated with both birth interval length and the risk of LBW. Panel (a) shows that both the sibling comparison and OLS models indicate that IPIs shorter than seven months are associated with an increase in the probability of LBW. Indeed, the fixed effects models show that the probability is 0.005 higher relative to the reference category. Taking the baseline probability (0.019) into account, this is a relative increase in the probability of LBW of 25.2 per cent. However, the sibling fixed effects models do not indicate that

long IPIs are associated with any significantly increased risk of LBW.

Panel (b), which is based on fixed effects sibling comparison models, shows the results stratified by maternal educational level. It shows that among mothers with less than tertiary education, IPIs both shorter than seven months and longer than 60 months are associated with an increased risk of LBW. Hence, our results indicate that the negative effects of very short and very long intervals shown in the fixed effects estimates in panel (a) appear somewhat more common for children with a more disadvantaged parental background.

Panel (c) shows the results stratified by maternal country of origin. These show some notable within-immigrant-group differences in the effects of short birth intervals. For example, children born after especially short IPIs (i.e. less than seven months) to mothers from Central and Eastern Europe are significantly more likely to be born with LBW than other children born to mothers from Central and Eastern Europe (after longer IPIs). However, given the overlapping confidence intervals, we cannot say that there are statistically significant between-immigrant-group differences in the negative effects of especially short or especially long birth intervals.

Preterm birth

The results from our models examining the relationship between IPIs and the probability of preterm birth are shown in Figure 3. Full results tables with detailed output for the results underlying Figure 3 can be found in Tables S10–S12 in the supplementary material. Panel (a) shows that estimates from both the OLS and fixed effects models indicate an increased risk of preterm birth for children born after IPIs of less than 13 months and >60 months relative to the reference category of 19–24 months. Relative to the baseline probability (0.035), the relative probability after an IPI of 0–6 months is 46.6 per cent higher, and the relative probability after an IPI of >60 months is 17.0 per cent higher. Panel (b) shows that the increased probability of preterm birth after short IPIs is similar regardless of the mother's educational level, but for long intervals is only observed among mothers with less than tertiary education. Panel (c) of Figure 3 shows point estimates indicating an increased probability of preterm birth after an IPI of >60 months among children born to all mothers, with the exception of those originating from Central and Eastern Europe.

Table 1 Summary statistics for low birth weight (LBW), preterm birth, and hospitalization before first birthday and at ages 1–3, 4–6, and 7–10, by length of preceding interpregnancy interval (IPI): children born in Sweden 1981–2010

IPI length (months)	LBW (percentage)	Preterm (percentage)	Hospitalized aged 0 (percentage)	Hospitalized aged 1–3 (percentage)	Hospitalized aged 4–6 (percentage)	Hospitalized aged 7–10 (percentage)
0–6	2.9	5.8	12.1	19.2	10.1	9.0
7–12	2.9	3.8	10.3	18.0	9.8	8.6
13–18	1.9	3.1	10.2	17.5	9.8	8.3
19–24	1.5	3.1	10.1	17.6	9.7	8.4
25–30	1.7	3.1	10.0	17.3	9.5	8.2
31–36	1.7	3.4	10.0	18.1	9.3	7.9
37–42	2.0	3.3	10.6	18.0	8.8	7.7
43–48	1.9	3.4	10.6	18.1	8.6	7.5
49–54	1.8	3.4	10.7	18.4	8.2	7.4
55–60	2.0	3.8	10.9	18.4	8.6	7.1
>60	2.2	4.5	12.1	17.9	8.3	6.6
All children	1.9	3.5	10.5	17.8	9.3	8.0

Note: Further details available in the supplementary material.
 Source: Swedish register data; authors' own calculations.

Hospitalization before the first birthday

Figure 4 shows the results for our first analyses of health outcomes beyond those measured directly after birth, focusing on hospitalization during the first year of life. Full results tables with detailed output for the results underlying Figure 4 can be

found in Tables S13–S15 in the supplementary material. Panel (a) contrasts the results from our fixed effects models with the regular OLS models on the same sample population. The between-family comparison shows an elevated probability of hospitalization before age one for those born after IPIs of less than seven months relative to the

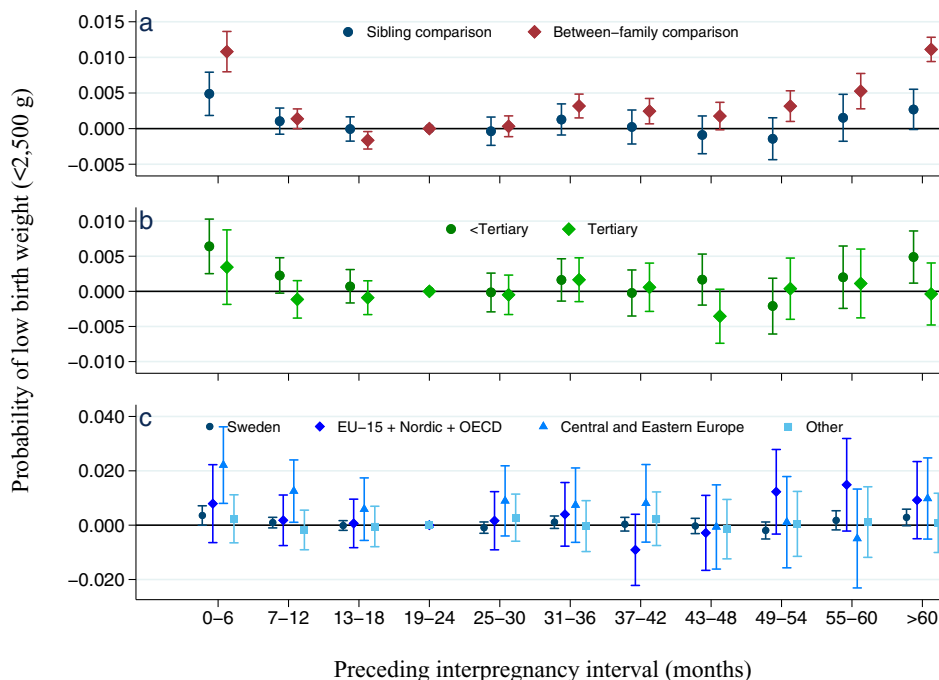


Figure 2 Relationship between IPI length and the probability of low birth weight: (a) in the pooled sample (OLS vs. fixed effects models); (b) by maternal educational level (fixed effects models); and (c) by maternal immigrant status (fixed effects models): children born in Sweden 1981–2010.

Notes: Error bars are 95 per cent confidence intervals. Reference category is an IPI of 19–24 months.
 Source: Swedish register data; authors' own calculations.

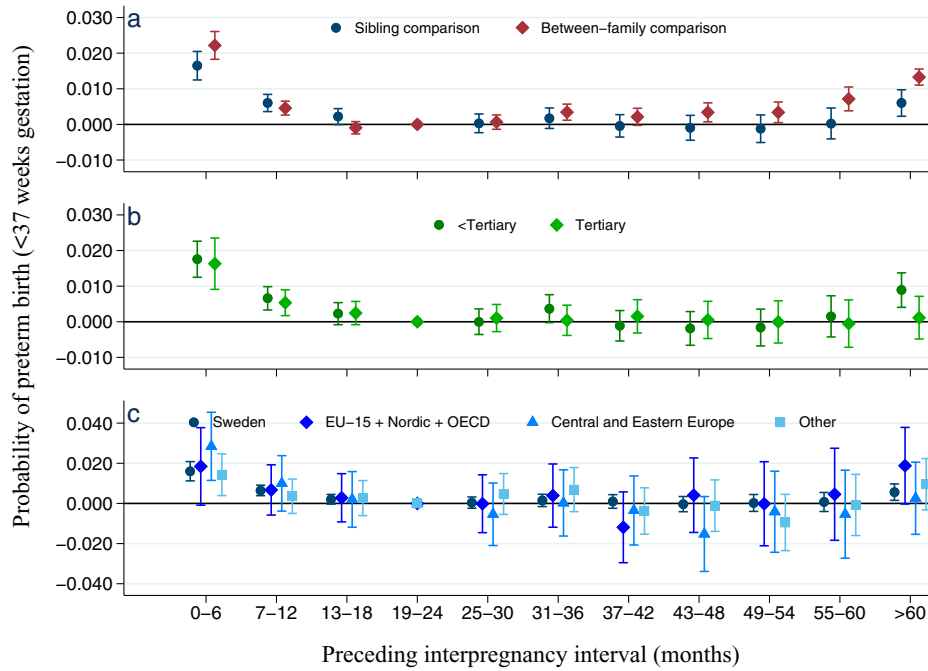


Figure 3 Relationship between IPI length and the probability of preterm birth: (a) in the pooled sample (OLS vs. fixed effects models); (b) by maternal educational level (fixed effects models); and (c) by maternal immigrant status (fixed effects models): children born in Sweden 1981–2010.

Notes: Error bars are 95 per cent confidence intervals. The reference category is an IPI of 19–24 months.

Source: As for Figure 2.

reference category, but no other meaningful relative differences. The fixed effects model, however, shows that short IPIs are barely related to the probability of hospitalization, but IPIs of 43 months or longer *decrease* the risk of hospitalization. For example, relative to the baseline probability (0.105), the relative probability of hospitalization after an IPI of >60 months is 31.1 per cent lower. The results shown in panel (b) support the conclusion that this is consistent regardless of maternal educational level. Panel (c), however, suggests that this pattern is visible only for Swedish mothers and those from non-OECD and non-European countries.

Hospitalization at ages 1–3

Figure 5 shows the results from models examining the relationship between the length of the preceding IPI and hospitalization at ages 1–3. Full results tables with detailed output for the results underlying Figure 5 can be found in Tables S16–S18 in the supplementary material. The between-family comparisons in panel (a) show that both very short IPIs and longer IPIs are associated with an increased probability of hospitalization at ages 1–3, while the fixed effects results show that only IPIs of 31 months or longer

are associated with an increased probability of hospitalization at these ages. For example, relative to the baseline probability (0.178), the relative probability of hospitalization after an IPI of >60 months is 9.0 per cent higher. Panel (b) shows that the pattern observed in the pooled sibling comparison analysis is consistent regardless of maternal educational level, while panel (c) suggests that this pattern is driven by Swedish mothers rather than mothers born outside Sweden.

Hospitalization at ages 4–6

The results from our analyses of the relationship between the IPI length and hospitalization at ages 4–6 are shown in Figure 6. Full results tables with detailed output for the results underlying Figure 6 can be found in Tables S19–S21 in the supplementary material. Panel (a) in Figure 6 shows that the association between IPI length and the probability of hospitalization is weaker at ages 4–6 than at ages 1–3, though there is some evidence that shorter intervals, as well as IPIs of >60 months, increase the probability of hospitalization. For example, relative to the baseline probability (0.093), the relative probability of hospitalization

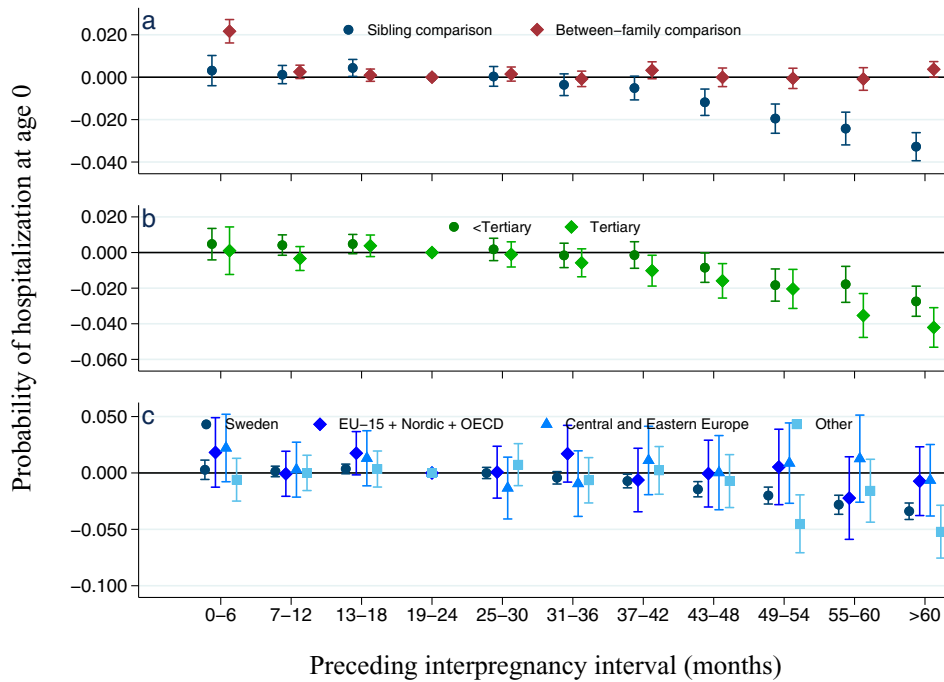


Figure 4 Relationship between IPI length and the probability of hospitalization before first birthday: (a) in the pooled sample (OLS vs. fixed effects models); (b) by maternal educational level (fixed effects models); and (c) by maternal immigrant status (fixed effects models): children born in Sweden 1981–2010.

Notes: Error bars are 95 per cent confidence intervals. The reference category is an IPI of 19–24 months.

Source: As for Figure 2.

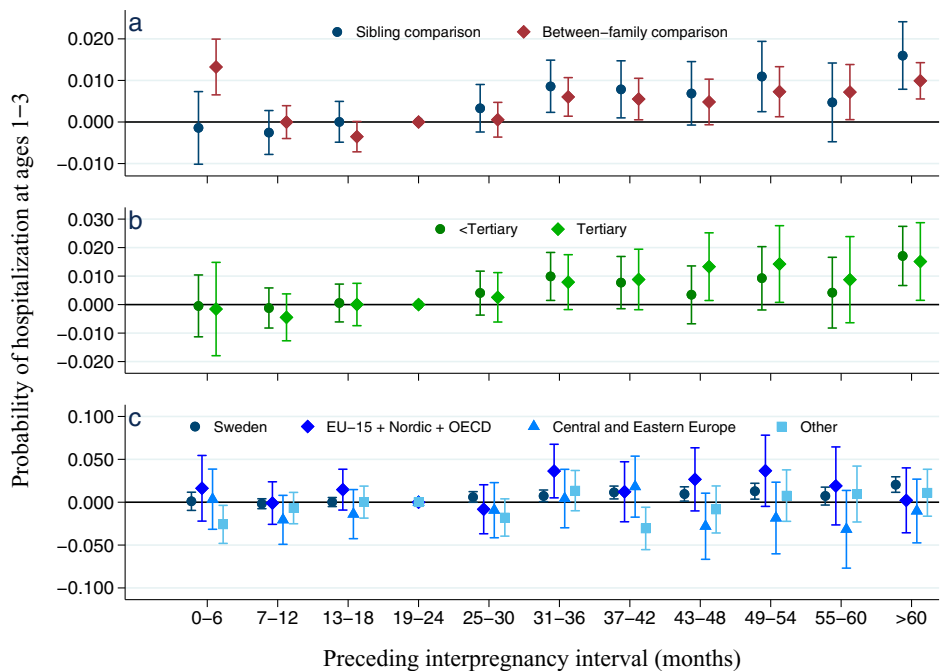


Figure 5 Relationship between IPI length and the probability of hospitalization at ages 1–3: (a) in the pooled sample (OLS vs. fixed effects models); (b) by maternal educational level (fixed effects models); and (c) by maternal immigrant status (fixed effects models): children born in Sweden 1981–2010.

Notes: Error bars are 95 per cent confidence intervals. The reference category is an IPI of 19–24 months.

Source: As for Figure 2.

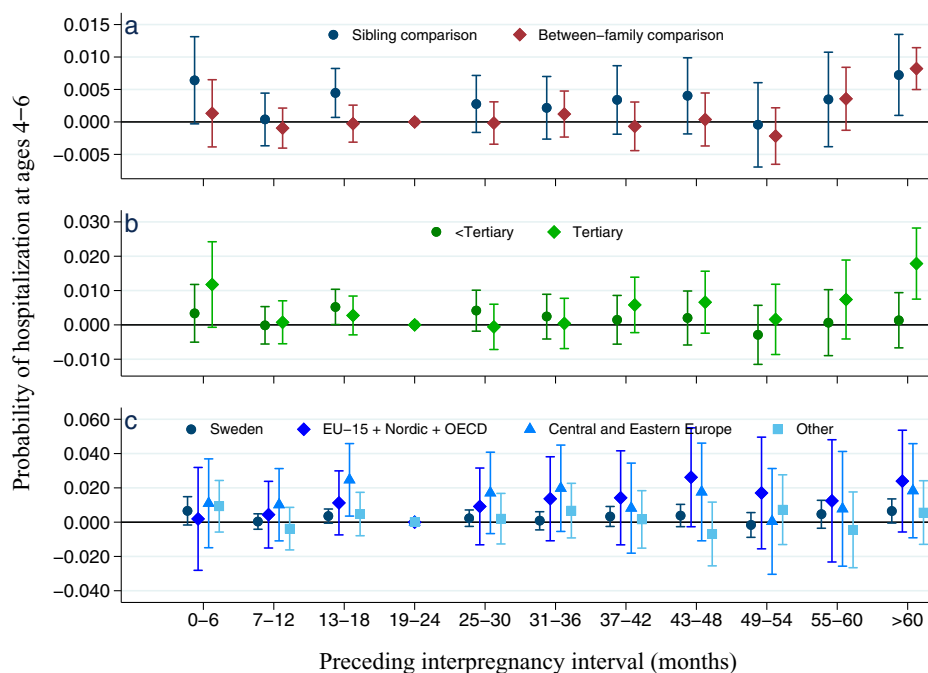


Figure 6 Relationship between IPI length and the probability of hospitalization at ages 4–6: (a) in the pooled sample (OLS vs. fixed effects models); (b) by maternal educational level (fixed effects models); and (c) by maternal immigrant status (fixed effects models): children born in Sweden 1981–2010.

Notes: Error bars are 95 per cent confidence intervals. The reference category is an IPI of 19–24 months.

Source: As for Figure 2.

after an IPI of >60 months is 7.8 per cent higher. The results from models stratified by maternal educational level, in panel (b), show that among children born to mothers with a tertiary education, the probability of hospitalization is higher for those born after IPIs of >60 months. We do not observe those within-group differences among children born to mothers with less than a tertiary education. The results shown in panel (c) do not allow us to infer that there are significant differences across immigrant groups in the effects of very long IPIs on the probability of hospitalization at ages 4–6.

Hospitalization at ages 7–10

The results for our analyses of hospitalization at later childhood ages are consistent with the weakening relationship between the length of IPIs and probability of hospitalization at ages 4–6. Figure 7 shows that there are no clear patterns of hospitalization by the IPI length in either the pooled sample, by maternal educational level, or by the country of origin of the mother. Full results tables with detailed output for the results underlying Figure 7 can be found in Tables S22–S24 in the supplementary material.

Supplementary analyses

We also conducted a number of supplementary analyses. Previous research has shown that children born ‘early-term’ (37–38 weeks of gestation) experience relatively worse long-term health outcomes than children born ‘late-term’ (39+ weeks). We found that children born after intervals shorter than 19 months were particularly less likely to be born late-term, and this pattern persisted regardless of the educational level or country of origin of the mother. These results can be seen in Tables S25–S27 in the supplementary material. We also conducted several additional analyses to check the robustness of our results to restricting the analytical sample to families with exactly three children (Tables S28–S33), and with additional controls for birth month and the sex composition of the sibling group at the time of birth (Tables S34–S39). Those results were fully consistent with the results presented earlier.

Discussion

In this study we have examined the effects of IPI length on the probability of poor perinatal outcomes and the risk of hospitalization during childhood, as

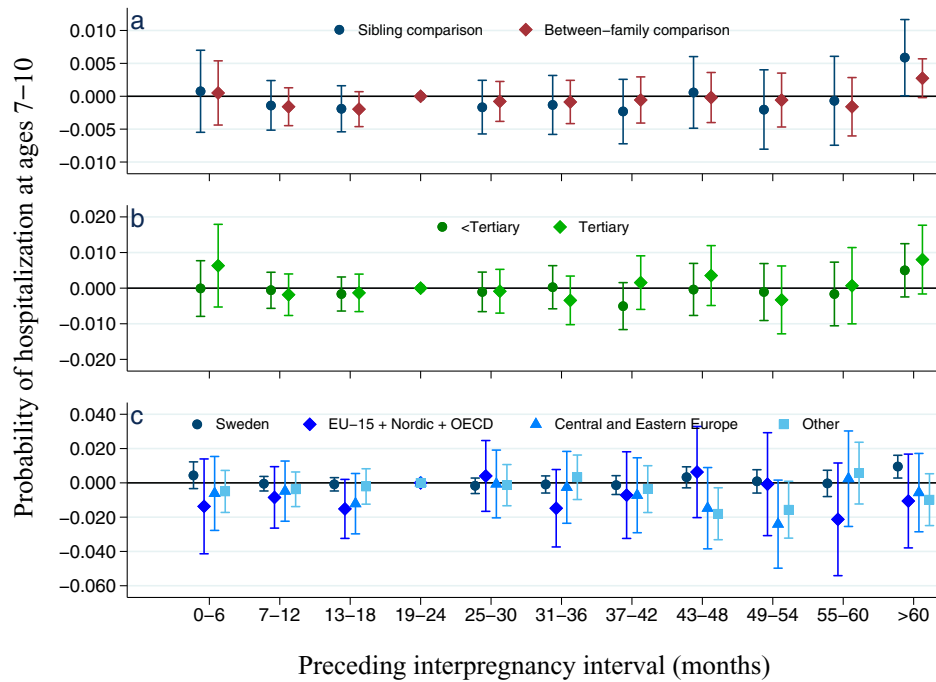


Figure 7 Relationship between IPI length and the probability of hospitalization at ages 7–10: (a) in the pooled sample (OLS vs. fixed effects models); (b) by maternal educational level (fixed effects models); and (c) by maternal immigrant status (fixed effects models): children born in Sweden 1981–2010.

Notes: Error bars are 95 per cent confidence intervals. The reference category is an IPI of 19–24 months.

Source: As for Figure 2.

well as how these patterns vary according to the mother's level of education and country of origin.

Overall, we found that after controlling for shared factors within the sibling group, IPI length does not generally influence the probability of the child experiencing poor perinatal outcomes. The exceptions to this are that very short and very long IPIs do increase the probabilities of LBW and preterm birth. For example, the probabilities of LBW and preterm birth for children conceived after IPIs of less than seven months are 25.2 and 46.6 per cent higher, respectively, than the probabilities of LBW and preterm birth for children conceived after IPIs of 19–24 months. However, it should be said that these very short IPIs are relatively uncommon, accounting for only 2.9 per cent of intervals in our analytical population. As a consequence of the low prevalence of such short IPIs, the overall population health impact of these short intervals is likely to be small.

These results address the recent series of studies that have raised questions about whether IPI length matters for perinatal health in high-income countries. These studies have shown that very short IPIs do not matter for the risk of low birth weight, preterm birth, and being small for gestational age in Australia (Ball et al. 2014) and Canada (Hanley et al. 2017) after

adjusting for shared risk factors within the sibling group. However, our results support those of other recent studies using data from the US (Shachar et al. 2016; Mayo et al. 2017) and the Netherlands (Koullali et al. 2017), which found that very short intervals (0–5 months) were associated with the risk of LBW, preterm birth, or both, even after adjusting for shared maternal frailty. Some of these studies, such as the work using Canadian data, have also found that very long IPIs (60+ months) increase the risk of LBW, as our study did. Based on the results of this study, we would like to echo the recent calls for more research on this topic (e.g. Copen et al. 2015; Klebanoff 2017), and particularly for further work to explain why birth intervals seem to matter for perinatal health in some high-income contexts but not others.

In this study we also extended the literature by examining health outcomes during childhood in relation to IPI length; this had not been done before with sibling comparison models. We examined hospitalization during several different age windows in the first ten years of childhood. The results from these analyses suggest that IPI length is more important for the probability of hospitalization before age four. Intriguingly, our estimates suggest that longer birth intervals are protective against hospitalization

in the first year of life, but that they increase the risk of hospitalization at later ages, up to age seven. This pattern is difficult to explain, but may be related to medical practice norms regarding how sick infants are treated. In Sweden doctors typically prefer a child to be at home with the parents if at all possible, rather than being hospitalized (Socialstyrelsen 1993; Braveman et al. 1995; Johansson et al. 2010). Furthermore, those infants who are identified with health problems at birth are more likely to be kept at the hospital until the problems are solved, meaning that this hospitalization would not be recorded as a separate event from the hospital birth itself. Although we can only speculate, this might explain why children born after very short or very long intervals experience worse perinatal outcomes, but also a lower risk of hospitalization in the first year of life.

We also extended previous research on this topic by examining whether there are differences in the effects of IPIs on perinatal and child health by maternal educational level and maternal country of origin. Overall, we did not find significant differences in the effects of maternal educational level or country of origin on the probability of poor perinatal outcomes or hospitalization during childhood. Given known differences in factors such as health behaviours and opportunities for navigating the health-care system by maternal educational level and country of origin, it is interesting that we did not find many differences in the effects of IPI length on perinatal outcomes across these different social categories. This suggests either that these differences in behaviour across social groups are smaller than believed, or that they have relatively little impact on the risk of poor perinatal and child health outcomes after especially short or long IPIs in a high-income setting such as Sweden. It might also be the case that the medical and social system in Sweden is able to moderate such differences in maternal health and maternal health behaviours adequately through both prenatal and postnatal care. However, we also note that our analyses by maternal country of origin were underpowered, despite using the population registers, and this may be the main reason for our not being able to detect statistically significant differences in child health outcomes by maternal country of origin.

Examining the effects of IPI length on childhood hospitalization in this study also allowed us to bridge the gap between recent research using a sibling comparison approach on perinatal health outcomes and research on long-term educational, socio-economic, and health outcomes in Sweden. Previous research has shown that even especially short and

especially long birth intervals are not associated with poor long-term educational, socio-economic, and health outcomes in Sweden (Barclay and Kolk 2017, 2018), but it is not clear whether this previous finding was because birth intervals did not matter even for perinatal health outcomes in contemporary Sweden, or whether the null finding for the long-term effects might be due to some kind of moderating effect of the Swedish welfare state in negating disadvantage early in life. Our results largely confirm previous results on the small impact of birth intervals on children's outcomes, though we found a substantial negative effect of extremely short IPIs on perinatal outcomes. Given that previous literature has shown that LBW and preterm birth can have serious long-term consequences for health and for educational and socio-economic attainment (Conley and Bennett 2000; Black et al. 2007; Swamy et al. 2008), our study suggests that there may be a moderating, ameliorating effect of medical, social, or environmental conditions in Sweden that breaks the link between the negative effects of extremely short IPIs on perinatal outcomes and on poor long-term socio-economic, educational, and health outcomes.

Although this study has many strengths, it is also important to acknowledge the limitations. Chief among these is that, in order to estimate our fixed effects models, we needed to focus on families with at least three children because of the requirement to observe variance in IPI length within the sibling group. Although excluding one-child families was unavoidable as we could not observe any birth interval in this group, we also excluded two-child families, the most common sibling group size in Sweden. There is an inevitable trade-off between the generalizability of our findings to the full population and the great benefit of being able to control for all unobserved factors shared among siblings that might be driving the relationship between IPI length and perinatal and child health. Given our chosen approach, we need to be careful about generalizing our findings to two-child sibling groups, as it is possible that the effects of IPIs on perinatal and child health are quite different in two-child families in comparison to families with three or more children. Nevertheless, we feel that this is a relatively small problem. First, we would expect the mechanisms that could link IPI length to perinatal and child health, such as maternal nutrient depletion or sibling competition for resources, to be more severe in larger sibling groups than smaller ones. Second, by studying families with at least three children we did still study the majority of empirically observed IPIs in the population, as larger sibling groups contribute

far more intervals than two-child sibling groups. For example, a four-child sibling group provides three times as many intervals as a two-child sibling group. Another limitation of our analysis is that the fixed effects analysis did not control for factors that vary within the family. Although we did control for some factors that vary within the family, such as maternal age at birth and birth order, there may be time-varying factors not captured by those variables. If, for example, there are negative spillover effects of having another sibling with LBW, this would not necessarily have been adjusted for in our analysis.

To conclude, we feel that the strengths of this study deserve further emphasis. We examined childhood health in a research area previously mainly concerned with perinatal outcomes. We also examined whether specific social groups drive the average pattern of association between IPI length and perinatal and child health in the general population, and we did so using high-quality population registers and sophisticated statistical methods that allowed us to adjust for all unobserved factors that are shared among siblings in our fixed effects approach. In doing so we have contributed to an important and ongoing debate about the relative importance of IPI length for the health of children in high-income societies.

Notes and acknowledgements

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