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Abstract

This paper analyzes the long-term effects of potentially avoidable C-sections on children's health. Using Finnish administrative data, we document that physicians perform more unplanned C-sections during their regular working hours on days that precede a weekend or public holiday and use this exogenous variation as an instrument for C-sections. We supplement our instrumental variables results with a differences-in-differences estimation that exploits variation in birth mode within sibling pairs and across families. Our results suggest that avoidable unplanned C-sections increase the risk of asthma, but do not affect other immune-mediated disorders previously associated with C-sections.

Key words: c-section, child health, natural experiment, instrumental variables, family fixed effects

JEL classes: I10, I12, I18, J13

1 Introduction

There is little doubt that prenatal health and early childhood circumstances can have long-term effects on mortality, morbidity and human capital development. The theory of the developmental origins of adult health and disease has proven to describe a surprisingly general phenomenon. The effects of prenatal health conditions and early-life events extend to a wide spectrum of educational, cognitive, behavioral and demographic outcomes (Almond, Currie and Duque, 2018).

In human development, the transition from fetal to newborn life at birth is an abrupt event that represents major physiological challenges for the neonates. There is accumulating evidence that many medical and operative interventions at birth are associated with long-term health. Most notably, cesarean delivery for low-risk pregnancies is associated with a wide variety of adverse short- and long-term health outcomes. However, the causal nature of these relationships has received little attention.

The most prominent mechanism thought to mediate the long-term effects of cesarean sections on health and disease emphasizes the importance of early exposure to a diverse range of microbes that adjust the human immune system to appropriately react to extrauterine environment. This general class of mechanisms is often dubbed either as the hygiene hypothesis (Strachan, 1989) or the old friends hypothesis (Scudellari, 2017). According to these hypotheses, children born by cesarean section lack the beneficial exposure to their mother's vaginal microbiome and are more prone to develop immune-mediated diseases.

Cesarean section is the most commonly performed major surgery in many countries. Understanding the consequences of cesarean sections on later-life health and human capital development is important from a number of perspectives varying from clinical decision making to economic and health policy. The rapidly growing incidence of cesarean sections across the globe suggests that even small increases in mortality and morbidity due to C-sections would lead to large reductions in life expectancy and substantial losses of human welfare.[1]

[1] Cesarean section rates have increased in the US from 20.7 percent in 1996 to 32.9 percent in 2009 (Currie and Macleod, 2017). In OECD countries, the rate of cesarean sections has increased from 20 percent in 2000 to 25 percent in 2013 (OECD, 2013). Currently, the highest rates of cesarean sections are reported in many of the world's most populous countries including among others China (41.3 percent in 2016) and Brazil (55.6 percent in 2015). Boerma et al. (2018) review the disparities in C-section use around the world.

This paper provides new evidence on the effect of potentially avoidable cesarean sections on several relevant health outcomes. To identify the causal effect and abstract from cases where C-sections respond to a clear medical indication, we exploit variation in physician demand for leisure. We show that the probability of unscheduled C-section increases substantially during the normal working hours (8am – 4pm) on working days that precede a leisure day. Importantly, we find that these excess C-sections are not driven either by selection of different mothers giving birth at these times or by advancing births that would have been cesarean deliveries in any event.

Using fine grained data on birth times and intrapartum diagnoses, we show that the increased likelihood of cesarean sections during the normal working hours on days that precede a leisure day is coupled with the increased use of more discretionary diagnoses. Moreover, we observe that physician demand for leisure does not affect mothers who are in the medical profession. Our data lend substantial support for the contention that the excess numbers of unplanned cesarean deliveries observed during the normal working hours on days that precede a leisure day are largely driven by physician incentives. We use this time variation as an instrument for C-section. We provide a detailed discussion and numerous robustness checks to support the validity of the required identification assumptions.

We investigate the effects of cesarean sections on infant and children outcomes using a comprehensive and precise administrative data resource which includes birth and health records for all children born in Finland between 1990 and 2014. We follow entire birth cohorts from birth to teenage years and use detailed diagnosis data to study the causal effects of cesarean sections on children's health. We focus on outcomes whose onset is hypothesized to be influenced by cesarean delivery: asthma and other atopic diseases, type 1 diabetes and obesity. These are among the most common chronic conditions in childhood (Torpy, 2010).[2]

Our instrumental variable estimates suggest that avoidable C-sections increase the probability of asthma diagnosis from early childhood onward. This effect is clinically and economically rele-

[2]Understanding and quantifying the potential contribution of C-sections to the development of these diseases is not limited to medical practice and health policy. Chronic health conditions cause an immense financial burden to households and public health care financing. The total cost of asthma in the working age population was estimated to be $24.7 billion during 1999-2002 in Europe (Global Asthma Network, 2018). The two other atopic diseases we investigate imply high costs: atopic dermatitis has been estimated to cost at least $5.3 billion (in 2015 USD) in the US (Drucker et al., 2017). The estimated annual cost of allergic rhinitis is in the range of $2–5 billion (in 2003 USD) (Reed, Lee and McCrory, 2004). Type 1 diabetes has been found to cost $14.4 billion a year in medical costs and lost income in the US (Tao et al., 2010). Finally, childhood obesity, which has been on the rise in recent years, has been calculated to imply $19,000 per child in lifetime medical costs in the US (Finkelstein, Graham and Malhotra, 2014).

vant. However, we do not find consistent evidence that cesarean sections affect the probability of developing atopic diseases at large, type 1 diabetes or obesity.

We complement our instrumental variables estimates using a differences-in-differences model with family fixed effects that compares the health gap between siblings in families where the second child was born by unplanned C-section with the health gap between siblings who were born by vaginal delivery. The results from our supplementary empirical strategy support our main findings. These estimates suggest that unplanned C-sections increase the risk of childhood asthma and enable to rule out meaningful effects on other atopic diseases, type 1 diabetes and obesity. We provide several sensitivity checks that suggest that the effect on asthma is unlikely to be explained by negative selection.

Our results are consistent with the hypothesis that the mode of delivery may influence the development of the immune system and have long-term effects on health and disease. However, our results paint a more nuanced picture about the long-term effects of cesarean deliveries than existing evidence based mostly on associations. Our findings suggest that C-sections cause a much narrower spectrum of diseases than currently hypothesized and call for a careful analysis on the relationships between the delivery mode and long-term health.

Our paper relates to an important literature estimating the effects of early interventions on long-term health and human capital development. Moreover, we contribute at least in three ways to a nascent economics literature on the effects of treatment choices at birth. First, we investigate the long-term effects of unplanned C-sections on children. To evaluate the costs and benefits of C-sections, it is crucial to investigate long-term effects, as potential alterations of the immune system and long-run consequences of C-sections are not necessarily visible at birth and in early childhood. Moreover, we report age-by-age estimates for entire cohorts from birth to teenage years and provide evidence about the effects of early life events during the middle childhood, thus expanding our knowledge about the "missing middle" years.[3] Existing papers investigating the effects of potentially avoidable C-sections have concentrated on neonatal outcomes or short-term

[3] Almond, Currie and Duque (2018) discuss that, due to data availability, most of the literature analyzes the effect of early life events on birth or adult outcomes. This implies that we have little knowledge about how developmental trajectories are affected by policies or shocks experienced over the life course. They refer to this gap in the literature as the "missing middle".

effects.[4] Costa-Ramón et al. (2018) investigate the effects of cesarean sections on neonatal health using time variation in unplanned C-section rates. Card, Fenizia and Silver (2019) study the short-term health effects of hospital delivery practices using relative distance from a mother's home to hospitals with high and low C-sections rates.[5]

Second, we study the effects of discretionary unplanned C-sections that could potentially be avoided, while existing papers have not been able to separate planned (elective) and unplanned C-sections or have concentrated on C-sections with a clear medical indication. Hannah et al. (2000), Jensen and Wüst (2015) and Mühlrad (2017) show that breech babies can benefit from C-section delivery. However, these results concern medically necessary C-sections in a specific high-risk group and do not readily generalize to cesarean deliveries in general or for avoidable unplanned C-sections, in particular. While C-sections are often life-saving at the top of the risk distribution (Currie and Macleod, 2017), more evidence is required about the effects of discretionary C-sections that could be potentially avoidable.

Third, to evaluate causal effects of C-sections, we use two different identification strategies based on somewhat different assumptions. Our instrumental variable strategy builds on previous work using time variation in C-section rates in combination with high-quality administrative data. Moreover, we employ a differences-in-differences research design that has not been used in previous papers on C-sections. In addition, for both methods we provide several pieces of evidence that support the credibility of the identification assumptions. Thus, by using two different strategies, we hope to provide more reliable evidence on the causal effects of avoidable unscheduled interventions at birth on children both in the short and long run.

The paper is structured as follows. Section 2 provides background information about the biological mechanisms hypothesized to mediate the effects of mode of delivery on infant outcomes, about the different types of cesarean sections, and about the institutional context of our analysis. Section 3 introduces the data, provides key descriptive statistics and lays out our econometric approach.

[4] To our knowledge, the only paper looking at longer-term effects is by Jachetta (2015), who explores the relation of cesarean delivery with hospitalizations using regional variation in medical malpractice insurance premia in the US as an instrument for C-sections. However, the instrument used in that paper does not necessarily allow for credible causal inference, since the author finds that higher premia also predict delayed prenatal care, lower birth weight and reduced gestational age.

[5] A few papers have also examined the effects of cesarean sections on mothers. Halla et al. (2016) study the effects of C-sections on fertility and maternal labor supply. Tonei (2019) studies the impact on mental health for mothers with breech babies who undergo a C-section. Our findings on children health complement these maternal results and contribute to obtaining a more complete picture of the effect of cesarean sections.

Section 4 reports our main results. Section 5 presents robustness checks and additional evidence to support our main conclusions. The last section concludes.

2 Background

2.1 Mechanisms

A large body of literature documents the developmental origins of health and disease. The process of labor can be seen as one crucial step in adaptation to the extrauterine environment. The prevailing evidence highlights the role of vaginal delivery as an important early programming event with potentially life-long consequences (Hyde et al., 2012). While there is strong consensus that medically indicated cesarean sections decrease the risk of fetal death at birth, the absence or modification of vaginal delivery has been linked to several adverse health outcomes and anomalies in human development. In the following, we summarize some of the most widely acknowledged findings to understand how C-sections might have long-lasting effects on health and human development.

It is well-recognized that early exposure to microbes is necessary to train the human immune system to react appropriately to environmental stimulation. The original formulation of the theory, dubbed as the hygiene hypothesis, states that the lack of early childhood exposure to infectious agents and symbiotic microbes increases susceptibility to multiple autoimmune diseases by suppressing the natural development of the immune system (Strachan, 1989). Lately, refinements to the original formulation, known as the old friends hypothesis, have challenged the role of infectious pathogens and highlight the importance of early exposure to a diverse range of harmless microbes to strengthen the human immune system and combat the threat of environmental pathogens (Scudellari, 2017).

Mode of delivery may affect early exposure to microbes through several channels. First, bacteria from the mother and the surrounding environment colonize the infant's gut during birth (Neu and Rushing, 2011). Exposure to the maternal vaginal microbiota is interrupted in a cesarean birth and externally derived environmental bacteria play an important role for the infants' intestinal colonization. Consequently, infants delivered by C-sections acquire a microbiota that differs from that of vaginally delivered infants (Dominguez-Bello et al., 2016). Second, the transfer of microbiota continues through breastfeeding after birth. Breast milk contains a number of bioactive components that can have an important impact on infant's microbiota composition and health (Collado et al., 2015). The negative association between cesarean sections and the initiation of breastfeeding provides an additional mechanism to explain the differences in microbiota by type of birth (Prior et al., 2012).

The potential biological mechanisms are consistent with the reported associations between cesarean delivery and adverse infant outcomes. These studies relate cesarean deliveries to a marked increase in the susceptibility of multiple immune and metabolic conditions. Even though cesarean deliveries have been associated with a broad array of immune-mediated diseases, recent meta-analyses conclude that C-sections are most robustly related to asthma, atopic diseases, type 1 diabetes and obesity (Blustein and Liu, 2015; Keag, Norman and Stock, 2018; Cardwell et al., 2008; Thavagnanam et al., 2008; Peters et al., 2018; Bager, Wohlfahrt and Westergaard, 2008).[6] However, the causal nature and clinical relevance of these relationships remains largely unknown.[7]

2.2 Classification of Cesarean Sections

Cesarean sections are performed for several indications at different stages of the pregnancy. Cesarean sections are classified either as scheduled (elective) or unscheduled operations. Scheduled C-sections occur without attempted labor and are agreed upon in advance. The large majority of scheduled C-sections are performed during the regular working hours (8am — 4pm) from Monday to Friday. Medical indications that make scheduled C-sections advisable include, among others, multiple pregnancies with non-cephalic presentation of the first fetus or placenta previa. We exclude all scheduled C-sections from our sample.

Most C-sections are performed with no scheduled intervention after spontaneous or medically induced onset of labor. Unscheduled C-sections are surgeries where an attempt of vaginal birth is transformed to a cesarean delivery after the mother has been admitted to a hospital. Unscheduled

[6] In addition to health outcomes, literature has associated cesarean sections with worse cognitive and emotional development (Bentley et al., 2016).

[7] Hyde et al. (2012) summarize evidence from 14 RCTs that compare the effects of cesarean and vaginal deliveries on infant health. All these studies are small RCTs conducted in populations of at risk babies (e.g. breech delivery). These studies have had exceptionally large problems to achieve target recruitment and do not include long-term follow-ups. Overall, there exist no RCTs to date that would enable to investigate the long-term effects of cesarean sections on infant health. Hyde and Modi (2012) report evidence from survey studies that investigate the perceived acceptability of randomizing the mode of delivery to address long-term health outcomes in low-risk pregnancies. The perceived acceptability of randomizing the mode of delivery in healthy, term, cephalic and singleton pregnancies remains low among obstetricians and mothers, suggesting that adequately powered large-scale RCTs to compare the effects of cesarean and vaginal deliveries on long-term outcomes may remain unrealized in the near future.

C-sections are classified by urgency. Emergency C-sections are performed within 30 minutes of the decision, due to an immediate threat to the life of the mother or the baby (NICE, 2011). However, most unscheduled C-sections are performed without such immediate threat. The optimal timing and indication for these operations are imprecise and give large discretion to the clinician. Slow progression of labor or cephalopelvic disproportion are examples of diagnoses that may require an unplanned non-urgent cesarean section. There is wide variation among clinicians in the use of discretionary diagnoses that justify C-sections (Barber et al., 2011; Fraser et al., 1987). Our data contains the registered diagnosis linked to the C-section for a subsample of births. These observations enable us to verify that the peaks in unplanned C-sections are coupled with the use of more discretionary diagnoses.

2.3 Institutional Context

Finland has universal public health coverage. Comprehensive pre- and postnatal care services are included in the publicly provided services. There are no private medical institutions running maternity wards. Consequently, all deliveries take place in public hospitals. All medical expenses related to prenatal care, delivery and postnatal care are fully covered by the public health care system.

Pregnant women usually give birth in the nearest hospital. Only high-risk pregnancies are systematically directed to a higher-level hospital for obstetric care and delivery. Expectant women do not have pre-assigned midwifes or physicians for the delivery. Midwives take care of the delivery in all hospitals, while physicians have the ultimate responsibility for obstetric care, decide on the type of delivery and perform C-sections. There are no delivery units led by midwifes. The C-section rate (15.5% in 2015) is relatively low from an international perspective (OECD, 2017).

The regular working shifts for physicians are from 8 am to 4 pm from Monday to Friday. The on-call hours for physicians may not exceed 24 hours during the regular working week and last typically from 8 am to 8 am. On weekends, the on-call hours for physicians are from 8 am to 9 am on next day.[8] Midwives follow the same rotation regardless of the type of day and work in three shifts of around 8 hours.[9]

3 Data and methods

3.1 Data

The two main data sources used in our analysis are the Finnish Medical Birth Register and the Hospital Discharge Register. The Finnish Medical Birth Register was established in 1987. This administrative data resource includes data on all live births and on stillbirths of fetuses with a birth weight of at least 500 grams or with a gestational age of at least 22 weeks. The register includes information on maternal background, health care utilization, and medical interventions during pregnancy and delivery. It also includes mother's diagnoses during delivery (ICD-10 codes) and newborn outcomes until the age of 7 days. From 1990, the register contains detailed information about the type of C-section (scheduled vs. unscheduled). These data are collected at all delivery hospitals.

We exclude from our sample planned C-sections and multiple pregnancies. For our instrumental variable strategy, we focus only on first births.[10] Our analysis sample includes 392,560 deliveries that took place from 1990 to 2014. For the differences-in-differences analysis, we focus on both first and second births from families where the first child was born by vaginal delivery (more details are provided in section 3.2.2). The analysis sample consists of 645,292 children from 322,646 sibling pairs. There are 43 hospitals in our sample. Table A1 shows summary statistics for all births in Finland between 1990 and 2014.

[8] Even though the statutes that govern on-call arrangements have changed in recent years, during most years covered in our data, small hospitals with less than 1000 annual births could autonomously decide their on call arrangements. In certain hospitals, physicians were allowed to be at home while on duty, if they could arrive to the hospital within 30 minutes from home.

[9] An example of midwives' schedules: (i) from 7 am to 3 pm, (ii) from 2 pm to 9.30 pm, and (iii) from 9.15 pm to 7.15 am.

[10] We follow a common practice in literature and focus on first births, which also allows us to keep just one birth per mother, and abstract from a potential source of correlation between the observations. First-time mothers are also the group of mothers where we find larger variation. Given the faster pace of labor in higher-order births (NICE, 2014) and the high risk of repeated C-section, there is less room for discretion in the decision to perform an unplanned C-section in subsequent deliveries. Our results are qualitatively similar but less precise when we include higher order births.

We match the Finnish Medical Birth Register to the Finnish Hospital Discharge Register, which contains information about the diagnosed medical conditions, medical operations, and the date of diagnoses. This hospital register contains all inpatient consultations in Finland from 1990 to 2013. From 1998, the data include all outpatient visits to hospitals. All diagnoses are coded using the International Classification of Diseases (ICD) tool.[11]

We explore two sets of outcome variables. First, to test whether unplanned C-sections have an impact on neonatal health, we analyze indicators of neonatal health included in the birth register. We study Apgar scores one minute after birth, admission to intensive care unit (ICU), need of assisted ventilation and early neonatal mortality (defined as neonatal death in the first week of life).[12] Second, we study longer term outcomes using detailed inpatient and outpatient diagnosis data from the Finnish Hospital Discharge Register. We use primary diagnoses.[13] To maintain a relatively large sample size, we follow individuals from birth until age 15. We focus on the four metabolic and immune-related conditions that have been most robustly associated with cesarean delivery: asthma, atopic diseases (atopic dermatitis and allergic rhinitis), type 1 diabetes and obesity. Table A2 in the appendix provides more detail about each of these diagnoses.

3.2 Empirical strategy

We aim to estimate the impact of a cesarean delivery on child's health at birth and older ages. We define a binary variable CS_i that takes value 1 if the delivery is an unplanned C-section and 0 if it is a vaginal delivery. Thus, we aim to estimate the following equation:

$$Y_i = \beta_0 + \beta_1 CS_i + X_i' \beta_2 + \delta_m + \lambda_y + \phi_h + \epsilon_i, \tag{1}$$

[11]Diagnoses for years from 1990 to 1995 are recorded using ICD-9 classification. Diagnoses from 1996 onwards are recorded using ICD-10 classification. The quality and completeness of the Finnish Hospital Discharge Register has been assessed in multiple validation studies that have compared recorded data entries with external information. The completeness and accuracy of the data are found to be exceptionally high (Sund, 2012). We assess to what extent our data is able to identify the individuals with a certain diagnosis in the Results section.

[12]Apgar scores result from the examination of the newborn by the midwife or pediatrician one minute after the birth. Five different dimensions are measured and graded from 0 to 2: appearance (skin color), pulse (heart rate), grimace (reflex irritability), activity (muscle tone), and respiration. The resulting score takes values from 1 to 10.

[13]We replicated all our analysis using both primary and secondary diagnoses. All results remain unchanged. Results are available upon request.

where Y_i is the health outcome of infant i, X_i is a vector of covariates and δ_m, λ_y, ϕ_h are fixed effects for the month, year, and hospital of birth, respectively.[14]

The estimation of equation (1) is, however, likely to provide biased estimates of β_1 due to potential selection into cesarean birth.[15] To study the causal effects of cesarean delivery on health, we exploit two different empirical strategies.

3.2.1 IV strategy: Variation by time and type of day

Our instrumental variable strategy exploits the higher likelihood of being born by C-section during the normal working shift on pre-leisure days compared to regular working days. We use the interaction between the type of day and work shift as an instrument for the mode of delivery.

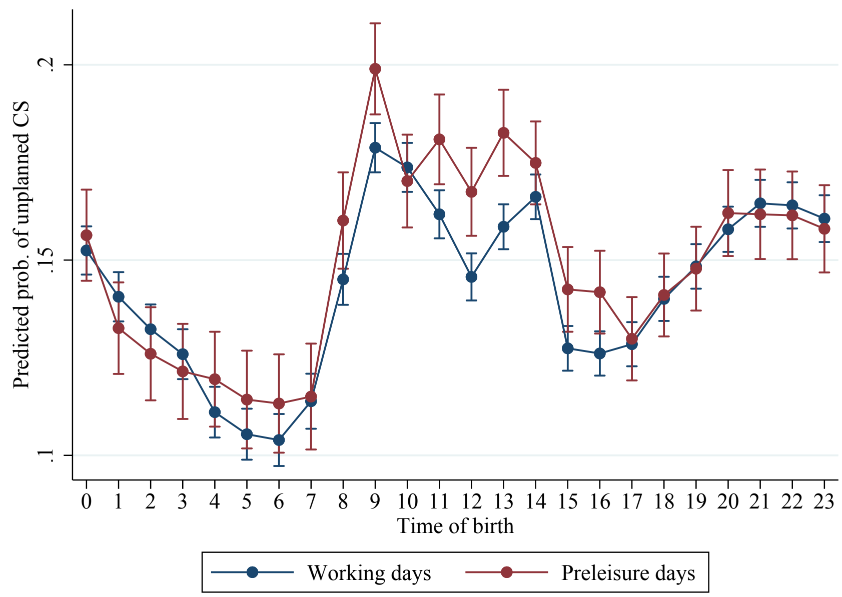
Figure 1 presents the predicted probability of unplanned C-section delivery by hour and type of day. We adjust for hospital, month and year of birth fixed effects. Figure 1a plots the distribution of C-sections over a 24-hour cycle for working days that precede a leisure day compared to other working days.[16] We find that substantially more C-sections are performed during regular working hours on days that precede a leisure day compared to the rest of working days. Figure 1b presents the predicted probability of having an unplanned C-section by work shift and type of day. We find that the gap in C-section rates between a day that precede a leisure day and the rest of working days emerges only during the regular working hours (from 8 am to 4 pm).

Importantly, we find that the excess C-sections performed in days that precede a leisure day are not driven by advancing births that would have been cesarean deliveries in any event. We do not observe any relative fall in C-sections during the evening hours preceding a leisure day compared to the evenings of regular working days (Figure 1a) or during the leisure day (Figure A2 in the

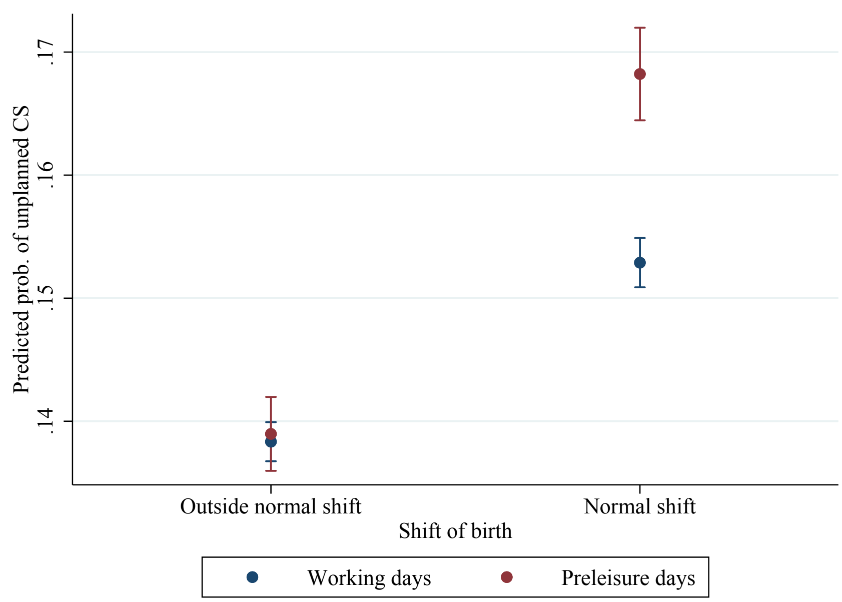
[14]The vector of covariates includes the gender of the baby, the mother's marital status, nationality, socioeconomic status, age and smoking status. In addition, we include a wide range of pregnancy and delivery related indicators that include in-vitro fertilization, amniocentesis during pregnancy, ultrasound during pregnancy, gestational diabetes, maternal hospitalization due to hypertension, maternal hospitalization due to placenta previa, maternal hospitalization due to eclampsia, gestational weeks, induced labor, prostaglandin pre-induction, epidural use, and laughing gas anesthesia.

[15]Figure A1 in the appendix shows that mothers and babies who undergo a C-section are very different from those mothers and babies who undergo a vaginal delivery.

[16]Working days that precede a leisure day include Fridays and days preceding public holidays. Table A3 documents all public holidays in Finland. Friday is not considered a working day that precedes a leisure day if it is a holiday.



(a) By time of birth



(b) By shift of birth

Figure 1: Predicted probability of unplanned C-section

Notes: Figure (a) presents the predicted probability of unplanned C-section by hour and type of day. Figure (b) shows the predicted probability of unplanned C-section by shift and type of day. Both figures adjust for hospital, month, and year of birth fixed effects. Pre-leisure days include working days that precede a Finnish public holiday or a weekend, while working days include the rest of working days. Sample is restricted to singleton first births which are either unscheduled C-sections or vaginal births.

Appendix).[17] These observations suggest that physicians perform C-sections during the regular working hours on pre-leisure days that would not have been performed otherwise.

The time pattern of C-sections is consistent with previous work by Brown (1996) and Halla et al. (2016) that documents an increase in C-section rates on days that precede a leisure day. Halla et al. (2016) exploit this variation in an instrumental variable framework to study the impact of delivery mode on maternal fertility and labor supply. Like the existing literature, we attribute the pre-leisure anomaly in the time pattern of C-sections to physician demand for leisure. This incentive arises from the higher time cost and uncertainty of vaginal births. A cesarean section takes on average 30-75 minutes and is perceived as a relatively easy surgical intervention with low complication rates (NICE, 2011).The average duration of labor for first-time mothers who have a vaginal birth is 11 hours (NICE, 2014).

We provide two pieces of complementary evidence to validate that the excess rate of C-sections is not driven by medical factors. First, we build on previous evidence that some medical diagnoses linked to a cesarean birth are more discretionary than others. Dystocia (prolonged or obstructed labor), one of the most common indications for primary cesarean section, is believed to provide the greatest room for diagnostic discretion (Fraser et al., 1987). The number of dystocia diagnoses has been shown to strongly respond to physician incentives (Evans et al., 1984; Fraser et al., 1987; McCloskey, Petitti and Hobel, 1992). We examine if there is an excess number of dystocia diagnoses during regular working hours on pre-leisure days. Our results (Table A4) show that giving birth during the regular hours on a pre-leisure day increases the probability of having a dystocia diagnosis compared to other working days. Importantly, we do not find this temporal pattern for medical emergencies, for which there should not be any room for discretion. In particular, we find that our instrument does not predict additional examinations of the fetus during labor, which doctors should perform if there are any signs of fetal suffering.[18]

Our second piece of evidence builds on the literature showing that physician mothers are less likely to receive C-sections driven by financial incentives (Johnson and Rehavi, 2016). Consequently, we expect that the probability of having a C-section does not respond to physician demand for

[17] This figure compares the predicted probability of unplanned C-section by hour separately for Saturdays or holidays (the leisure day following the pre-leisure day) and Sundays (a leisure day that is not preceded by a working day). We do not see any relative drop in the C-section rate on Saturdays compared to Sundays at any time of day.

[18] We examine whether physicians take measurements of intrapartum or fetal scalp pH, which proxies the oxygen saturation of fetal blood during labor.

leisure among physician mothers and other medical professionals. Our results (Table A5) support this hypothesis. We do not find that medical professionals have an increased risk of having a C-section during the regular shift on pre-leisure days, while we do find this increase for non-medical mothers with an equivalent level of education.[19]

We exploit the variation in the probability of unplanned C-sections by time and type of day and adopt an instrumental variable approach. We first estimate a standard two-stage least squares (2SLS) with the following first stage:

$$\begin{aligned} CS_i = \gamma_0 + \gamma_1 NS_i + \gamma_2 Preleisure_i + \gamma_3 NS_i \times Preleisure_i \\ + X_i' \gamma_4 + \delta_m + \lambda_y + \phi_h + \upsilon_i \end{aligned} \tag{2}$$

and the corresponding second stage:

$$Y_i = \alpha_0 + \alpha_1 NS_i + \alpha_2 Preleisure_i + \alpha_3 \widehat{CS}_i + X_i' \alpha_4 + \delta_m + \lambda_y + \phi_h + \varepsilon_i \tag{3}$$

where NS_i is a dummy that takes value 1 for births that take place during the normal shift (from 8 am to 4 pm) and 0 otherwise, $Preleisure_i$ takes value 1 for Fridays or working days preceding a Finnish public holiday and 0 for other working days, $\widehat{CS}_i$ in equation (3) are the predicted C-sections from the first stage, X_i is the vector of individual controls,[20] and δ_m, λ_y, ϕ_h are month, year, and hospital of birth fixed effects, respectively. The interaction between regular working hours and a day preceding a leisure day will serve as an instrument. As a result, we will be comparing mothers who give birth in the same hospital during the same shift, but on different types of days (working days preceding a leisure day or other working days). We expect a positive $\widehat{\gamma}_3$ due to increasing physician demand for leisure on days preceding a weekend or public holiday.

[19]Our definition of medical professionals includes physicians, midwifes and nurses. Our observation relates to a large literature on physician-induced demand in health care. Since the work of Arrow (1963), it has been recognized that asymmetric incentives between physicians and their patients are a central feature of the medical marketplace. The role of financial incentives on the supply of cesarean sections has been documented by Gruber and Owings (1996). Johnson and Rehavi (2016) observe that financial incentives have a particularly large effect on the probability of having a cesarean section among non-physicians. Our results complement the literature on physician-induced demand and show that the excess rate of C-section on pre-leisure days is restricted to non-medical professionals.

[20]Gender of the baby, mother's marital status, nationality, socioeconomic status, age, smoking status, and the following pregnancy and delivery characteristics: gestational weeks and indicators for in-vitro fertilization, amniocentesis during pregnancy, ultrasound during pregnancy, gestational diabetes, maternal hospitalization due to hypertension, maternal hospitalization due to placenta previa, maternal hospitalization due to eclampsia, induced labor, prostaglandin pre-induction, epidural use, and laughing gas anesthesia.

Table 1: First stage

	Unplanned CS	
	(1)	(2)
Normal shift	0.015***	0.017***
	(0.001)	(0.001)
Preleisure day	0.001	-0.002
	(0.002)	(0.002)
Normal shift× Preleisure	0.015***	0.014***
	(0.003)	(0.003)
Observations	392561	392561
Controls	NO	YES
$\overline{Y}$	0.145	0.145
First-stage F	26.650	25.209
Adjusted R^2	0.008	0.070

This table shows estimates from the first stage (see equation (2)). All specifications include hospital, year and month of birth fixed effects. Controls: gender, maternal age, marital status, nationality, mother occupation (long-term unemployed, high-skilled white collar, low-skilled white collar, manual worker, student, other), whether mother smoked during pregnancy, high/low number of prenatal visits, IVF, gestation weeks, induced labor, prostaglandin preinduction, epidural or laughing gas anesthesia. Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

Our instrumental variables estimation needs to meet three conditions to yield valid estimates. First, the instrument should strongly influence the probability of C-section (first stage). Second, there should be no selection of mothers who give birth during the regular shift on different types of days. Finally, being born during the regular shift on pre-leisure days, compared to other working days, should only affect child outcomes through the increased probability of being born by C-section (exclusion restriction).

Table 1 shows the results from the estimation of the first stage. Column (1) shows the first stage estimates including month, year, and hospital fixed effects. Column (2) includes a richer set of controls. These estimates show that being born during the normal shift increases the probability of C-sections for all working days. Moreover, being born during the normal shift on pre-leisure days increases the probability of C-section by 1.5 percentage points. The first stage F-statistics are larger than 25 in both specifications. Following the common critical values for weak instruments (Stock and Yogo, 2005), we can reject the null hypothesis that the instrument is weak.

Figure 2 shows that our instrument does not predict a large set of maternal and pregnancy characteristics, including medical conditions that could predict a C-section. This indicates that mothers giving birth during the regular shift on pre-leisure days compared to other working days are similar in observable characteristics, suggesting that the observed increase in C-sections at these times cannot be explained by selection.

Finally, regarding the exclusion restriction, we focus on births that take place on working days, when hospital resources and quality of care should be constant. Moreover, to compromise our empirical strategy, any change in the quality of care would need to happen on pre-leisure days only during the regular working hours. We provide numerous supplementary analyses in section 5.1 that reinforce the credibility of this assumption.

The two-stage least squares estimator enables us to identify a local average treatment effect (LATE). This is the effect of C-sections for infants whose mothers' mode of delivery is sensitive to the subjective assessment of the physician. More accurately, we capture births where the type of day affects the decision of the doctor to perform a C-section during the normal shift. The counterfactual for these births is unlikely to be exclusively a cesarean section later on, given that we do not find a relative drop in C-sections on pre-leisure days after the normal shift or during the following day. The LATE will not be informative of the effect of medically indicated C-sections, as those are not affected by leisure incentives. Moreover, the LATE does not capture the effect of unplanned C-sections for babies who had a very fast delivery, leaving no room for physician discretion.

Our primary health outcomes and the endogenous variable are binary. Consequently, besides the 2SLS models we estimate (recursive) bivariate probit models. These specifications mirror equations (2) and (3) and assume that cesarean delivery (CS_i) and the binary indicator of health Y_i are determined by the following latent indices:

$$CS_i = \mathbb{1}[\rho_1 NS_i + \rho_2 Preleisure_i + \rho_3 NS_i * Preleisure_i + X_i' \rho_4 + \delta_m + \lambda_y + \phi_h + \nu_i > 0] \quad (4)$$

$$Y_i = \mathbb{1}[\pi_1 NS_i + \pi_2 Preleisure_i + \pi_3 CS_i + X_i' \pi_4 + \delta_m + \lambda_y + \phi_h + \xi_i > 0] \quad (5)$$

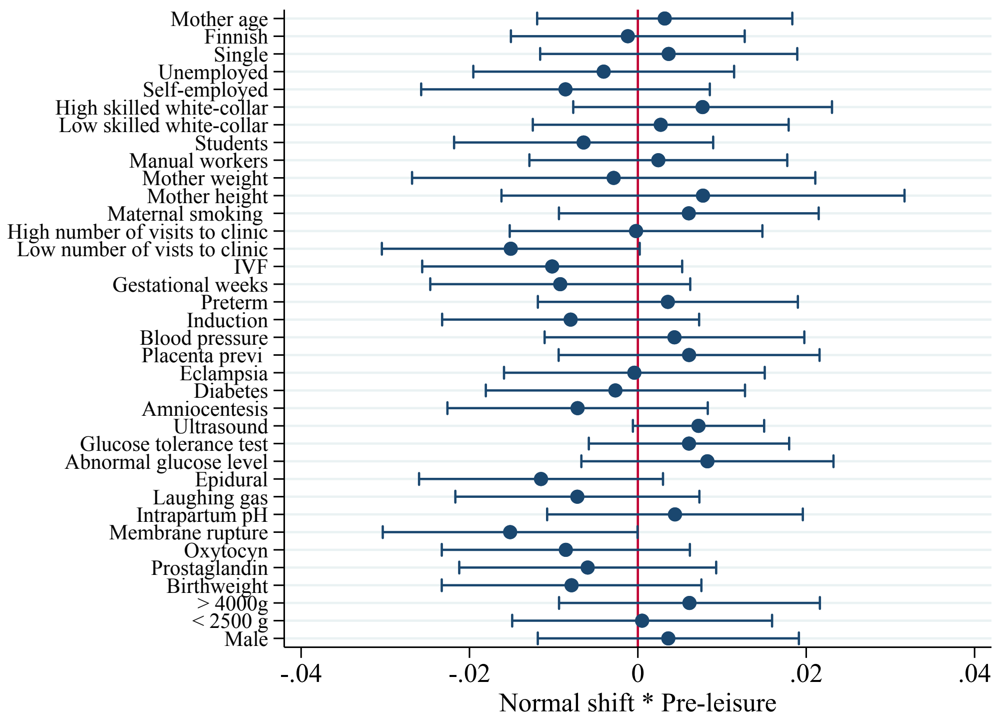


Figure 2: Instrument and baseline characteristics

Notes: The figure represents the coefficients and 95% CI from separate regressions of each (standardized) predetermined variable on the instrument (Normal shift * Pre-leisure), controlling for normal shift time, pre-leisure day, and hospital, month, and year of birth fixed effects. Sample is restricted to single births, unscheduled C-sections and vaginal births that take place on working days.

where (ν_i, ξ_i) follow a bivariate standard normal distribution with unknown correlation. These equations can be estimated through maximum likelihood. Identification in this setting relies on the same assumptions that are needed to estimate the 2SLS model together with an additional assumption about the joint normality of the error terms.

Bivariate probit estimation is expected to present substantial advantages in the context of this paper. The bivariate probit estimation is shown to be more efficient and less biased than 2SLS when treatment and outcome probabilities are close to 0 or 1 (Chiburis, Das and Lokshin, 2012; Bhattacharya, Goldman and McCaffrey, 2006; Nielsen, Smith and Çelikaksoy, 2009). Given that we work in a low C-section rate setting and examine relatively rare outcomes, we expect bivariate probit to outperform 2SLS in terms of efficiency. In the results section, we report marginal effects for both estimators.[21]

3.2.2 Differences-in-differences

Our second empirical strategy applies a differences-in-differences approach to a sample of sibling pairs. We restrict the sample to families where the older sibling was born by vaginal delivery and compare the health gap between siblings in families where the second child was born by an unplanned C-section against families where the second child was born by vaginal delivery. This enables us to control for all time-invariant unobserved heterogeneity at the family level and the effect of birth order. Our empirical strategy builds on numerous papers that have used siblings fixed-effects to estimate the impact of health shocks while in-utero or after birth (e.g. Oreopoulos et al., 2008; Almond, Edlund and Palme, 2009; Almqvist et al., 2012; Aizer, Stroud and Buka, 2016) and extends the model to a difference-in-differences specification with family fixed-effects. A related approach is used by Black et al. (2017) to study the impact of child disability on sibling outcomes.

We estimate the following equation:

$$Y_{if} = \psi_0 + \psi_1 Secondborn_{if} + \psi_2 Secondborn_{if} \times CS_{if} + X'_{if}\psi_3 + \gamma_f + \delta_m + \lambda_y + \phi_h + \eta_{if}, \quad (6)$$

[21] Bivariate probit models estimate unconditional average causal effects. In contrast, 2SLS estimates the LATE. However, in practice, the average causal effects produced by bivariate probit are likely to be similar to 2SLS estimates (Angrist and Pischke, 2009).

where Y_{if} is the health outcome of child i in family f, $Secondborn_{if}$ is a dummy variable equal to 1 for the second child and 0 for the first child, CS_{if} is an indicator equal to 1 for unplanned C-section and 0 for vaginal delivery, X_{if} is a vector with the same pregnancy and maternal controls of equation (3), except for maternal characteristics that are time-invariant, and diagnoses during delivery (prolonged and obstructed labor)[22], γ_f, δ_m, λ_y and ϕ_h are family, month, year, and hospital of birth fixed effects, respectively.[23] We cluster standard errors at the family level. Our parameter of interest is ψ_2, which identifies the change in the health gap between siblings in families where the first child was born by vaginal delivery and the second child by C-section compared to families where both children were born by vaginal delivery.

We do not include families whose older child was born by C-section for two reasons. First, mothers who have a C-section in the first delivery and a vaginal birth in the second delivery are a very selected sample, given the very high probability of having a repeat C-section.[24] Second, some studies find that having a C-section is associated with lower fertility (Halla et al., 2016; Keag, Norman and Stock, 2018). We abstract from these concerns by focusing on mothers whose first birth was a vaginal delivery.

Even though our rich data sources make it possible to control for a large set of observable characteristics, it could be that there are sibling-specific unobservable differences that vary within family. In particular, younger siblings born by C-section could be negatively selected compared to their vaginally-delivered older siblings if the cesarean delivery is caused by complications, either during the pregnancy or delivery, that we cannot observe in our data. These unobservable complications could cause our estimates to be negatively biased. Thus, our difference-in-difference estimates could overestimate the impact of C-sections on the different diagnoses. In section 5.2 we assess the magnitude of the potential bias and provide evidence that it is relatively small. We will nonetheless keep the direction of this bias in mind when interpreting the results from this strategy.

[22] We do not include these diagnoses during labor as controls in the IV specification, given that we find evidence that they can be an outcome of the time and type of day.

[23] We cannot estimate the baseline effects of the CS_{if} indicator, which are absorbed by the interaction $Secondborn_{if} \times CS_{if}$, since by construction of our sample only second children have C-sections.

[24] In 2010, The American College of Obstetricians and Gynaecologists (ACOG) encouraged doctors to allow women to opt for a vaginal delivery after a C-section, but the number of vaginal births after C-section has remained low (American College of Obstetricians and Gynecologists, 2010).

4 Results

4.1 Neonatal outcomes

We first estimate the impact of C-sections on neonatal outcomes. Table 2 shows our OLS (first panel), 2SLS (second panel), bivariate probit marginal effects (third panel) and differences-in-differences (fourth panel) estimates. We find that the OLS results replicate existing findings. Cesarean sections are associated with adverse outcomes at birth and higher neonatal mortality.[25] Our 2SLS estimates are not significant for any of the outcomes. However, the magnitude of coefficients and large standard errors suggest that we cannot reject that there is a (potentially large) effect on neonatal outcomes. As discussed in section 3.2.1, 2SLS estimates are expected to be particularly uninformative with low treatment and outcome probabilities.

The bivariate probit coefficients are substantially more precisely estimated than the 2SLS results. Yet, all point estimates from the bivariate probit models are within the confidence intervals of the 2SLS estimates. The bivariate probit results suggest that unplanned C-sections increase the probability of having a low Apgar score (Apgar lower than 7), being admitted to the intensive care unit and receiving assisted ventilation. The magnitude of the bivariate probit estimates are similar to OLS estimates. However, we do not find significantly increased mortality risk within seven days after birth. The results from the differences-in-differences models give support to these findings with similarly-sized and more precise coefficients. Overall, our results suggest that unplanned C-sections have a negative impact on neonatal health. However, these adverse effects do not translate into a higher probability of early neonatal mortality.

4.2 Later infant health

We now turn to the results of the long-run effects of C-sections on health outcomes. Table 3 shows the OLS (first panel), two-stage least squares (second panel), bivariate probit (third panel) and differences-in-differences (fourth panel) marginal effect estimates at ages 5 and 10. We analyze health conditions that have been extensively documented in the literature as being positively associated with cesarean deliveries: type 1 diabetes, obesity, asthma, and other atopic diseases (atopic

[25] The OLS estimation is ran in a sample that only excludes planned C-sections and births for which we do not observe parity. The specification includes the full set of controls and fixed effects described in equation (1), as well as controls for birth order.

Table 2: Neonatal outcomes

	(1) Low Apgar 1	(2) ICU	(3) Assisted ventilation	(4) Neonatal mortality
OLS	0.068***	0.118***	0.027***	0.002***
	(0.001)	(0.001)	(0.001)	(0.000)
$\overline{Y}$	0.049	0.087	0.009	0.001
N	1119467	1120932	1120932	1119842
2SLS	-0.018	-0.088	-0.006	0.006
	(0.140)	(0.170)	(0.061)	(0.023)
$\overline{Y}$	0.066	0.106	0.012	0.002
N	392017	392560	392560	392173
Biprobit	0.104***	0.163***	0.017***	-0.001
	(0.008)	(0.009)	(0.005)	(0.005)
$\overline{Y}$	0.066	0.106	0.012	0.002
N	392017	392560	392560	392173
Diff-in-diff	0.053***	0.111***	0.036***	0.001
	(0.007)	(0.007)	(0.004)	(0.002)
$\overline{Y}$	0.038	0.070	0.006	0.001
N	644551	645292	645292	644746
First-stage F	24.996	25.216	25.216	26.007

This table shows the estimates of the effect of an unplanned CS on different neonatal health indicators by OLS, 2SLS, bivariate probit and differences-in-differences estimation (see equations (2), (3), and (6)). Specifications as detailed in section 3.2, with the full set of fixed effects and controls. Robust standard errors (in parentheses) in panels 1-3, and standard errors clustered at the family level in the differences in differences panel. First-stage F statistic from 2SLS and bivariate probit specifications. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

dermatitis and allergic rhinitis). Given that we study health outcomes for children who are born from 1990 to 2014, the sample size decreases as we consider older ages. We report year by year bivariate probit and diff-in-diff estimates up to age 15 in Figures 3 and 4, respectively. We report our OLS estimates in Figure A3.

The OLS estimates suggest that cesarean sections are associated with a higher probability of

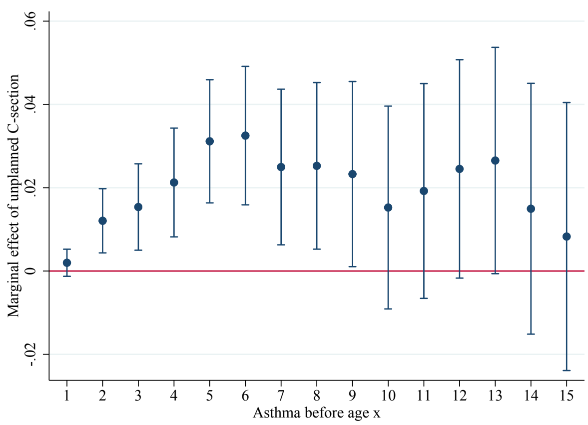
Table 3: Child diagnoses by age

	Type 1 diabetes		Asthma		Obesity		Atopy	
By age:	5	10	5	10	5	10	5	10
OLS	0.000	0.000	0.007***	0.010***	0.000***	0.002***	0.002**	0.004***
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
$\overline{Y}$	0.003	0.006	0.045	0.071	0.001	0.004	0.044	0.061
N	807035	556009	807035	556009	807035	556009	807035	556009
2SLS	0.089**	0.062	0.074	-0.121	0.001	0.000	0.022	0.110
	(0.036)	(0.044)	(0.113)	(0.139)	(0.013)	(0.034)	(0.112)	(0.127)
$\overline{Y}$	0.003	0.006	0.040	0.070	0.001	0.004	0.041	0.058
N	296998	217768	296998	217768	296998	217768	296998	217768
Biprobit	0.003	0.003	0.031***	0.015	0.001	0.003	-0.008	0.021
	(0.002)	(0.004)	(0.009)	(0.015)	(0.001)	(0.003)	(0.010)	(0.013)
$\overline{Y}$	0.003	0.006	0.040	0.070	0.001	0.004	0.041	0.058
N	296998	217768	296998	217768	296998	217768	296998	217768
Diff-in-diff.	-0.001	-0.001	0.014**	0.011	0.001	0.001	0.003	-0.001
	(0.001)	(0.003)	(0.006)	(0.009)	(0.001)	(0.002)	(0.005)	(0.007)
$\overline{Y}$	0.003	0.006	0.045	0.070	0.001	0.004	0.044	0.060
N	510075	366885	510075	366885	510075	366885	510075	366885
First-stage F	25.725	29.546	25.725	29.546	25.725	29.546	25.725	29.546

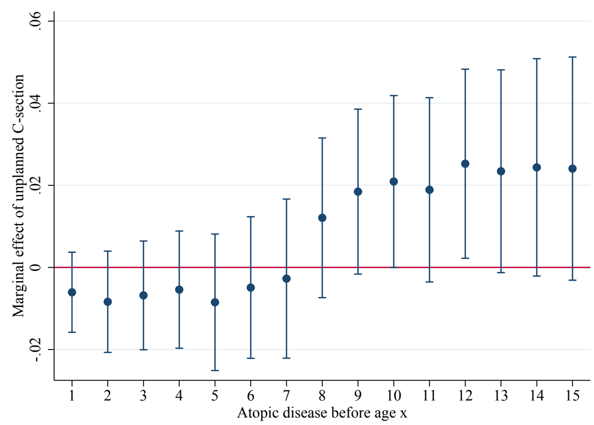
This table shows the estimates of the effect of an unplanned CS on the probability of the child having each diagnosis by age by OLS, 2SLS, bivariate probit and differences-in-differences estimation (see equations (2), (3), and (6)). Specifications as detailed in section 3.2, with the full set of fixed effects and controls. Robust standard errors (in parentheses) in panels 1-3, and standard errors clustered at the family level in the differences in differences panel. First-stage F statistic from 2SLS and bivariate probit specifications. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

asthma, obesity and atopic diseases. These findings are consistent with existing studies that have documented significant associations between cesarean sections and metabolic and immune-related conditions. However, we do not detect that C-sections are associated with a higher probability of type 1 diabetes diagnosis.

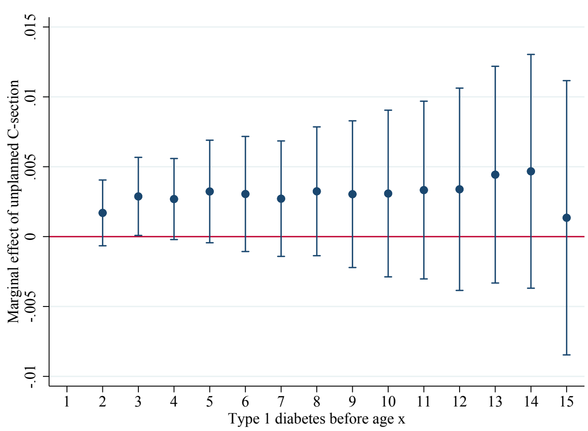
The 2SLS results suggest that unplanned C-sections increase the probability of having a type 1 diabetes diagnosis before age 5, even though the effect is not significant by age 10. The effect size of the estimate is large, but very imprecise. Our results suggests 9 percentage point increase in the probability of type 1 diabetes, but are consistent with an increase ranging from 6.3 to 12.5 percentage points. The 2SLS estimates for asthma are not significant. However, the lack of precision does not enable us to rule out even very large (positive or negative) effects. For instance, the estimates by age 5 suggest that the impact of C-sections may range from -4.2 pp to 18.4 pp. Finally, the 2SLS estimates for obesity and atopic diseases are not significant, but also too imprecise to rule out very large effects.



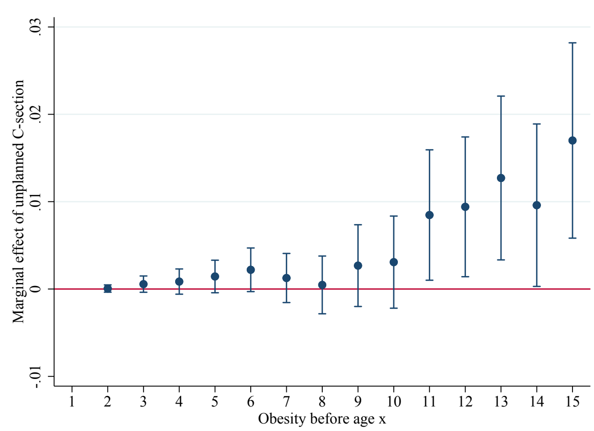
(a) Asthma



(b) Atopy



(c) Type 1 Diabetes



(d) Obesity

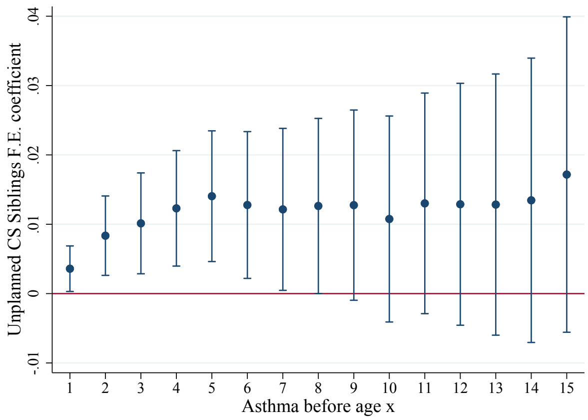
Figure 3: Bivariate probit estimation – Child diagnoses by age

Notes: The figure plots the marginal effects from the bivariate probit estimation of the effect of unplanned CS on the probability of each diagnosis by age, with our usual specification. All regressions include hospital, year and month of birth fixed effects and the full set of controls as described in Section 3.2.1.

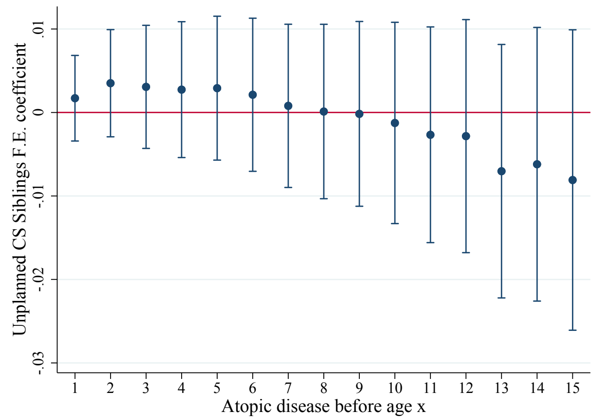
Similarly to our results for neonatal outcomes, the bivariate probit estimates (marginal effects) are substantially more precisely estimated than the 2SLS coefficients. Yet, practically all point estimates from the bivariate probit models are within the confidence intervals of the 2SLS estimates. For type 1 diabetes, the coefficient is much smaller than the coefficient from the linear model and not significant. For asthma, the results suggest a significant increase in the probability of a diagnosis by age 5 of 0.031 (95% CI 0.022–0.04). Even though estimates are noisier and no longer significant by age 10, the results in Figure 3 show that unplanned C-sections significantly increase the probability of an asthma diagnosis for children as young as 2 years old. The effect is statistically significant up to age 9. For obesity, the bivariate probit results are precisely estimated at zero at age 5 (0.001, 95% CI 0.000–0.002) and 10 (0.003, 95% CI 0.000–0.006). However, the results in Figure 3 show a statistically detectable effect from age 11. Finally, we do not find a significant impact on atopic diseases at age 5 or 10.

The differences-in-differences results are very similar to the bivariate probit results. We find that the second-born child has substantially greater risk of having an asthma diagnosis by age 5 than the first-born child in families where the second child is born by C-section. Similarly to the bivariate probit estimates, Figure 4 shows that this effect is significant from ages 1 to 8. Despite the fact that our differences-in-differences estimates could be negatively biased (Section 3.2.2), we do not find any significant effects on obesity, atopic diseases or type 1 diabetes. These results reinforce the conclusion that C-sections do not have impact on these outcomes.

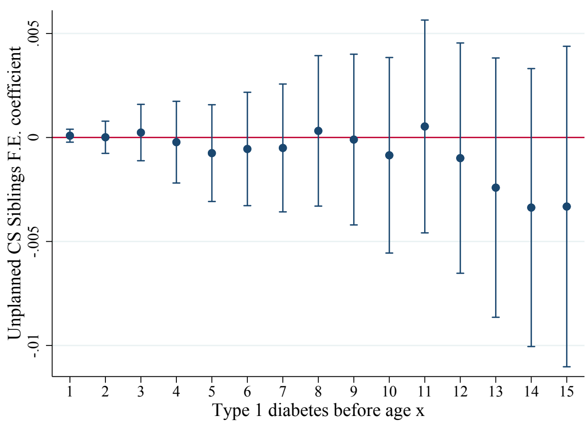
Overall, our results suggest that unplanned C-sections increase the probability of suffering from asthma during childhood. The magnitude of this effect differs slightly depending on the estimation method. The bivariate probit estimates indicate a slightly larger but more imprecisely estimated impact (around 2 pp on average for ages 5 to 10) than the estimates based on differences-in-differences analysis (1.3 pp). By comparing these estimates to the sample mean, we find that the less precise bivariate probit estimates suggest a 36% increase in the probability of having asthma diagnosis (compared to the mean of 5.5% over ages 5-10), while the differences-in-differences estimates suggest a 21% increase (compared to the sample mean of 5.8%). The latter is closer to the 20% increase in the risk of asthma that is documented in recent meta-analyses (Thavagnanam et al., 2008; Keag, Norman and Stock, 2018).



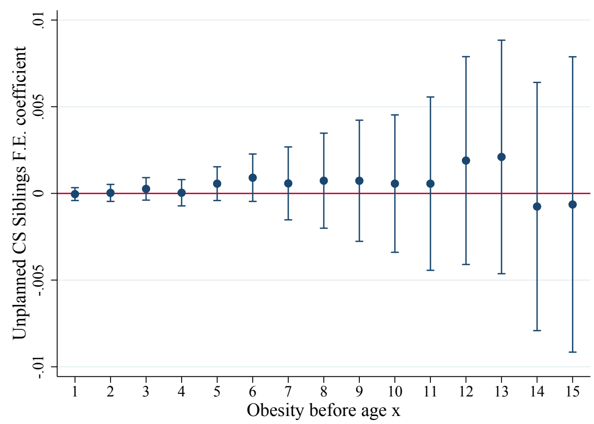
(a) Asthma



(b) Atopy



(c) Type 1 Diabetes



(d) Obesity

Figure 4: Diff-in-diff analysis – Child diagnoses by age

Notes: The figure plots the coefficient of unplanned C-section for each diagnosis by age in family fixed effects models. All regressions include family, hospital, year and month of birth fixed effects and the full set of controls as described in Section 3.2.2.

Our analysis indicates that C-sections do not increase the probability of type 1 diabetes or atopic diseases. For diabetes, we can rule out effects larger than 0.7 pp at age 5 using the bivariate probit model and larger than 0.1 pp using the differences-in-differences model. For atopic diseases, in turn, our results discard effects larger than 1.2-1.3 pp with both methods. Finally, bivariate probit results suggest there might be an effect of C-sections on obesity after age 11. This observation is consistent with the evidence that puberty is a vulnerable period for the development of overweight and obesity (Lobstein, Baur and Uauy, 2004). However, our analysis is not conclusive in this regard, as the results from the differences-in-differences estimation do not corroborate this finding.

For younger ages, all methods suggest that there is no impact on obesity. For instance, estimates at age 5 enable us to rule out effects larger than 0.3 pp.

One potential limitation of our analysis is that we study diagnoses made at inpatient or outpatient visits to a hospital. For some outcomes, these diagnoses may be a good approximation to the true prevalence of the disease, while for others hospital diagnoses may lead to underestimation. A previous study on type 1 diabetes documents that in Finland practically all new type 1 diabetes diagnoses are made in a hospital and listed in the Hospital Discharge Register (Harjutsalo, 2008). This evidence implies that we are able to observe practically all type 1 diabetes diagnoses in our population of interest. However, since 1994, diagnoses for asthma in Finland are often made by general practitioners (Tuomisto et al., 2010). Thus, we are likely to trace only the most severe cases of asthma. The same might be true for atopic disesase and obesity.[26] In any case, OLS results show that C-sections in general are associated even with these hospital diagnoses. Our analysis thus highlights the importance of dealing with the endogeneity of the delivery mode.

5 Validity checks

5.1 Exclusion restriction and sensitivity checks

Our instrumental variables strategy relies on the assumption that the interaction of regular working hours and days that precede a weekend or public holiday affects health outcomes only through its impact on the likelihood of cesarean sections. We argue that, in this setting, this is likely to hold, since a violation would require other changes to happen on days that precede a public holiday but only during the regular shift. In the following, we provide several pieces of evidence that support the credibility of this assumption.

First, we explore the overall activity at maternity wards across the different types of days. Figure A4 (the first panel) shows the proportion of planned cesarean sections by time of birth and type of day. We find that scheduled activity is organized very similarly during all working days. Moreover, we compare the number of births by type of day and weekday (Figure A4, second panel)

[26]There is some evidence that, among children, ICD-coding underestimates the true prevalence of obesity. ICD-coded cases have a higher BMI and higher healthcare utilization than those not coded (Kuhle et al., 2011).

Table 4: Validity checks

	Birth weight	Asthma at age 5 for sample: Thursdays vs Fridays	Asthma at age 5 for sample: Excluding inductions
Biprobit	-	0.023	0.036^{***}
	-	(0.015)	(0.010)
$\overline{Y}$	-	0.040	0.039
N	-	117826	246933
Diff-in-diff.	-5.416	-	0.017^{**}
	(7.617)	-	(0.007)
$\overline{Y}$	3566.117	-	0.044
N	645134	-	440291

This table shows, in column 1, a placebo regression where the outcome is birth weight; and in columns 2 and 3, the results from the bivariate probit (top) and the differences in differences (bottom) estimation of the impact of unplanned CS on the probability of asthma diagnosis by age 5 restricting the sample to births taking place on Thursdays or Fridays (col. 2) or to non-induced births (col. 3). Specifications as detailed in sections 3.2.1 and 3.2.2, with the full set of fixed effects and controls. Robust standard errors (in parentheses) for bivariate probit results, and standard errors clustered at the family level in the differences in differences panel. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

and do not find any evidence of maternity ward crowding during the days that precede a public holiday.

Second, we explore the quality of care provided during different weekdays. The first panel of Figure A5 shows that the probability of having a low Apgar score (below 7) does not differ between weekdays or type of day, suggesting that the quality of care during labor and delivery does not differ by type of day. Figure A5 (second panel) shows the probability of early neonatal mortality, defined as death of a live-born baby within the first seven days of life, by weekday and type of day. We expect that this measure would capture changes in the quality of care. We do not find evidence that early neonatal mortality is higher for babies born on days that precede a public holiday compared to other weekdays. Moreover, we do not find that mothers who have a C-section on a day that precedes a public holiday have a longer length of stay than mothers who have a C-section on other weekdays (Figure A6). We interpret these findings as evidence that the quality of care remains constant across all working days.

Third, since babies born on days that precede a public holiday or weekend stay in the hospital during the following non-working days, one could argue that their quality of post-natal care is worse compared to children born on other working days. This would be constant for both babies born during the regular shift and at other times, and hence would not necessarily comprise the exclusion restriction. Yet, in what follows we assess this concern. Table 4 shows the coefficients for IV regressions that restrict the sample to babies born on Thursdays or Fridays.[27] We find, despite the reduced sample size, that the results from this estimation are consistent with our main results.

Finally, we report in Figure 2 that mothers who give birth during the regular working hours on days that precede a public holiday do not have higher probability of having induced labor. However, the induction of labor is likely to offer more room for discretionary behavior, in which case the decision to perform a C-section might be more sensitive to physician demand for leisure.[28] In other words, we expect that mothers whose labor has been artificially induced are more likely to be part of the complier population. Column 3 in Table 4 shows that our coefficients remain about the same if we exclude mothers whose labor was induced from our sample. The same conclusion holds if we exclude inductions from our differences-in-differences estimation. These results suggest that our findings are not driven by mothers whose labor has been induced after an admission to the maternity ward.

5.2 Differences-in-differences validity checks

The results from our differences-in-differences model with family fixed effects could be biased if there are unobservable characteristics correlated with the mode of delivery that vary within family and across siblings. Under this scenario, this methodology would yield upward biased estimates. However, as shown in Section 4, our differences-in-differences results suggest that C-sections do not increase the risk of developing various immune-mediated diseases that have previously been associated with cesarean births.

To assess the extent to which these results could be explained by selection, we first run a regression using birth weight as a placebo outcome, given that it cannot be affected by unplanned C-sections. Table 4 shows that our differences-in-differences model with family fixed effects does

[27]The average length of stay in our sample is four days. The majority of babies born on Thursdays and Fridays are hospitalized during the weekend.

[28]Recent evidence casts doubt on the commonly-held belief that induction of labor increases the risk for cesarean delivery. In particular, recent studies show that inductions at full term do not increase the risk of cesarean delivery (Saccone and Berghella, 2015) or even lower it (Mishanina et al., 2014), with no increased risks for the mother and some benefits for the fetus.

not predict birth weight. This result supports the validity of this strategy: family fixed-effects, jointly with the large set of controls, seem to be taking into account general health differences between siblings born by C-section and vaginal delivery.

Second, we compare our differences-in-differences estimates to those from other samples of sibling pairs where we expect the second child to be negatively selected with respect to their older sibling, but where none of them was born by C-section. These samples include (i) a sample of siblings where the first child is born by eutocic birth and the second child is born either by eutocic or by instrumented birth, and (ii) a sample of siblings where the first born had a low-risk pregnancy and the second born had either a low- or a high-risk pregnancy, while all children in the sample were born by vaginal delivery.[29] Consequently, we assess the health gap between siblings across families that had a complication during the second birth or during the second pregnancy compared to families where none of the siblings encountered any of these complications during pregnancy or birth.

Table 5 shows our differences-in-differences estimates using these samples of siblings. The first four columns show that, compared to families where both siblings were born by eutocic birth, second children born by instrumented vaginal delivery have worse neonatal health than their older siblings who had an eutocic birth. We find a significantly higher probability of having low Apgar scores and of being admitted to the ICU (top panel). In the bottom panel, we can see that children who experienced a high-risk pregnancy do not have significantly worse neonatal health by any of the indicators, even though all coefficients have a positive sign. In the last four columns, we explore if negative selection leading to instrumented birth or risk pregnancy is associated with a higher probability of having any of the diagnoses we analyze in section 4. We do not find evidence that siblings born by instrumented vaginal delivery or those who had a high-risk pregnancy have an increased risk of type 1 diabetes, asthma, atopic diseases or obesity at age 5. These observations suggest that our differences-in-differences results for asthma are unlikely to be explained by negative selection.

[29] An eutocic delivery is a vaginal delivery with no instrumentation. We define a high-risk pregnancy as a pregnancy where the mother had at least one of these complications: a positive result in the glucose tolerance test, an hospitalization during pregnancy due to blood loss, hypertension, eclampsia or placenta previa. A low-risk pregnancy is defined as the absence of these issues.

Table 5: Validity of differences-in-differences

	Neonatal health				Diagnosis by age 5			
	Low Apgar	ICU	Assisted Ventilation	Neonatal mortality	Type 1 diabetes	Asthma	Obesity	Atopy
Instrumented	0.060***	0.020**	0.001	-0.001	-0.001	-0.004	-0.001	-0.006
	(0.009)	(0.009)	(0.003)	(0.002)	(0.002)	(0.008)	(0.001)	(0.009)
$\overline{Y}$	0.028	0.061	0.005	0.001	0.003	0.044	0.001	0.044
N	534119	534689	534689	534264	428392	428392	428392	428392
Risk pregnancy	0.001	0.016	0.003	0.001	-0.001	0.002	-0.000	0.005
	(0.007)	(0.010)	(0.004)	(0.002)	(0.002)	(0.009)	(0.001)	(0.009)
$\overline{Y}$	0.035	0.062	0.005	0.001	0.003	0.044	0.001	0.044
N	608688	609368	609368	608909	482536	482536	482536	482536

This table shows the results from sibling fixed effect models, following the specification in equation (6), for two different samples of children: in the top panel, for a sample of sibling pairs where the first child was born by eutocic birth, and the second child is born either by eutocic or instrumented vaginal birth; in the bottom panel, for vaginally delivered sibling pairs where the first child did not have a high-risk pregnancy and the second child had a low- or high-risk pregnancy. The top panel coefficient represents the change in the health gap between siblings in families where the second child was born by instrumented vaginal delivery, while the bottom panel coefficient represents the same for families where the second child had a high-risk pregnancy. All specifications include family, hospital, year and month of birth fixed effects and the controls described in section 3.2.2. Standard errors are clustered at the family level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

6 Conclusions

This paper provides new evidence on the effects of avoidable cesarean sections on various short- and long-term health outcomes. We use a novel instrumental variable estimation strategy to overcome the potential endogenenity of birth mode and abstract from cases in which C-sections respond to a clear clinical indication. Our empirical strategy builds on the finding that unplanned C-sections are more common during regular working hours on Fridays and working days preceding public holidays. We complement this empirical strategy by estimating a differences-in-differences model with family fixed effects that compares the health gap between siblings in families where the second child was born by unplanned C-section with the health gap between siblings who were both born by vaginal delivery.

Our results suggest that C-sections have a substantial negative impact on neonatal health. However, these adverse effects are not severe enough to translate into a higher probability of increased neonatal mortality. Our long-run analysis follows children from birth to age 15 and investigates the impact of C-sections on four health outcomes that have been consistently associated with C-sections: type 1 diabetes, asthma, obesity, and atopic diseases. In contrast to the OLS estimates, our instrumental variable and differences-in-differences estimates show that unplanned C-sections do not have a significant effect on the probability of having a type 1 diabetes, obesity, or atopic disease diagnosis. However, we do find that being born by an unplanned C-section increases the probability of having asthma. This effect is detectable from ages 1-2 and of similar size to the associations reported by previous studies (Thavagnanam et al., 2008; Keag, Norman and Stock, 2018). Our results are consistent with the hypothesis that mode of delivery can affect the development of immune-related conditions, but suggest more nuanced effects of C-sections than previous work.

This paper provides first evidence on the long-term effects of unplanned C-sections that do not respond to a clear medical indication, using inpatient and outpatient data for all children born in Finland from 1990 to 2014. Although we are able to observe most of the cases of type 1 diabetes, for some diagnoses (asthma, atopic disease, and obesity) we might be only able to trace the most severe cases, given that these conditions are often treated by general practitioners. However, the fact that our OLS estimation, which includes a large set of controls, shows significant associations of cesarean birth with these outcomes, highlights the importance of dealing with omitted variable bias when analyzing the impact of mode of delivery. Future work should focus on analyzing the causal effect of C-sections on obesity and other metabolic disorders using primary care data and anthropometric measurements.

We make use of the detailed diagnosis data to show that variation by time and type of day can be a valid source of variation to investigate the impact of avoidable C-sections. First, we show that mothers who give birth at regular working hours on pre-leisure days are comparable in terms of a extensive list of pregnancy, health, and sociodemographic characteristics to mothers who give birth during these times on the rest of working days. Second, we show that during the normal shift on these pre-leisure days physicians make greater use of more discretionary diagnoses as justification for the C-section. We also show that these additional C-sections are not performed to mothers who are in the medical profession, and whose mode of delivery has been shown by the literature not to respond to doctors' incentives (Johnson and Rehavi, 2016).

All in all, our results suggest that the additional C-sections performed during regular working hours on pre-leisure days are not driven by medical factors. We provide this evidence in the context of Finland, one of the countries with the lowest C-section rate in the world (OECD, 2017). We would expect this variation to provide an even stronger source of identification in other countries with higher rates of medical interventionism during childbirth. Thus, this paper hopes to provide a solid base upon which future research on the effects of avoidable cesarean sections can be built.

References

Aizer, Anna, Laura Stroud, and Stephen Buka. 2016. "Maternal Stress and Child Outcomes: Evidence from Siblings." *Journal of Human Resources*, 51(3): 523–555.

Almond, Douglas, Janet Currie, and Valentina Duque. 2018. "Childhood Circumstances and Adult Outcomes: Act II." *Journal of Economic Literature*, 56: 1360–1446.

Almond, Douglas, Lena Edlund, and Mårten Palme. 2009. "Chernobyl's Subclinical Legacy: Prenatal Exposure to Radioactive Fallout and School Outcomes in Sweden." *The Quarterly Journal of Economics*, 124(4): 1729–1772.

Almqvist, C., S. Cnattingius, P. Lichtenstein, and C. Lundholm. 2012. "The impact of birth mode of delivery on childhood asthma and allergic diseases–a sibling study." *Clinical & Experimental Allergy*, 42(9): 1369–1376.

American College of Obstetricians and Gynecologists. 2010. "ACOG Practice bulletin no. 115: Vaginal birth after previous cesarean delivery." *Obstetrics and Gynecology*, 116(2): 450–63.

Angrist, Joshua, and Jorn-Steffen Pischke. 2009. *Mostly Harmless Econometrics: An Empiricist's Companion.* Princeton University Press.

Arrow, Kenneth J. 1963. "Uncertainty and the Welfare Economics of Medical Care." *American Economic Review*, 53(5): 941–973.

Asher, I, and N Pearce. 2014. "Global burden of asthma among children." *The International Journal of Tuberculosis and Lung Disease*, 18(11): 1269–1278.

Bager, P., J. Wohlfahrt, and T. Westergaard. 2008. "Caesarean delivery and risk of atopy and allergic disesase: Meta-analyses." *Clinical & Experimental Allergy*, 38(4): 634–642.

Barber, E. L., L. S. Lundsberg, K. Belanger, C. M. Pettker, E. F. Funai, and J. L. Illuzzi. 2011. "Indications Contributing to the Increasing Cesarean Delivery Rate." *Obstetrics and Gynecology*, 118(1): 29–38.

Bentley, J. P., C. L. Roberts, J. R. Bowen, A. J. Martin, J. M. Morris, and N. Nassar. 2016. "Planned Birth Before 39 Weeks and Child Development: A Population-Based Study." *Pediatrics*, 138(6): e20162002–e20162002.

Bhattacharya, Jay, Dana Goldman, and Daniel McCaffrey. 2006. "Estimating probit models with self-selected treatments." *Statistics in Medicine*, 25(3): 389–413.

Black, Sandra E, Sanni Breining, David N Figlio, Jonathan Guryan, Krzysztof Karbownik, Helena Skyt Nielsen, Jeffrey Roth, and Marianne Simonsen. 2017. "Sibling Spillovers." National Bureau of Economic Research Working Paper 23062.

Blustein, Jan, and Jianmeng Liu. 2015. "Time to consider the risks of caesarean delivery for long term child health." *BMJ*, 350.

Boerma, Ties, Carine Ronsmans, Dessalegn Y. Melesse, Aluisio J.D. Barros, Fernando C. Barros, Liang Juan, Ann Beth Moller, Lale Say, Ahmad Reza Hosseinpoor, Mu Yi, Dácio de Lyra Rabello Neto, and Marleen Temmerman. 2018. "Global epidemiology of use of and disparities in caesarean sections." *The Lancet*, 392(10155): 1341–1348.

Brown, H.Shelton. 1996. "Physician demand for leisure: Implications for cesarean section rates." *Journal of Health Economics*, 15(2): 233 – 242.

Card, David, Alessandra Fenizia, and David Silver. 2019. "The Impacts of Hospital Delivery Practices on Infant Health." *NBER Working Paper, 25986.*

Cardwell, C. R., L. C. Stene, G. Joner, O. Cinek, J. Svensson, M. J. Goldacre, R. C. Parslow, P. Pozzilli, G. Brigis, D. Stoyanov, B. Urbonaité, S. Šipetić, E. Schober, C. Ionescu-Tirgoviste, G. Devoti, C. E. de Beaufort, K. Buschard, and C. C. Patterson. 2008. "Caesarean section is associated with an increased risk of childhood-onset type 1 diabetes mellitus: a meta-analysis of observational studies." *Diabetologia*, 51(5): 726–735.

Chiburis, Richard C., Jishnu Das, and Michael Lokshin. 2012. "A practical comparison of the bivariate probit and linear IV estimators." *Economics Letters*, 117(3): 762 – 766.

Collado, Maria Carmen, Samuli Rautava, Erika Isolauri, and Seppo Salminen. 2015. "Gut microbiota: a source of novel tools to reduce the risk of human disease?" *Pediatric Research*, 77: 182 – 188. Review.

Costa-Ramón, Ana María, Ana Rodríguez-González, Miquel Serra-Burriel, and Carlos Campillo-Artero. 2018. "It's about time: Cesarean sections and neonatal health." *Journal of Health Economics*, 59: 46 – 59.

Currie, Janet, and W Bentley Macleod. 2017. "Diagnosing Expertise: Human Capital, Decision Making, and Performance among Physicians." *Journal of Labor Economics*, 35(1): 1–43.

Dominguez-Bello, Maria G, Kassandra M De Jesus-laboy, Nan Shen, Laura M Cox, Amnon Amir, Antonio Gonzalez, Nicholas A Bokulich, Se Jin Song, Juana I Rivera-vina, Keimari Mendez, Rob Knight, and Jose C Clemente. 2016. "Partial restoration of the microbiota of cesarean-born infants via vaginal microbial transfer." *Nature Medicine*, 22(3): 250–253.

Drucker, Aaron M., Annie R. Wang, Wen Qing Li, Erika Sevetson, Julie K. Block, and Abrar A. Qureshi. 2017. "The Burden of Atopic Dermatitis: Summary of a Report for the National Eczema Association." *Journal of Investigative Dermatology*, 137(1): 26–30.

Evans, M. I., D. A. Richardson, J. S. Sholl, and B. A. Johnson. 1984. "Cesarean section. Assessment of the convenience factor." *J Reprod Med*, 29(9): 670–676.

Finkelstein, E. A., W. C. K. Graham, and R. Malhotra. 2014. "Lifetime Direct Medical Costs of Childhood Obesity." *Pediatrics*, 133(5): 854–862.

Fraser, William, Robert H. Usher, Frances H. McLean, Carol Bossenberry, Mary Ellen Thomson, Michael S. Kramer, L.Paul Smith, and Hugh Power. 1987. "Temporal variation in rates of cesarean section for dystocia: Does "convenience" play a role?" *American Journal of Obstetrics and Gynecology*, 156(2): 300 – 304.

Global Asthma Network. 2018. *The Global Asthma Report 2018.* Auckland, New Zealand:Global Asthma Network.

Gruber, Jonathan, and Maria Owings. 1996. "Physician Financial Incentives and Cesarean Section Delivery." *The RAND Journal of Economics*, 27(1): 99.

Halla, Martin, Harald Mayr, Gerald J. Pruckner, and Pilar Garcia-Gomez. 2016. "Cutting Fertility? The Effect of Cesarean Deliveries on Subsequent Fertility and Maternal Labor Supply." IZA Discussion Paper

Hannah, Mary E, Walter J Hannah, Sheila A Hewson, Ellen D Hodnett, Saroj Saigal, Andrew R Willan, and Term Breech Trial Collaborative. 2000. "Planned caesarean section versus planned vaginal birth for breech presentation at term: a randomised multicentre trial." *The Lancet*, 356(9239): 1375–1383.

Harjutsalo, V. 2008. "Time trends in the incidence of type 1 diabetes in Finnish children: a cohort study." *Lancet (London, England)*, 371(9626): 1777–82.

Hyde, Matthew J., Alison Mostyn, Neena Modi, and Paul R. Kemp. 2012. "The health implications of birth by Caesarean section." *Biological Reviews*, 87(1): 229–243.

Hyde, Matthew James, and Neena Modi. 2012. "The long-term effects of birth by caesarean section: The case for a randomised controlled trial." *Early Human Development*, 88(12): 943–949.

Jachetta, Christine. 2015. "Cesarean Sections and Later Health Outcomes.". Unpublished, Available at http://www.christinejachetta.com.

Jensen, Vibeke Myrup, and Miriam Wüst. 2015. "Can Caesarean section improve child and maternal health? The case of breech babies." *Journal of Health Economics*, 39: 289 – 302.

Johnson, Erin M., and M. Marit Rehavi. 2016. "Physicians Treating Physicians: Information and Incentives in Childbirth." *American Economic Journal: Economic Policy*, 8(1): 115–41.

Keag, Oonagh E., Jane E. Norman, and Sarah J. Stock. 2018. "Long-term risks and benefits associated with cesarean delivery for mother, baby, and subsequent pregnancies: Systematic review and meta-analysis." *PLOS Medicine*, 15(1): 1–22.

Knip, M, and O Simell. 2012. "Enviornmental Triggers of Type 1 Diabetes." *Cold Spring Harbor perspectives in medicine*, 2(7): a007690.

Kuhle, Stefan, Sara F L Kirk, Arto Ohinmaa, and Paul J Veugelers. 2011. "Comparison of ICD code-based diagnosis of obesity with measured obesity in children and the implications for health care cost estimates." *BMC Medical Research Methodology*, 11: 173.

Leung, Donald Y.M., Mark Boguniewicz, Michael D. Howell, Ichiro Nomura, and Qutayba A. Hamid. 2004. "New insights into atopic dermatitis." *The Journal of Clinical Investigation*, 113: 651–657.

Lobstein, T., L. Baur, and R. Uauy. 2004. "Obesity in children and young people: a crisis in public health." *Obesity Reviews*, 5(s1): 4–85.

McCloskey, L., D. B. Petitti, and C. J. Hobel. 1992. "Variations in the use of cesarean delivery for dystocia: lessons about the source of care." *Med Care*, 30(2): 126–135.

Mishanina, Ekaterina, Ewelina Rogozinska, Tej Thatthi, Rehan Uddin-Khan, Khalid S. Khan, and Catherine Meads. 2014. "Use of labour induction and risk of cesarean delivery: a systematic review and meta-analysis." *Canadian Medical Association Journal*, 186(9): 665–673.

Mühlrad, Hanna. 2017. "Cesarean section for high-risk births: short and long term consequences for breech births.". https://www.dropbox.com/s/xto1qlsf1qtxf7d/C-section_Muhlrad.pdf. Accessed: 26-12-2017.

Neu, Josef, and Jona Rushing. 2011. "Cesarean Versus Vaginal Delivery: Long-term Infant Outcomes and the Hygiene Hypothesis." *Clinics in Perinatology*, 38(2): 321 – 331. Delivery After Previous Cesarean.

NICE. 2011. "Cesarean section." National Institute for Health and Care Excellence NICE Clinical Guideline CG190. https://www.nice.org.uk/guidance/cg132/chapter/1-guidance. Accessed: 06-12-2017.

NICE. 2014. "Intrapartum care for healthy women and babies." National Institute for Health and Care Excellence NICE Guideline CG190. https://www.nice.org.uk/guidance/cg190. Accessed: 06-02-2017.

Nielsen, Helena Skyt, Nina Smith, and Aycan Çelikaksoy. 2009. "The effect of marriage on education of immigrants: Evidence from a policy reform restricting marriage migration." *Scandinavian Journal of Economics*, 111(3): 457–486.

OECD. 2013. *Health at a Glance 2013: OECD Indicators.* Paris:OECD Publishing.

OECD. 2017. *Health at a Glance 2017: OECD Indicators.* Paris:OECD Publishing.

Oreopoulos, P., M. Stabile, R. Walld, and L. L. Roos. 2008. "Short-, medium-, and long-term consequences of poor infant health: An analysis using siblings and twins." *Journal of Human Resources*, 43: 88–138.

Ottosson, Filip, Louise Brunkwall, Ulrika Ericson, Peter M Nilsson, Peter Almgren, Céline Fernandez, Olle Melander, and Marju Orho-Melander. 2018. "Connection Between BMI-Related Plasma Metabolite Profile and Gut Microbiota." *The Journal of Clinical Endocrinology & Metabolism*, 103(4): 1491–1501.

Peters, Lilian L., Charlene Thornton, Ank de Jonge, Ali Khashan, Mark Tracy, Soo Downe, Esther I. Feijen-de Jong, and Hannah G. Dahlen. 2018. "The effect of medical and operative birth interventions on child health outcomes in the first 28 days and up to 5 years of age: A linked data population-based cohort study." *Birth*, 1–11.

Prior, Emily, Shalini Santhakumaran, Chris Gale, Lara H Philipps, Neena Modi, and Matthew J Hyde. 2012. "Breastfeeding after cesarean delivery: a systematic review and meta-analysis of world literature." *The American Journal of Clinical Nutrition*, 95(5): 1113–1135.

Reed, Shelby D, Todd A Lee, and Douglas C McCrory. 2004. "The Economic Burden of Allergic Rhinitis." *PharmacoEconomics*, 22(6): 345–361.

Saccone, Gabriele, and Vincenzo Berghella. 2015. "Induction of labor at full term in uncomplicated singleton gestations: a systematic review and metaanalysis of randomized controlled trials." *American Journal of Obstetrics and Gynecology*, 213(5): 629 – 636.

Scudellari, Megan. 2017. "News Feature: Cleaning up the hygiene hypothesis." *Proceedings of the National Academy of Sciences*, 114(7): 1433–1436.

Skoner, David P. 2001. "Allergic rhinitis: Definition, epidemiology, pathophysiology, detection, and diagnosis." *Journal of Allergy and Clinical Immunology*, 108(1, Supplement): S2 – S8.

Stock, James, and Motohiro Yogo. 2005. "Testing for Weak Instruments in Linear IV Regression." In *Identification and Inference for Econometric Models.* , ed. Donald W.K. Andrews, 80–108. New York:Cambridge University Press.

Strachan, D P. 1989. "Hay fever, hygiene, and household size." *BMJ (Clinical research ed.)*, 299(6710): 1259–60.

Sund, Reijo. 2012. "Quality of the Finnish Hospital Discharge Register: A systematic review." *Scandinavian Journal of Public Health*, 40(6): 505–515.

Tao, Betty, Massimo Pietropaolo, Mark Atkinson, Desmond Schatz, and David Taylor. 2010. "Estimating the cost of type 1 diabetes in the U.S.: A propensity score matching method." *PLoS ONE*, 5(7).

Thavagnanam, S., J. Fleming, A. Bromley, M. D. Shields, and C. R. Cardwell. 2008. "A meta-analysis of the association between Caesarean section and childhood asthma." *Clinical & Experimental Allergy*, 38(4): 629–633.

Tonei, Valentina. 2019. "Mother's mental health after childbirth: Does the delivery method matter?" *Journal of Health Economics*, 63: 182–196.

Torpy, Janet M. 2010. "Chronic diseases of children." *JAMA - Journal of the American Medical Association*, 303(7): 682.

Tuomisto, L.E., M. Erhola, T. Luukkaala, H. Puolijoki, M.M. Nieminen, and M. Kaila. 2010. "Asthma Programme in Finland: Did the use of secondary care resources become more rational?" *Respiratory Medicine*, 104(7): 957 – 965.

Wright, Suzanne M., and Louis J. Aronne. 2012. "Causes of obesity." *Abdominal Radiology*, 37(5): 730–732.

Appendix

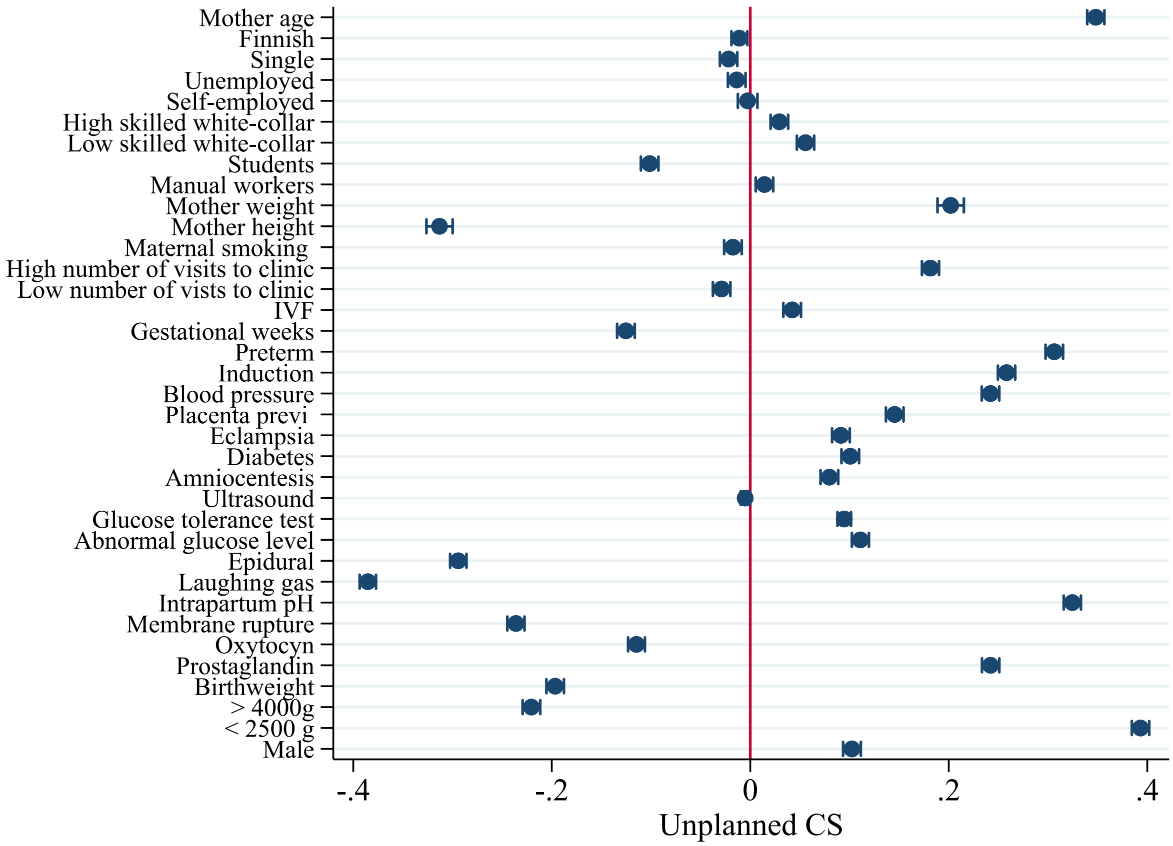


Figure A1: Difference in baseline characteristics by type of birth

Notes: The figure represents the coefficients and 95% CI from separate regressions of each (standardized) predetermined variable on an indicator taking value 1 if the mother had an unplanned C-section, and 0 if it was a vaginal delivery, controlling for normal shift time, pre-leisure day, and hospital, month, and year of birth fixed effects. Sample is restricted to single births, unscheduled C-sections and vaginal births that take place on working days.

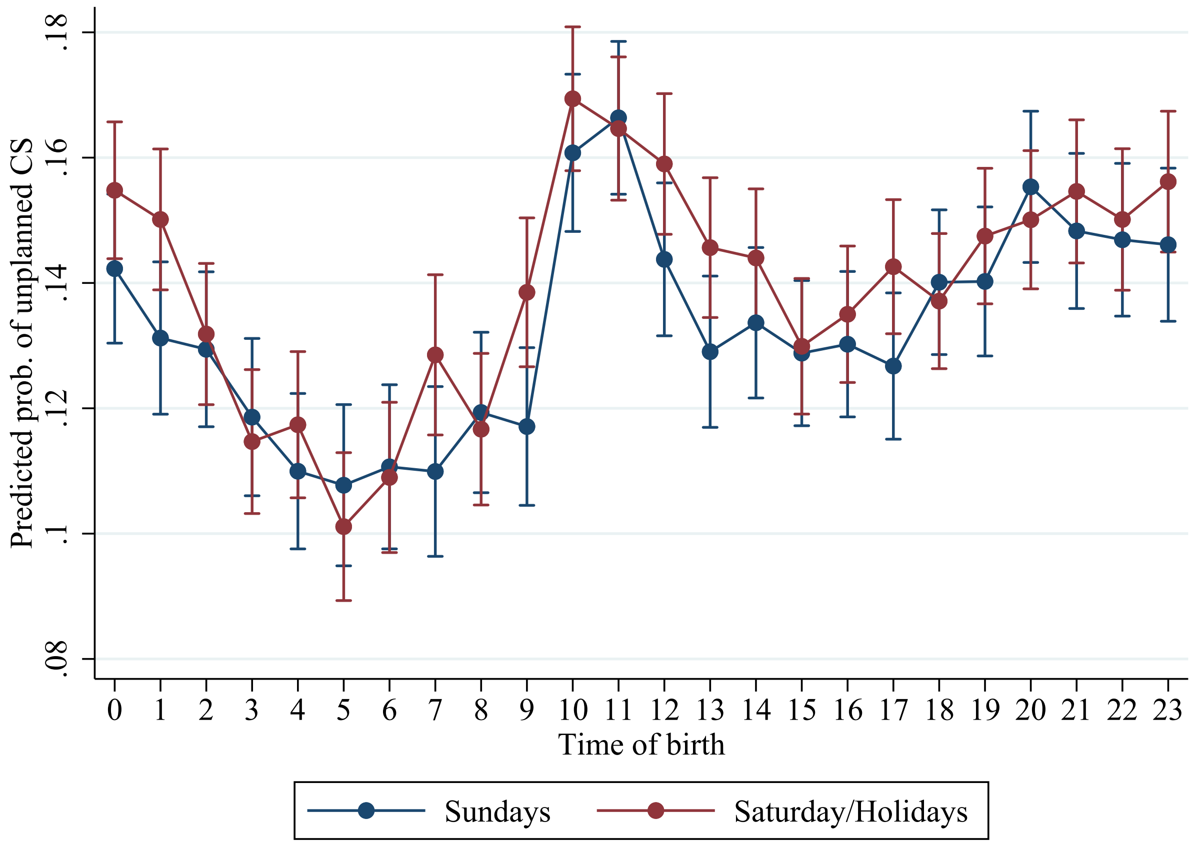
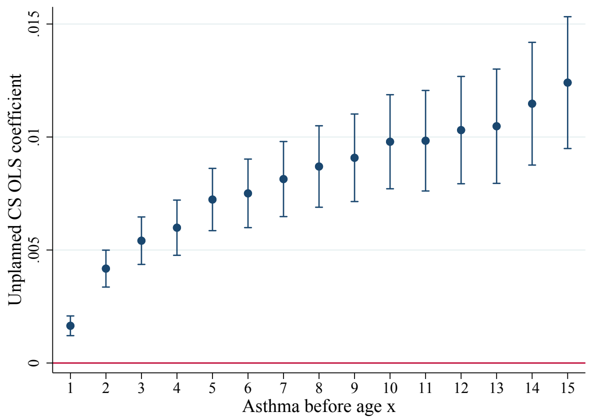
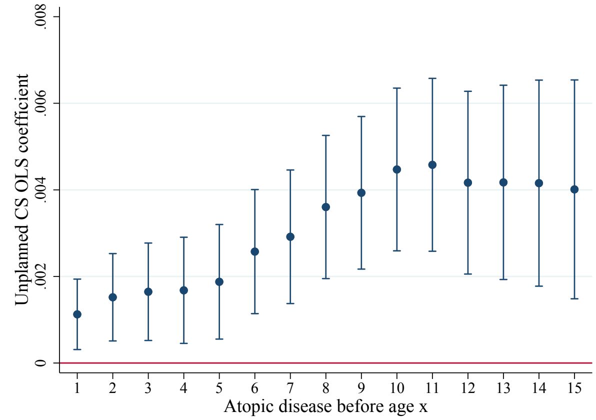


Figure A2: Predicted probability of unplanned C-section by time on weekends

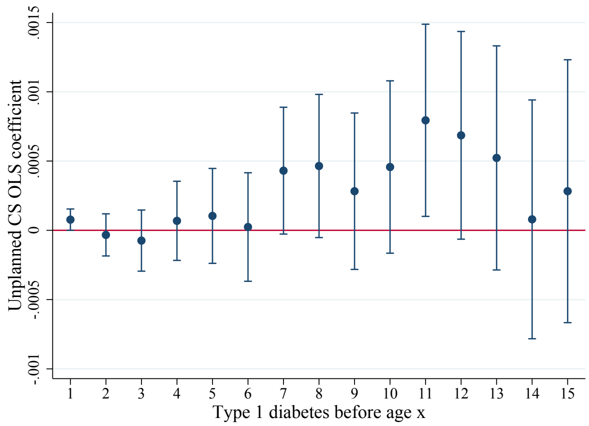
Notes: The figure represents the predicted probability of unplanned C-sections by time of birth for Sundays and for Saturdays or holidays, adjusting for hospital, month, and year of birth fixed effects. Sample is restricted to single births, unscheduled C-sections and vaginal births that take place on Saturdays or holidays and Sundays.



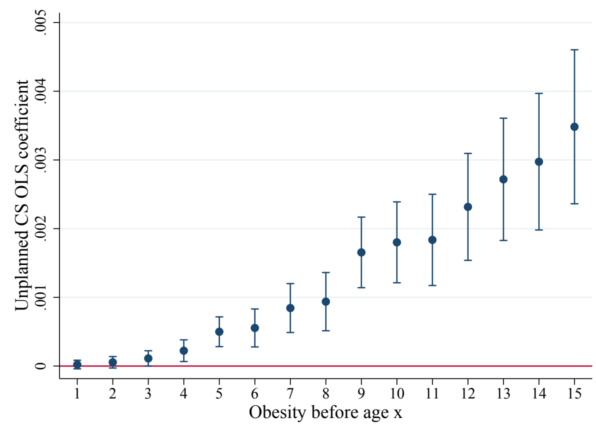
(a) Asthma



(b) Atopy



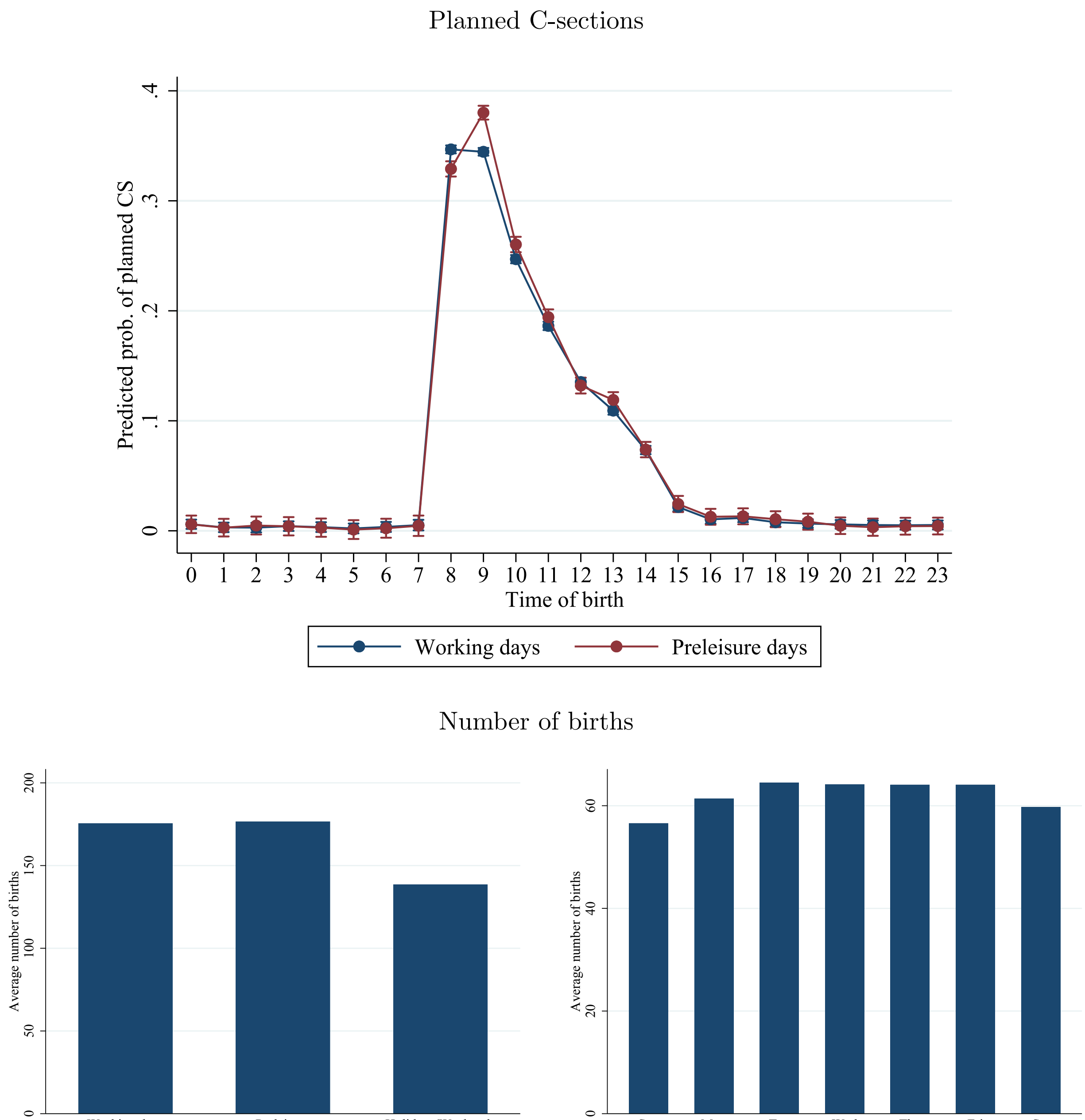
(c) Type 1 Diabetes



(d) Obesity

Figure A3: OLS estimation: Child diagnoses by age

Notes: The figure plots the results from the OLS estimation of the effect of unplanned CS on the probability of each diagnosis by age, with our usual specification. All regressions include hospital, year, and month of birth fixed effects and the full set of controls described in section 3.2.



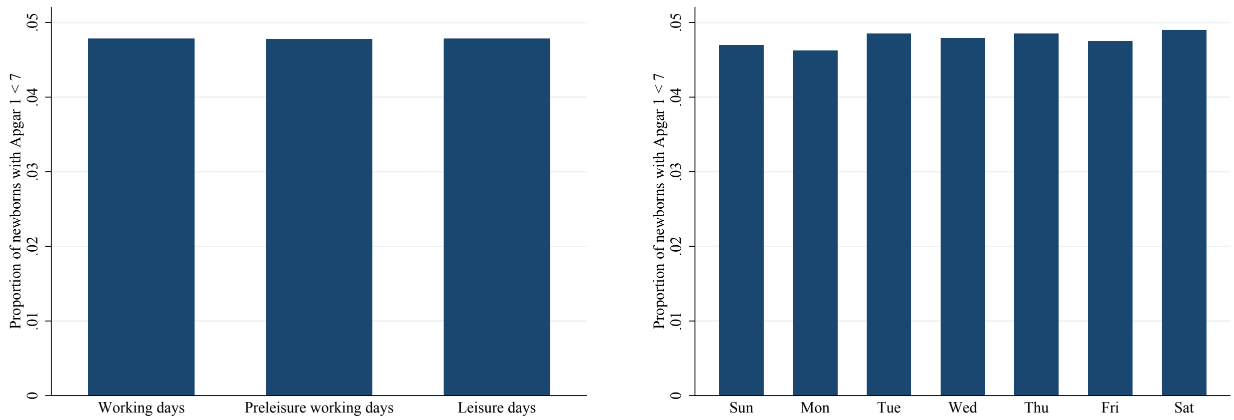
(a) Births by type of day

(b) Births by weekday

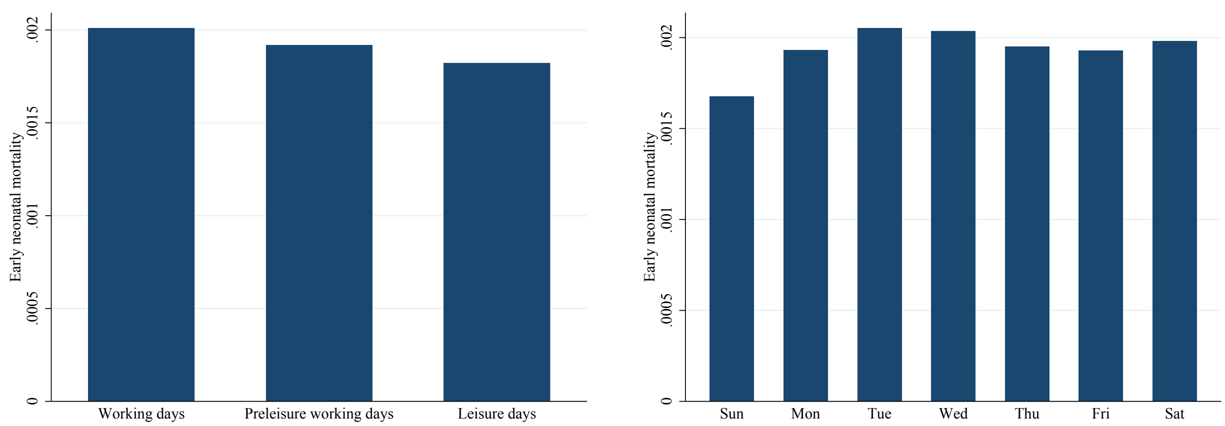
Figure A4: Activity at maternity wards by type of day

Notes: This figure plots, in the first panel, the probability of planned C-section by time of birth on pre-leisure working days and other working days, and in the second panel, the average number of births by type of day (column (a)) and by weekday (column (b)).

Low Apgar score



Early neonatal mortality

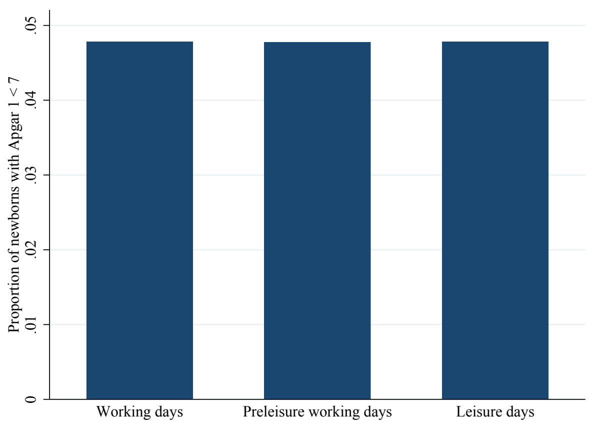


(a) By type of day

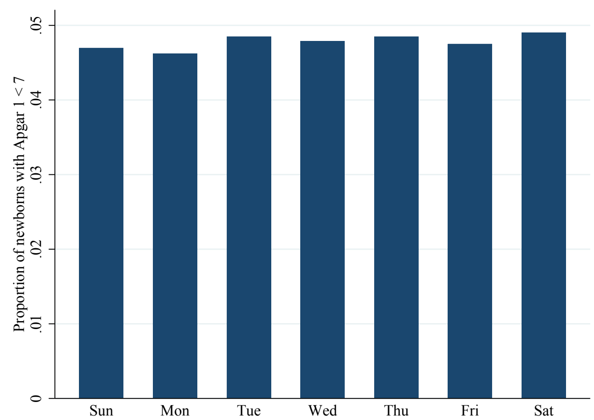
(b) By weekday

Figure A5: Quality of care by type of day

Notes: This figure plots, in the first panel, the probability of the newborn having low Apgar score and in the second panel the probability of early neonatal mortality by type of day (column (a)) and by weekday (column (b)). Sample is restricted to single births, unscheduled C-sections and vaginal births.



(a) By type of day



(b) By weekday

Figure A6: Mother length of stay by type of day

Notes: This figure plots, in the left panel, the average length of stay of the mother for mothers who had a C-section by type of day, and in the right panel, by day of the week. Sample is restricted to single births and unscheduled C-sections.

Table A1: Summary statistics

	Full sample	
	Mean	SD
Background characteristics		
Mother's age	29.369	5.335
Finnish	0.958	0.200
Married	0.628	0.483
Unemployed	0.004	0.061
Selfemployed	0.017	0.128
High skilled white-collar	0.178	0.382
Low skilled white-collar	0.433	0.496
Student	0.095	0.294
Manual workers	0.180	0.384
Pregnancy characteristics		
Mother weight	66.780	14.033
Mother height	165.562	6.032
Tobacco during pregnancy	0.128	0.334
High visits clinic	0.239	0.426
Low visits clinic	0.190	0.392
IVF	0.003	0.057
Gestational weeks	39.702	1.853
Preterm	0.056	0.230
Previous CS	0.099	0.299
First birth	0.410	0.492
Blood pressure hospitalization	0.033	0.178
Placenta previa	0.003	0.052
Eclampsia	0.000	0.022
Gestational diabetes	0.007	0.085
Amniocentesis	0.029	0.168
Ultrasound	0.458	0.498
Glucose Tolerance Test	0.183	0.387
Glucose Tolerance Test Positive	0.049	
Childbirth characteristics		
Induction	0.165	0.372
Epidural	0.326	0.469
Laughing gas	0.453	0.498
Intrapartum pH	0.042	0.201
Membrane rupture	0.448	0.497
Oxytocyn	0.401	0.490
Prostaglandin	0.076	0.265
Birth weight	3520.736	571.55
Male	0.511	0.500
Mode of delivery		
Planned CS	0.071	0.257
Unplanned CS	0.101	0.301
Eutocic	0.763	0.425
Ventose	0.066	0.248
Forceps	0.001	0.033
Breech vaginal	0.005	0.073
Observations	1482884	

Table A2: Long-term outcome variables

Outcome	ICD-10 codes	Description
Asthma	J45, J46	Asthma is the most common chronic disease in children (Asher and Pearce, 2014). Asthma is an inflammatory disorder characterized by recurrent attacks of breathlessness and wheezing and can also cause cough, particularly in children. Recurrent asthma symptoms frequently cause sleeplessness, daytime fatigue, reduced activity levels and school and work absenteeism.[a] It is caused by a complex combination of genetic and environmental factors.
Atopic diseases	L20, J30.1-30.4, J30.8, J30.9	It includes atopic dermatitis and allergic rhinitis. Atopy is a predisposition toward developing certain allergic hypersensitivity reactions. Atopic dermatitis is a chronic inflammatory skin disease associated with cutaneous hyperreactivity to environmental trigger. It is believed to be the product of interactions between susceptibility genes, the environment and immunologic responses (Leung et al., 2004). Allergic rhinitis is characterized by one or more symptoms including sneezing, itching, nasal congestion, and rhinorrhea (Skoner, 2001).
Type 1 Diabetes	E10	Type 1 diabetes is a chronic auto-immune mediated disease. The body destroys beta cells, which are cells located in the pancreas that produce and segregate insulin, the hormone that regulates glucose levels in the blood. In type 1 diabetes patients, the body is unable to regulate glucose levels. This disease develops in genetically susceptible individuals, but the medical literature has recognized environmental factors as crucial in the triggering and development of the condition (Knip and Simell, 2012).
Obesity	E65-E68	It includes obesity, overweight, localized adiposity and other hyperalimentation. Obesity is defined as abnormal or excessive fat accumulation that may impair health. The prevalence of overweight and obesity among children and adolescents aged 5-19 has risen dramatically from just 4% in 1975 to just over 18% in 2016.[b] Although obesity is most commonly caused by excess energy consumption (dietary intake) relative to energy expenditure, the etiology of obesity is highly complex and includes genetic, physiologic, environmental, psychological, social and economic factors (Wright and Aronne, 2012). Recent research highlights the role of gut microbiota in the development of obesity (Ottosson et al., 2018).

[a] http://www.who.int/respiratory/asthma/en/
[b] http://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight

Table A3: Public Holidays in Finland (Year 1992)

Public holiday	Date (1992)	Weekday (1992)
New Year's Day	January, 1	Wednesday
Epiphany[a]	January, 6	Monday
Good Friday[b]	April, 17	Friday
Easter Sunday[c]	April, 19	Sunday
Easter Monday[d]	April, 20	Monday
May Day	May, 1	Friday
Ascension Day[e]	May, 28	Thursday
Whit Sunday[f]	June, 7	Sunday
Midsummer Eve[g*]	June, 19	Friday
Midsummer Day	June, 20	Saturday
Finnish Independence Day	December, 6	Sunday
Christmas Eve[*]	December, 24	Friday
Christmas Day	December, 25	Saturday
Boxing Day	December, 26	Sunday

[a] Epiphany was moved to January 6 in 1992. Previously, Epiphany was the Saturday following January 5. [b] Moveable Friday before Easter Sunday. [c] Moveable Sunday following the first full moon on or after March 21. [d] Moveable Monday after Easter Sunday. [e] Moveable Thursday 39 days after Easter Sunday. Until 1992, the Ascension Day was the Saturday before the Thursday1. [f] Moveable Sunday 49 days after Easter Sunday. [g] First Friday on or after June 19. [*] No legal status as a public holiday, but included in collective labor agreements.

Table A4: Relation of the instrument with discretionary diagnoses vs. medical emergencies

	(1) Dystocia	(2) Suspected fetal suffering
Preleisure day	-0.002**	-0.001
	(0.001)	(0.001)
Normal shift	-0.002**	0.005***
	(0.001)	(0.001)
Normal shift*Preleisure	0.005**	0.002
	(0.002)	(0.002)
Observations	392560	392560
Adjusted R^2	0.074	0.057
Controls	YES	YES
F-statistic	9.211	0.607

This table shows the results from our usual first-stage specification, but with the following dependent variables: in column 1, an indicator for prolonged or obstructed labor; in column 2, an indicator equal to 1 if fetal scalp pH measurements were taken during labor. All specifications include hospital, year, and month of birth fixed effects, and the full set of controls as described in equation (2). Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$

Table A5: First stage – Medical Professional Mothers vs. Others

Sample:	All non-medical mothers		Non-medical mothers with university education		Medical mothers	
Unplanned CS	(1)	(2)	(3)	(4)	(5)	(6)
Normal shift	0.014***	0.017***	0.014***	0.018***	0.025***	0.025***
	(0.001)	(0.001)	(0.002)	(0.005)	(0.006)	(0.005)
Preleisure day	0.001	-0.002	-0.001	-0.002	0.000	-0.002
	(0.002)	(0.002)	(0.003)	(0.007)	(0.007)	(0.007)
Normal shift*Preleisure	0.016***	0.015***	0.015**	0.014**	-0.004	-0.003
	(0.003)	(0.003)	(0.005)	(0.012)	(0.012)	(0.012)
Observations	367825	367825	147463	147463	22526	22526
Adjusted R^2	0.008	0.071	0.008	0.072	0.006	0.068
Controls	NO	YES	NO	YES	NO	YES
Mean of Y	0.146	0.146	0.152	0.151	0.154	0.154
First-stage F	28.998	27.378	10.428	9.609	0.092	0.067

This table shows the usual first stage, with unplanned C-section as dependent variable, for different groups of mothers: all mothers not in the medical profession (columns 1-2), for mothers not in the medical profession with university education (columns 3-4), and for mothers in the medical profession (5-6). Medical mothers include doctors, nurses and midwives. All specifications include hospital, year, and month of birth fixed effects and the full set of controls as described in equation (2). Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.001$