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Maternity ward crowding, procedure use, and child health☆

Jonas Maibom[a,*], Hans H. Sievertsen[b], Marianne Simonsen[c], Miriam Wüst[d]

[a] Aarhus University and IZA, Denmark
[b] University of Bristol, VIVE, and IZA, United Kingdom
[c] Aarhus University, Denmark
[d] University of Copenhagen, CEBI, VIVE, and IZA, Denmark

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ABSTRACT

This paper studies the impact of day-to-day variation in maternity ward crowding on medical procedure use and the health of infants and mothers. Exploiting data on the universe of Danish admissions to maternity wards in the years 2000–2014, we first document substantial day-to-day variation in admissions. Exploiting residual variation in crowding, we find that maternity wards change the provision of medical procedures and care on crowded days relative to less crowded days, and they do so in ways that alleviate their workload. We find very small and precisely estimated effects of crowding on child and maternal health. Thus our results suggest that, for the majority of uncomplicated births, maternity wards in Denmark can cope with the observed inside-ward variation in daily admissions without detectable health risks.

1. Introduction

Childbirth is one of the most common reasons for hospitalizations in developed health care systems. Across countries and over the past decades, the typical hospital birth has changed: We have witnessed an increase in the use of medical procedures, such as Caesarean sections (CS) and inductions, not only for at-risk populations but also for a more general and healthy population of births. While an existing literature has documented large benefits of additional medical care and specialized medical technologies for at-risk births in the short- and longer-run (Almond et al., 2010; Almond and Doyle, 2011; Bharadwaj et al., 2013; Daysal et al., 2015; Jensen and Wüst, 2015), we lack causal evidence on the impact of the level and variability of medical care that is informative for the majority of ex ante uncomplicated births. This paper starts filling this gap by studying the impact of one factor that may impact both the allocation of care and patient health, namely naturally occurring variation in the number of admissions to maternity wards or temporary maternity ward crowding. Thus we ask: What is the causal impact of being admitted for birth on a busy day rather than a less busy day on both procedure use and on child and maternal health?

Crowding breaks the link between underlying patient characteristics and assigned health care treatment because of the nature of maternity ward admissions: While wards can anticipate some of the variation in admissions (Macfarlane, 1978; Allin et al., 2015; Johnson and Rehavi, 2016), they cannot perfectly predict it. Maternity

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* Corresponding author.
E-mail addresses: maibom@econ.au.dk (J. Maibom), h.h.sievertsen@bristol.ac.uk (H.H. Sievertsen), msimonsen@econ.au.dk (M. Simonsen), miriam.w@econ.ku.dk (M. Wüst).

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wards operate in a similar fashion as emergency rooms, with admissions that are hard to schedule for (expected) uncomplicated birth. Thus our empirical strategy exploits variation in daily maternity ward admissions conditional on ward, year, season, day of week and ward times year fixed effects. Controlling for these factors allows us to study the impact of the residual variation in crowding beyond the expected admission load on a given day of admission for otherwise similar patients with a spontaneous birth.[1]

To examine the impact of crowding on procedure use and health, we exploit data on all admissions to Danish maternity wards in the years 2000–2014. In our data, we observe large day-to-day variation in admissions of well above 100 percent of mean admissions, and deviations of above 200 percent are not rare. Furthermore, the within-ward (over time) variation in crowding is similar to the level of variation we observe across maternity wards, i.e. in the number of daily admissions across small and large wards.

We first show that maternity wards change their care provision due to unexpected fluctuations in the number of daily admissions. This analysis is informative both in its own right but also for understanding potential consequences for patient health: Capacity or lack hereof may be among non-medical factors that impact procedure use. We find that maternity wards use fewer procedures for births admitted on crowded days relative to less crowded days.[2] Specifically, we find small but significant decreases in the probability of experiencing a medically induced birth. These findings may indicate that maternity ward staff attempt to alleviate pressure by avoiding to speed up deliveries (and postpone inductions). This finding is interesting in the light of the steadily increasing induction rates in many developed health care systems and accompanying debates on the benefits of the procedure in marginal cases. Moreover, in supplementary analyses on a subset of our data, we find that maternity wards adjust the timing of admission on a given day during busy periods: Mothers admitted on crowded days give birth faster, i.e. they are likely admitted at later stages of their birth. Likely related to the (on average) shorter stays at the maternity ward for women in labor, we find that those admitted on crowded days are less likely to receive pain relief, measured as the probability of having an epidural. Finally, while we see different types of adjustments in the wards with respect to procedures used and their timing, we do not detect effects on waiting times for pain relief in the form of epidurals (for those receiving an epidural), the timely initiation of skin-to-skin contact between the mother and the infant, and mothers' probability of having an emergency CS (our closest measures of patient experience).

[1] Importantly, as the patient-staff ratio is likely endogenous to the risk-profile of the admitted women, and as we cannot observe the actual patient-staff ratio or the staff assigned to a specific birth, we focus on the reduced form impact of being admitted on a busy vs. a less busy day. We detail these points in Section 2.

[2] While we account for scheduled CS in our measure of crowding, we do not assess the impact of crowding on scheduled CS as those are scheduled well in advance and taking many factors into account. We detail our identification strategy in Section 3.

Next, we examine the health consequences of temporary crowding on the day of the mother's admission for birth outcomes and child health in the first two years of life. We show that while crowding induces changes to the provision of care, it has only small effects on child and mother health in our sample. These health outcomes include infant well-being as measured by the probability of having a low APGAR score (a measure for infant Appearance, Pulse, Grimace, Activity, and Respiration) at 5 min; the probability of experiencing birth and post-birth complications for mothers; children's mortality, post-birth hospital stay, neonatal care admission, and readmissions and contacts to general practitioners (GPs) during the first two years of their life. Among these measures we specifically consider outcomes that relate to staff intensity (severe lacerations during birth) and severity (post-birth maternal complications that require additional medical procedures or operations). For maternal complications at and shortly after birth we find small but significant decreases due to more crowding–a result that likely relates to the decreased use of procedures such as inductions and pain relief on crowded days.

Our results for both health outcomes and procedure use are similar across alternative measures of temporary crowding such as an absolute measure based on the number of daily admissions and relative measures defined within a given ward. Furthermore, we do not find evidence of threshold effects, i.e. we do not find that our main results based on a continuous crowding measure and a linear regression model mask heterogeneity by the level of crowding (in the range observed in our data). Finally, we find limited evidence for heterogeneity in the effects across characteristics of the birth or hospital. Our findings suggest that the effect of crowding on the probability of experiencing an induction is strongest for first-born children, children born at a gestational age above 41 weeks, and children admitted to the largest maternity wards. Given that pregnancies at term or after are the main target group for inductions, our finding of stronger effects of crowding on inductions for beyond-term births and the absence of detectable health effects may indicate that maternity wards provide too many inductions on less busy days.

Our work contributes to an established literature on the impact of crowding for health care provision and health outcomes.[3] In this literature, studies vary in (i) the health care settings studied (and, as a result, the patient pool and health care organization considered), (ii) their measure of crowding (number of admissions, staff-patient ratios) and (iii) their approach towards handling unobserved factors that may impact both, crowding and patient health.

A number of studies has shown negative associations between crowding and patient health outcomes across settings (see, for example, Aiken et al., 2002; Morley et al., 2018).[4] Building on these correlational findings

[3] Related to this literature, a broader question in health economics concerns the importance of variations in health care resources (Chandra et al., 2011; Skinner, 2011) and ways to identify the health impacts of access to these resources (see, for example, Doyle, 2011; Doyle et al., 2015).

[4] For example, reviewing evidence from studies on crowding at the emergency department, Morley et al. (2018) conclude that crowding and patient health are (negatively) related. Using hospital level information

that predominantly use across-hospital variation, the literature on the impact of crowding has moved towards causally-identified estimates. These causal studies fall in two broad strands that either exploit legislative changes that permanently alter staffing levels (Cook et al., 2012; Matsudaira, 2014), or use sudden (within) hospital shocks that temporarily change the staff-patient ratio to identify the impact of crowding (Evans and Kim, 2006; Facchini, 2017; Woodworth, 2020). Our work is closely related to the second strand of studies, which–across different health care settings–has typically found smaller (if any) impact of changes in the patient-staff ratio or crowding shocks on health outcomes: Exploiting unexpected surges in hospital admissions that result in changes in the staff-patient ratio, Evans and Kim (2006) find only limited evidence for impacts of large shocks to hospital admissions on the length of the hospital stay and the risk of a subsequent readmission. Focusing on emergency room care, on the other hand, Woodworth (2020) uses sudden crowding shocks in established emergency departments due to the opening of new emergency departments to show that an alleviation of emergency department patient volume does matter for patient health: lower volumes lead to significantly lower patient mortality.[5] We complement this existing work on temporary crowding by providing evidence from the maternity ward – an until now under-studied setting. Moreover, our estimates for the health effects of crowding focus on an (on average) more healthy patient group than considered in much of the existing work: mothers, who give birth spontaneously. Finally, we study the policy-relevant margin of day-to-day variation in crowding. This analysis distinguishes our paper from studies that consider the impact of larger crowding shocks (such as closures or openings of new wards).

Besides providing estimates for the health impacts of crowding, we contribute novel evidence on crowding and the allocation of care and procedures in the maternity ward. Evidence on the ways in which crowding influences treatment decisions is scarce but instrumental for our understanding of drivers of medical care allocation. Existing research shows that crowding impacts decisions on the allocation of care: Harris et al. (2019) show that higher work-load in primary care settings leads to fewer procedures, fewer diagnoses, and more referrals. Within the area of neonatal care, Freedman (2016) exploits variation in empty beds at hospital neonatal intensive care units (NICUs) to document that short-term excess capacity increases NICU utilization among relatively low-risk infants but does not impact usage among at-risk infants. This finding suggests that the greater availability of resources affects the provision of care, especially for infants where the treatment decision is highly dependent on the discretion of medical professionals. Facchini (2017) uses data from one Italian maternity ward to document that crowding affects decisions about care allocation and procedure use. Specifically, women admitted for birth at times with a low midwife/patient ratio are more likely to receive an unscheduled CS than women admitted at times with better coverage. He also studies health outcomes and–in line with other causal studies on crowding–finds no significant effects on measures such as skin-to-skin contact, breastfeeding, APGAR<9, or NICU admissions but large standard errors preclude a conclusion of no important health effects.[6]

While we do not observe the patient-staff ratio (as in Facchini (2017)), our paper contributes new evidence on the causal impact of crowding on a broader set of medical treatments assigned to births (other than CS), and we are not constrained to one maternity ward and resulting power issues. Thus we extend on a closely related study by Marks and Choi (2019), who study the impact of temporary crowding at the maternity ward on the health of at-risk infants and health care spending in the U.S. They find that at-risk infants born on “slow days” receive more costly care (measured as overall hospital spending)—but they find limited mortality benefits of this additional spending. By studying procedure use and health outcomes in maternity wards in Denmark, we highlight the importance of accumulating empirical evidence on central policy questions across different settings: First, we open the black box of health care spending by providing evidence on the impact of crowding on specific procedures and treatments. Second, while Marks and Choi (2019) focus on the impact of crowding on the 10 percent at-risk infants in their data, we study the majority of non at-risk infants. We document changes in care and procedures provided for this group, while Marks and Choi (2019) do not find that crowding predicts spending for low-risk births in the U.S. This finding implies that also care for low-risk infants is susceptible to the impact of crowding.[7] Third, by considering a different margin of the patient health distribution, we confirm that, although

about ambulance diversion hours, Sun et al. (2013) find that emergency department crowding increases mortality and hospital stays. Sprivulis et al. (2006) show that crowding at the emergency room is associated with increased mortality. Closely related to our work, Snowden et al. (2017) use variation in crowding around actual delivery days (i.e. not on the day of admission) and compare busy days to less busy days at Californian maternity wards. They find that a busy day is related to significantly worse infant health outcomes (baby well-being as measured by a value on the APGAR score below 7, neonatal intensive care admissions, and length of post-birth hospital stay).

[5] In a related paper, crowding at emergency departments has also been shown to increase the costs of care: Exploiting variation induced by assignment of patients to different nurses, Woodworth and Holmes (2019) show that prolonged waiting time for patients with serious conditions increases hospital costs to care for the patient.

[6] Related to these findings, Avdic et al. (2018) provide indirect evidence on the impact of crowding in their study of maternity ward mergers. Those mergers resulted in the closure of smaller wards in Sweden. While they show that mergers do not have negative health effects for newborns, they find small negative impacts of hospital mergers on maternal health, as measured by a summary measure of maternal trauma. They show that a contributing factor for their result may be crowding that decreases the use of a central medical procedure: Caesarean Sections. As discussed above, in our setting, we do not find that crowding results in changes in the probability of having an emergency CS, which may explain, why we do not find strong post-natal health effects on mothers in our study.

[7] We also argue that we only can isolate exogenous variation in crowding for the non at-risk group given that hospitals typically schedule CS for at-risk pregnancies and this practice violates our identifying assumption. Furthermore, we abstain from instrumental variable strategies for the impact of crowding (applied in Marks and Choi (2019)), because we argue that crowding may impact infants through many channels–not all

crowding impacts procedure use also in this patient group, health effects are limited.

In sum, our paper contributes causally-identified evidence on crowding and its limited impact on patient health for a general and (on average) healthy population of patients in a so far understudied setting: the maternity ward. Moreover, we show that crowding impacts procedure use and thus we contribute new evidence on drivers of medical care allocation. Important for health care policy, our findings on the impact of crowding in Danish maternity wards suggest that wards react to temporary crowding by adjusting medical care assignment across several margins, among them the exact timing of admission during the day and the use of medical procedures. While our findings are not informative about the optimal absolute level of care in the maternity ward, we conclude that maternity wards in the Danish setting can balance natural variation in admissions for a general population of spontaneous births without negative health effects in the outcomes that we can study.

The paper proceeds as follows: Section 2 provides information on the institutional background and our data. Section 3 presents our empirical strategy and discusses the identifying assumptions. Section 4 presents our main results and examines their robustness. Finally, Section 5 concludes.

2. Background and data

2.1. Danish health care services during pregnancy and at birth

Health care around birth is publicly provided and free of charge for all residents in Denmark. Prior to birth, GPs and midwives provide prenatal care. Home births account for around two percent of all births in Denmark, and there are no private maternity wards. Hospital assignment occurs in the first trimester of pregnancy and, by default, women give birth at the hospital of their catchment area. However, in the event of excess capacity, pregnant women can choose freely among all other public hospitals. Anticipated high-risk births may be assigned to specialized hospitals.

Hospital births for (expected) uncomplicated births in Denmark are performed in the maternity ward and are as a default midwife-assisted. In our data period, we document that women on average spend around 10 h in the maternity ward (an average that masks large heterogeneity). During the course of labor, midwives (in cooperation with the prospective parents) determine treatment and procedure choices. Only in case of complications the midwife consults a physician, and all maternity wards have specialist physicians as backup for the case of complications during birth. At-risk births (that are performed as scheduled CS) do not enter the maternity ward on the described terms but are treated by a pre-allocated team of staff members including obstetricians, anesthesiologists, nurses, and midwives.

of which are observed. For further details on our identification strategy, see Section 3.

After uncomplicated hospital births, mothers and infants are either admitted to a separate hospital ward for continued care and observation or discharged on the same day. Postnatal hospital care involves guidance and care by hospital-based nurses (to help women to establish infant feeding), as well as health checks and screenings. Outpatient care after birth for higher parity mothers (and increasingly also first-time mothers) is common in Denmark. Mothers return to the hospital for health checks and screenings and receive early postnatal home visits by trained home visitors in the Danish home visiting program. In our sample, 36 percent of mothers are discharged on the day of birth.[8]

2.2. Data

We use data on all births (including stillbirths and multiple births) during 2000–2014 from the Danish Medical Birth Register.[9] From the raw data, we omit births that take place at home, resulting in 945,072 relevant births.[10]

We link these birth records to a number of other administrative data sources providing us with a set of individual level control variables for a range of pregnancy and parental characteristics, including an indicator of pregnancy complications, indicators for parental educational status (in education, completed higher education, completed university), parental non-western origin, parental disability pension status and parental disposable income (2010 level).[11]

2.2.1. Treatment variable and analysis sample

To construct our main treatment variable of crowding on the day of admission for birth, we link the birth records to the Danish Inpatient Register. Not all mothers are admitted to hospital on the day they give birth. To assign the relevant day of admission to each birth, for each mother we identify the hospital admission date that is closest to the date of birth of the relevant child and that is not separated from this date by a hospital discharge date. For 98 percent of mothers in our sample, the birth admission date to a maternity ward lies during the 3 days up to the birth of the child; for 94 percent, the relevant admission is on the day before or on the day of their child's birth. We use the full sample of hospital births to construct our treatment variables measuring crowding on the day of the birth-related hospital admission for each mother.[12] Thus we include scheduled CS and multiple births, the latter with the num-

[8] In our results section, we examine whether crowding impacts the probability of a same-day discharge for mothers.

[9] As stillbirth we define births that have completed at least 170 days of gestation and that have a death date on the day of birth. We exclude registered births with shorter gestation.

[10] Mothers have to make the decision to give birth in an assisted home birth already during the pregnancy.

[11] All characteristics are measured two calendar years prior to the relevant child's birth. For missing values, we set the value to zero and include an indicator variable for missing values for each of the covariates.

[12] We subtract the focal mother from the number of admissions on her admission day.

ber of children in the birth.[13] We construct two measures of maternity ward crowding: (i) the absolute (leave out) number of admissions to each maternity ward on any admission day and (ii) the percentile rank (between 0 and 1) of the given admission day (within hospital, season (quarter) and year cells).[14]

Having computed our measures of crowding on our full sample of hospital births, we constrain our estimation data in the following three ways: First, given that our analysis relies on an extensive set of fixed effects (i.e. compare outcomes in cells defined by year, ward, maternity ward × year, season, and day of the week cells), we drop births in small year × ward cells of less than 700 births (3 percent of the sample). Second, we omit scheduled CS (around 9 percent of our sample) and multiple births (in our sample, more than half of the multiple births are delivered through a scheduled CS). We omit scheduled CS as hospitals typically plan these births ahead and perform them well ahead of full term status. Thus, those births are less responsive to crowding and are performed under different circumstances than (attempted) spontaneous births (with a special focus of medical staff on planning them and on devoting extra resources to them).[15] These constraints result in a final analysis sample of 796,416 mothers and their (singleton) births.

2.2.2. Outcome variables

Ward-level Adjustments. Faced with crowding, maternity ward staff can adjust their behavior along various margins, some of which affect the interpretation of our estimates and some of which we can directly study in this paper. First, they may call in additional staff; second, they may try to affect the pool of patients arriving at the ward by referring some, maybe more complicated, cases to other hospitals; third, they may change their procedure use to less labor-intensive procedures. First, maternity wards typically have a number of staff on hold and can call in additional midwives or physicians in case of crowding: Danish midwives face ex ante large uncertainty about the exact timing of their work hours: only 54 percent of their total hours worked are planned well ahead of time and as many as 15 percent of work hours consist of time being available from home. Thus, as we would expect, hospitals can buffer some of the observed crowding (Danske Regioner, 2017). Unfortunately, we have no hospital- or individual-level data on staff or staff on hold but even with access to this type of information, the nature of the response—both in terms of the number of staff members called in and in terms of their skill set—would be endogenous to the severity of patient cases. Given that we consider the reduced form estimates of crowding, we likely underestimate the impact of crowding (that may be buffered by additional staff called into duty as an endogenous response to crowding).

Second, a channel of adjustment that we can study is the mothers' probability of being transferred to another hospital in the case of crowding. Aggregate data does not suggest that this channel is quantitatively important: A recent policy report from the Danish regions reports that women in active labor are only very rarely referred to other hospitals (Danish Regional Administration 2017): in 2013, in the Capital Region, out of about 20,000 births, 177 women were sent to other wards; in the Region of Southern Denmark, the corresponding numbers were as low as seven out of roughly 11,000. To explore the question as to whether transfer of births to other wards is impacted by crowding, we study the probability of being admitted to another hospital for birth than the one assigned in the first trimester of the pregnancy. This measure captures women who happened to be away from home at the start of labor, potential referrals to other wards because of crowding, and referrals during pregnancy, due to the need for specialized treatment. Therefore, this measure is also driven by other factors than ward responses to crowding.

Third, we study different types of procedure use. We exploit unique data on medical procedures and the timing of events during and after labor. We study mothers' probability of experiencing a (medical) stimulation during labor, their probability of experiencing an induction of labor, and the probability of experiencing an emergency CS.[16] All these procedures require more continuous support and monitoring of the birth by staff (midwives and, in the case of a CS, also physicians). Changes in those procedures may also impact other outcomes, for instance inductions may lead to a higher risk of experiencing an emergency CS.

In a subset of data for the period 2011–2014, we can study a final set of procedural outcomes which are informative of staff- and resource-demanding factors: the timing between admission to hospital and the birth, the waiting time for an epidural, and the timely establishment of skin-to-skin contact. Later admissions during labor may be quantitatively more important than transfers of women during labor. If hospitals attempt to cope with crowding by delaying new admissions, we may expect shorter birth spells on crowded days. The establishment of skin-to-skin contact between infant and parents within 2 h after birth was a central quality indicator for Danish hospitals in the period that we study, and we therefore create an indicator for the ward meeting this target in the given birth.

Taken together, our data on procedures and waiting times allow us to examine a range of potential margins for adjustments made by the maternity ward staff in the case of crowding. Our discussion of these potential adjustments also illustrates why we examine the impact of crowding on health in a reduced form framework: Crowding likely affects many margins of staff behavior and goes beyond adjusting the staff patient ratio.

[13] We have also generated crowding measures that exclude scheduled CS. Results are very similar and available on request.

[14] We have also experimented with other treatment measures, e.g. the number of admissions on any admission day relative to the hospital- and year-specific median day and crowding variables relative to ward×year cells with very similar results.

[15] In our main analyses, we control for the number of scheduled CS on the day of hospital admission.

[16] In our data emergency CS are CS performed subsequent to an attempted vaginal birth or performed with short notice, i.e. the decision for a CS is taken less than 8 h prior to the procedure.

Health Outcomes. Having studied maternity ward procedure use, we turn to an analysis of measures of health at birth and in the longer run. As a first set of measures, we use data from the Danish Inpatient Register on diagnoses (at birth and in the post-birth period). Using diagnoses given around birth in our study is not without complications: It is not straightforward to classify birth complications by severity and their sensitivity to staff action (which would be the relevant complications to study). Finally, using the many available and fine-grained ICD diagnosis codes used to classify complications in our data may lead to Type I errors: testing hypotheses for multiple and small groups of diagnosis subgroups may lead us to make inappropriate conclusions about the power of our results.[17]

As a consequence, to use the administrative data on diagnosis and operations around birth while balancing the above factors, we proceed in two steps: First, we create broad summary measures for both maternal complications at birth and post-birth, i.e. indicators that are one for a broad group of diagnosis groups related to complications at birth and to post-birth complications.[18] Second, we create three additional measures (two additional measures linked to birth and one additional post-birth measure) that allow us to zoom in on both the staff-intensity and severity of complications:[19] For complications at birth, we single out one diagnosis group (and do not include it in our initial summary measure) for further scrutiny: Lacerations of varying degree. This measure is suitable for our analysis for three reasons: (i) it is closely monitored by the national Danish health agencies as a measure of hospital performance (thus hospitals and personnel put emphasis on monitoring it), (ii) it is modifiable by staff (midwife) attention, and (iii) it allows us to measure the severity of the complication (by focussing on either relatively mild degree one to two, or severe degree three to four lacerations). For post-birth complications, we create a measure of severity by creating a complication indicator that is one only for mothers, who both have a relevant diagnosis of post-birth complications and a relevant operation code in the 90 days post birth. The reasoning for this measure is that these mothers suffer more severe complications that require additional attention by medical professionals.

To complete our measures of health at birth, we report results for the child's probability of having a low APGAR score at 5 min. We both consider a cut-off of APGAR > 7 and APGAR > 9. For the child, we consider a number of additional health measures: First, we study mortality as the probability of a stillbirth, a perinatal death (stillbirth or death in first week) and first-year death. Second, we use measures of health care usage in the short- and longer run: We study the probability of neonatal care unit admission,[20] the length of hospital stay after birth, readmissions to hospital, and contacts with GPs within the first month and during the first and second year of the child's life.[21]

2.3. Descriptive statistics

Appendix Table A.1 provides summary statistics for the key variables in our analysis dataset. Excluding the focal mother, the average daily number of maternity ward admissions across all hospitals and years is 8.4 in our sample. The same statistic excluding scheduled CS is 7.6. The table shows large variation in the number of daily admissions caused by both differences across wards and days. Note that, by construction, busy days have more births (and thus more observations) and therefore the average percentile rank in the sample of births is above 0.5.

The lower part of Table A.1 describes our central outcome measures. On average, 19 percent of mothers experience an induction. Illustrating that we use a relatively broad measure of complications at birth, 57 percent of mothers experience a complication (see Appendix B for a list of the ICD codes included in this measure.) Five percent of mothers fall into the group with post-birth complications. Measures of child health show that readmissions to hospital in the first year are not rare (22 percent) while mortality is at very low levels.

When moving to more detailed procedural data, our data only covers the years 2011–2014 and thus the number of observations is smaller. 24 percent of mothers in our sample have an epidural for pain relief and their average waiting time for the epidural to be administered is around 37 min.

To describe our treatment variable of interest, crowding at the maternity ward, in the sample, Appendix Fig. A.1 panel (a) illustrates the distribution in the raw number of admissions for all wards for the year 2010. Maternity wards experience between one and 25 admissions per day (see also Appendix Table A.1). The median number of admissions in our sample is seven. In panel (b) we show a residualized measure of admissions for the year 2010 (our residualized measure takes out year, season, weekday, ward and ward $\times$ year fixed effects, see the next section). The figure illustrates that although we account for those factors – e.g. that there are hospital wards of different size and that certain days of the week are more busy than others – there is remaining variation, namely days with deviations from the average day between -8 and 8 admissions.

Fig. 1 illustrates the number of admissions at the ward level. The top panel of Fig. 1 shows the daily admissions for the year 2010 for a small ward (Horsens) and Denmark's largest maternity ward (Hvidovre). These maternity wards

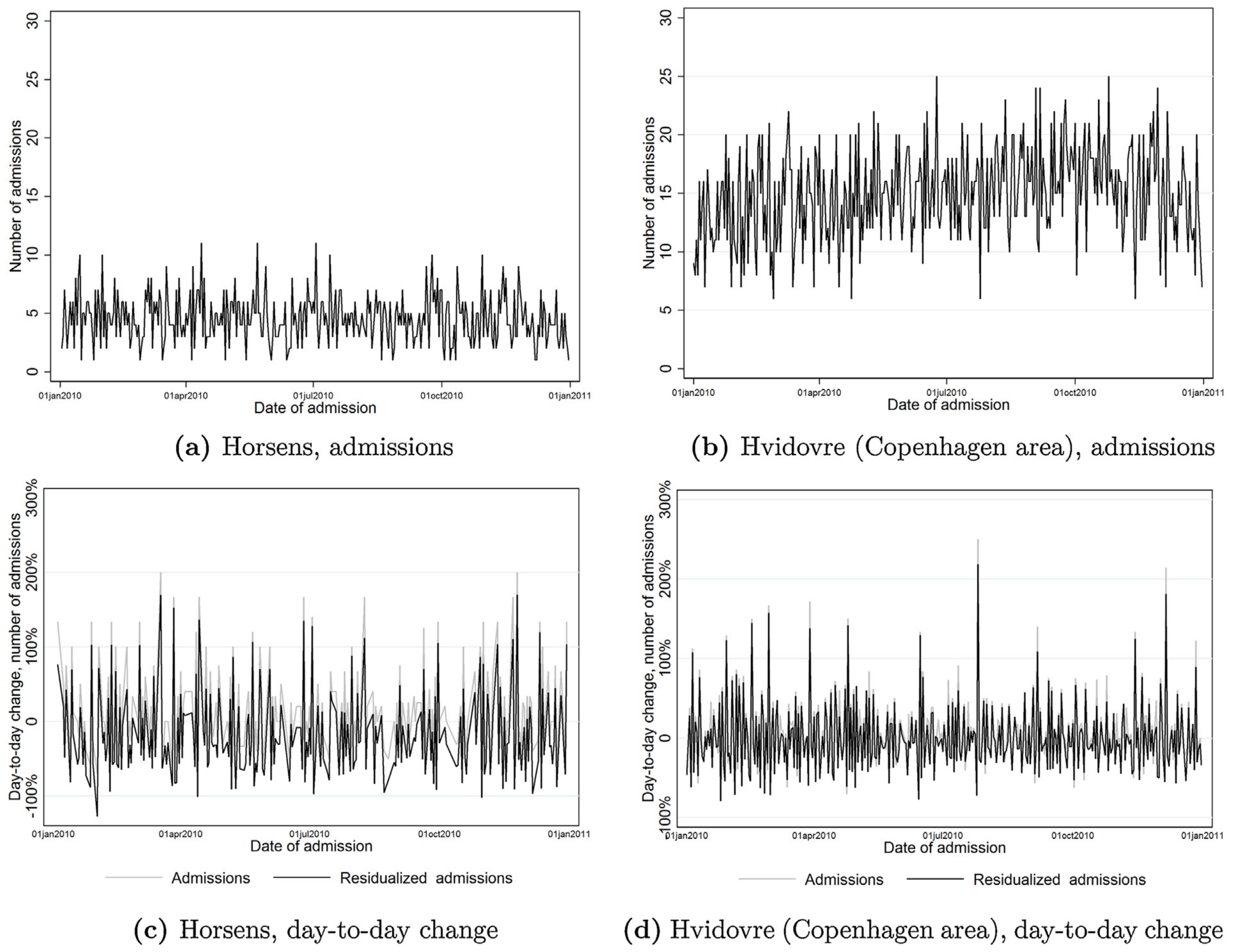
[17] Another issue is registration practice: we may be concerned that either the focus on detailed registrations of diagnoses or the member of staff responsible for registration could be a function of crowding and thus be impacted. However, typically registrations for the Inpatient Registry are made after the birth is completed (while during the birth midwives make notes) and according to monitoring requirements imposed by the national authorities, hospitals are required to complete registrations for every birth event in the Inpatient Registry. We therefore assume that this issue should be minor.

[18] For a list of the relevant ICD 10 groups, consult Appendix B.

[19] We fully acknowledge that this choice of specific outcomes focuses our analyses to specific diagnosis groups and is not exhaustive.

[20] Our measure of neonatal care admission comes from the medical birth registry and is defined as admission to a specialized paediatric ward and a diagnosis code from IDC10 group "P".

[21] For each outcome we omit children who die prior to the "measurement period", e.g. observations involving stillbirths are not included in the analysis sample for hospital admissions.



(a) Horsens, admissions

(b) Hvidovre (Copenhagen area), admissions

(c) Horsens, day-to-day change

(d) Hvidovre (Copenhagen area), day-to-day change

Fig. 1. Daily number of admissions and day-to-day variation in the number of daily admissions (residualized), selected maternity wards.

had on average, about five and 15 daily admissions, respectively. However, there is substantial variation in admissions in both the small and the large maternity ward. This point is underlined by the bottom panel of Fig. 1, which shows the relative day-to-day fluctuations in admissions for the same two wards. We observe that days with more than twice as many admissions than the day before are common in both the small and large maternity wards.[22] Furthermore, we observe day-to-day changes in both the raw measure of number of admissions and in our residualized measure in the two wards.

3. Empirical methods

To examine the impact of temporary crowding on maternal and child health, we exploit residual variation in the number of admissions to Danish maternity wards. Specifically, we estimate the reduced form relationship

$$Y_{idsyw} = \alpha_0 + \alpha_1 crowd_{idsyw} + \boldsymbol{\beta}' X_{idsyw} + \boldsymbol{\delta_y} + \boldsymbol{\lambda_s} + \boldsymbol{\theta_d} + \boldsymbol{\gamma_w} + \boldsymbol{\delta_y} \times \boldsymbol{\gamma_w} + \epsilon_{idsyw} \quad (1)$$

where Y is an outcome of interest for mother i admitted to ward w on weekday d in season (quarter) s of year y, such as the probability of the mother experiencing complications at birth. $crowd_{idsyw}$ is the level of crowding at the ward on the day of admission measured as (1) the (leave-out) number of admissions on the day of admission or (2) the percentile rank of the admission day (within a given maternity ward, season and year) in terms of the (leave out) number of admitted mothers.[23]

The vector X_{idsyw} includes observable mother and father and an indicator for pregnancy complications.[24] Further-

[22] This point is important because our sample of maternity wards consists of larger units in the end of the sample period compared to the initial years due to hospital mergers and an administrative reform in 2007.

[23] We have also computed alternative measures of crowding such as the (leave-out) number of admitted births relative to the median number of admitted women for a given maternity ward in a given year, or a moving average specification (i.e. computing crowding based on the previous day's and the current day's cumulated admissions). We discuss our results for alternative measures in Section 4.

[24] The exclusion of individual level control variables does not impact our conclusions and results for all main analyses excluding them are available on request.

more, we control for the number of scheduled CS on a given day and in a given ward.[25] To account for systematic differences across the population of mothers across years and season, we include year of birth (δ_y) and season fixed effects λ_s. These cohort effects also capture the impact of shocks such as nation-wide changes in recommendations on procedure use. Furthermore, to capture systematic variation in birth-related admissions over weekdays and weekends, we include weekday indicators (θ_d). γ_w accounts for time-invariant differences across maternity wards. Finally, by including ward × year fixed effects ($\delta_y \times \gamma_w$) we flexibly account for shocks specific to certain wards, such as changes in the population of mothers due to changes in catchment areas of hospitals or organizational changes within the ward.[26] The parameter of interest is α_1, which measures the reduced form effect of crowding. We cluster standard errors at the ward level to capture arbitrary correlations in unobservable characteristics across mothers within the same hospital.

To ease comparison across the two treatment measures and to give a sense of the variation in the level of crowding that mothers potentially can experience around their own admission for birth, we calculate for each admission day a "potential range of crowding". This measure captures the variation around the actual admission day, which mothers cannot perfectly control. For each admission day we calculate the absolute difference in admissions between the most and least crowded day considering the admission day, the day before and the day after the admission, see Appendix Table A.2. In our sample, this difference, or the potential range of crowding, is around 3.4 on average, i.e. it suggests that on average women can expect the number of admissions to vary with three births, when we consider the days just around the mothers' actual admission day (this variation is slightly smaller when we consider our residualized measure taking out year, season, weekday, ward and ward × year fixed effects, see Appendix Table A.2). Thus, when we discuss our main results for the absolute measure of crowding, we calculate the impact of an increase in admissions with three births.[27] Similarly, we compute the potential range of crowding based on our relative treatment measure. For the days around mothers' actual admission day, the average expectable variation is around 30 percentile ranks.

Identifying Assumptions To uncover a consistent estimate of α_1, we assume that the residual variation in the number of admissions for childbirth at a given hospital is uncorrelated with unobservable characteristics that also impact outcomes. Importantly, this assumption postulates the absence of policy changes or other time-varying characteristics of women or hospitals that systematically covary with our variation in (temporary) crowding. We argue that it is reasonable that our set of fixed effects and controls for parental and pregnancy characteristics take care of this threat.[28]

While this assumption is inherently untestable, Table 1 presents an informal assessment of the credibility of our design. Each row of Table 1 presents a series of estimation results for regressions of maternal, paternal and birth characteristics on our treatment variable, the (leave-out) number of admissions on the day of the admission of the mother. Moving from column (1) to (6) we add different sets of fixed effects to this regression. For our design to identify the effect of crowding, we expect predetermined characteristics of parents and the birth to be uncorrelated with our treatment variable once we account for factors that likely bias our estimation, such as a comparison between large (specialized) wards and small wards or different geographical locations.

As Table 1 shows, the regressions in column (1) show small albeit significant correlations for central observable characteristics and our treatment variable. These correlations decrease in size and loose significance when we move towards column (6) with the full set of fixed effects, our preferred specification.

Especially accounting for hospital and year fixed effects takes away predictive power of our treatment variable measure in our regressions with predetermined observable characteristics as outcomes. While our main estimate on mothers' income remains significant, the estimate is very small: One additional admission is associated with a 144 DKK (around 22 USD) difference in mothers' annual income. The significant effect of crowding on the probability of the father holding a university degree amounts to a 18 percent increase at the relevant sample mean.[29] Given few differences and our inclusion of parental characteristics as controls, our findings lend credibility to our identifying assumption that, conditional on the set of fixed effects and controlling for observable characteristics, we identify the impact of crowding on outcomes.

[25] Recall that those CS are included to calculate our measures of crowding but are omitted in the analysis.

[26] Such changes occur for at least two reasons: First, in 2007 the former 16 Danish counties were merged into five regions. As hospitals were administered by the counties until 2007 and since then by the new regions, both the organization and the catchment areas were potentially changed by this reform. Second, closures of maternity wards during the period that we consider affect nearby wards through the number and composition of patients. Such changes are absorbed by the year-specific maternity ward fixed effects and we further assess the robustness of our results by restricting the sample to wards which do not experience large changes in admission numbers in Section 4.

[27] Appendix Table A.2 also reports the 75th and 90th percentile of the distribution of the potential range of crowding to illustrate the effect size for mothers being admitted on a day with an unusually high level of crowding compared to close by days.

[28] Additional evidence to substantiate this claim comes from analyses that exclude wards that merge during our time period (a time-varying characteristic that may be of importance). As we detail in Section 4, our analysis and conclusions are not impacted by this sample constraint.

[29] All conclusions also hold for our relative measures of crowding, as reported in Appendix Table A.3. Importantly, the nature of potential biases is different when applying the different crowding measures, especially in column 1 where for the absolute measure, the regression compares primarily across small and large wards, while the percentile measure abstracts from this comparison being based on a calculation inside a given ward and year.

Table 1
The effect of crowding (absolute measure) on pre-determined characteristics, 2000–2014.

	(1)	(2)	(3)	(4)	(5)	(6)	*N*
Mother income	1.357***	0.517*	0.312***	0.312*	0.336***	0.144***	773,173
	(0.392)	(0.190)	(0.114)	(0.115)	(0.122)	(0.046)	
Mother university deg.	0.951***	0.221*	0.084	0.085	0.109	0.011	796,416
	(0.185)	(0.106)	(0.057)	(0.057)	(0.065)	(0.012)	
Mother age	0.064***	0.027***	0.017***	0.018***	0.017***	0.004*	773,173
	(0.017)	(0.007)	(0.003)	(0.003)	(0.004)	(0.002)	
Father income	1.151*	0.393*	0.376*	0.371*	0.406*	−0.011	765,675
	(0.582)	(0.201)	(0.171)	(0.174)	(0.180)	(0.076)	
Father university deg.	0.958***	0.182*	0.093*	0.092*	0.113*	0.026***	786,673
	(0.187)	(0.079)	(0.045)	(0.045)	(0.050)	(0.009)	
Father age	0.049***	0.021***	0.012***	0.013***	0.013***	0.002	765,675
	(0.016)	(0.007)	(0.003)	(0.003)	(0.003)	(0.002)	
Mother GP contacts	0.004	0.046***	0.002	0.003	−0.007	−0.003	775,943
	(0.023)	(0.015)	(0.005)	(0.005)	(0.005)	(0.003)	
Mother GP fees	−1.964***	−2.286*	0.057	0.067	0.011	−0.024	775,943
	(0.516)	(0.900)	(0.044)	(0.044)	(0.047)	(0.025)	
Birth weight (grams)	−3.081***	−0.200	0.285	0.154	0.303	−0.219	786,530
	(0.608)	(0.363)	(0.271)	(0.269)	(0.293)	(0.348)	
Hospital FE		Yes	Yes	Yes	Yes	Yes	
Year FE			Yes	Yes	Yes	Yes	
Quarter of Year FE				Yes	Yes	Yes	
Day of week FE					Yes	Yes	
Hospital × year FE						Yes	

Notes: Each cell presents point estimates from a separate regression. For a description of the main sample, see Section 2.2. All parental characteristics are measured two years prior to the birth of the focal child. Maternal GP contacts and the fees related to them are measured during a one year period. The outcome variable for all regressions in a given row is denoted in the first column. Standard errors are clustered at the hospital level and presented in parentheses. The table shows estimates for the absolute crowding measure (absolute number of admissions at a given ward and admission date). For an equivalent table based on the percentile rank, see Appendix Table A.3. The changing number of observations across rows (outcomes) is related to missingness of data. We deal with missing parental characteristics by including indicators for missing data in our main specifications.
Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

4. Results

In this section, we present our main results for the impact of crowding on ward-level adjustments. We then proceed to studying consequences of admission on a crowded day for maternal and infant health outcomes. In all tables, each cell shows point estimates and standard errors from a different regression. Columns 1 and 2 present the results for our two different crowding measures, respectively: the total number of admissions in the same ward and day and the percentile rank of the admission day (within hospital, season and year cells). All regressions are based on the full set of fixed effects and controls, as presented in equation (1). The bottom row of each table shows the mean range in the level of crowding, i.e. the range of crowding typically observed around a given admission day, see also Appendix Table A.2. In all tables, coefficients and control means for indicator variables are pre-multiplied with 100 to ease readability.

4.1. Maternity ward adjustments to crowding

Our analyses for procedure use and timing focus on potential adjustments and changes inside the maternity ward. A first potential adjustment of maternity wards is to direct patients to other, less crowded wards. As described in the data section, we do not observe mothers who call their ward while already in labor and who may then be directed to a different, less crowded ward. While other sources suggest that the transfer of women during labor between wards is quantitatively unimportant, we still attempt to study this margin. Thus (in the absence of data on phone contact with the designated maternity ward), we study the probability of giving birth at a different ward than the one assigned during the first trimester. As Table 2 illustrates, 18 percent of the women in our analysis sample do not give birth at their initially assigned ward. When we examine the impact of crowding on this measure, we do not find that crowding impacts this probability of being admitted to a different ward. While we think that this analysis suggests that transfers during labor are not driving our results, a caveat is that the majority of women who give birth at a different hospital than the initial assigned hospital are likely to be "scheduled movers", i.e. women who are transferred to specialized maternity wards prior to birth.

Next, we consider other channels for maternity ward adjustments. Specifically, we focus on typical procedures used during labor and observed in the medical records. We find that on crowded days maternity wards are less likely to perform inductions and stimulations, albeit the effects are small. Three additional birth admissions (the range of crowding) are related to a $3 \times 0.225 = 0.7$ percentage points difference in the probability of an induction. At the sample mean induction rate of 18.6 percent, this corresponds to about a four percent decrease.[30] Similarly, for the percentile rank measure, a change of 30 percentile ranks in crowding (which is the average variation around admission

[30] For mothers entering at days with unusually high levels of crowding the effect is a $7 \times 0.225 = 1.6$ percentage points difference in the probability of an induction, see Appendix Table A.2.

Table 2
The effect of crowding on transfers and procedure use, 2000–2014.

	Absolute (1)	Percentile (2)	Mean of dep. var	*N*
Admitted to other hosp than first hosp	0.006	−0.168	18.212	785,336
	(0.009)	(0.130)		
Stimulation of labor	−0.120***	−1.170***	28.055	796,416
	(0.018)	(0.238)		
Induction	−0.225***	−2.326***	18.612	796,416
	(0.023)	(0.191)		
Emergency CS	0.002	0.087	12.022	796,416
	(0.014)	(0.136)		
Mean of ‘expected’ variation in crowding	3.047	0.298		

Notes: Each cell presents point estimates from a separate regression. The first column presents the estimate for the impact of the absolute number of admissions, column (2) presents the estimate for the impact of the percentile rank of the admission day in the distribution of days in the hospital and year. All coefficients come from regressions accounting for fixed effects for the maternity ward (hospital), year, season, day of week, and ward × year, as well as the following set of control variables: the number of scheduled CS at the hospital and day of admission, an indicator for pregnancy complications, maternal and paternal wage income, maternal and paternal age at child birth, indicators for maternal and paternal education (higher education, university degree), indicators for maternal and paternal disability pension status, maternal and paternal education status (in education vs. not in education), indicators for maternal and paternal region non-western origin, and separate indicators that are one for individuals with missing values for the parental control variables. Standard errors are clustered at the hospital level. The mean of the variation in crowding is the mean range in crowding across the mother's day of admission, the day before and the day after (for more details, see Appendix Table A.2).
Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table 3
The effect of crowding on procedures at birth; constrained sample with timing and procedure data, 2011–2014.

	Absolute (1)	Percentile (2)	Mean of dep. var	*N*
Above median duration admission to birth	−0.208***	−2.150***	50.897	182,564
	(0.036)	(0.361)		
Indicator: Epidural	−0.136***	−1.514***	24.178	192,748
	(0.036)	(0.377)		
Indicator: Skin-to-skin	−0.017	−0.190	76.462	192,748
	(0.041)	(0.388)		
Above median waiting time for epidural	0.056	−0.133	48.274	41,430
	(0.087)	(0.917)		
Mean of ‘expected’ variation in crowding	3.263	0.290		

Notes: See notes for Table 2.
Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

days in our sample) corresponds to a $0.298 \times 2.3 = 0.7$ percentage points difference in the probability of an induction (or a difference of about four percent, evaluated at the sample mean). The effects are thus very similar regardless of whether we define the treatment as the number of admissions or relative to the number of admissions inside the ward, season and year.

Finally, Table 3 constrains our analysis sample to the most recent years (2011–2014) and examines outcomes indicative of the access to resources in the maternity ward for women. We analyze the impact of crowding on the time between admission time and birth, the propensity to receive an epidural, the waiting time for an epidural conditional on having one, and an indicator for skin-to-skin contact. While estimates are again small, we find that women admitted on more crowded days are less likely to have above-median duration ward stays, i.e. most likely arrive later at the ward and give birth faster. Given that women are typically in contact with their ward in the hours up to hospital admission, we take this finding as indication for wards delaying admissions during peak hours. After admission, we find that women admitted on more crowded days are less likely to have an epidural for pain relief. One reason for this result may be that maternity wards delay the admission of women. Thus women, who are admitted closer to their actual birth, will not be able to get an epidural (given the waiting time related to the admission of epidurals by physicians). At the same time, in line with wards being able to buffer temporary crowding, we do not find longer waiting times for actual epidurals and no clear indication for crowding impacting a measure of birth experience quality, namely the timely establishment of skin-to-skin contact between parents and child.

4.2. Mother and child health

Table 4 presents our main results for the effects of temporary crowding on the day of admission for birth on health outcomes.[31] In panel (A) we first report our results for birth

[31] To show that our findings are not driven by the choice of data period, Appendix Tables A.4 and A.5 replicate all our main results for the shorter sample of data from the years 2011–2014 used in our analyses on specific procedures. We find very similar results (albeit averages for the dependent variables increase illustrating the importance of control for year fixed effects): Effects for inductions and stimulations are slightly larger and we do not find a significant effect on the aggregate measure of complications

Table 4
The effect of crowding on birth outcomes and child health, 2000–2014.

	Absolute (1)	Percentile (2)	Mean of dep. var	*N*
A. Birth outcomes				
Comp. at birth	−0.049***	−0.466***	57.084	796,416
	(0.012)	(0.162)		
Comp. at birth: Laceration degree 1 or 2	−0.074***	−0.789***	34.899	796,416
	(0.017)	(0.194)		
Comp. at birth: Laceration degree 3 or 4	0.007	0.114	3.164	796,416
	(0.008)	(0.078)		
APGAR>7	−0.007	−0.046	97.642	796,416
	(0.008)	(0.080)		
APGAR>9	0.023	0.091	91.467	796,416
	(0.018)	(0.168)		
Post-birth complications, mom	−0.001	−0.019	4.889	796,416
	(0.006)	(0.083)		
Post-birth complications – severe, mom	−0.014***	−0.160**	2.632	796,416
	(0.004)	(0.059)		
B. Child health outcomes				
Hospital nights at birth	0.001	−0.003	3.470	791,290
	(0.004)	(0.039)		
Neonatal care admission	0.007	0.087	8.052	796,416
	(0.015)	(0.150)		
Readmitted first 28 days	−0.015*	−0.140	5.409	792,754
	(0.008)	(0.091)		
Readmitted first year	−0.012	−0.155	22.439	791,772
	(0.017)	(0.162)		
Readmitted second year	−0.018	−0.227	16.249	791,772
	(0.018)	(0.211)		
Contacts with gp first month	0.001	0.005	0.700	792,754
	(0.001)	(0.006)		
Contacts with gp first year	−0.010	−0.104	13.301	791,772
	(0.006)	(0.071)		
Contacts with gp second year	−0.008**	−0.068	7.756	791,772
	(0.003)	(0.049)		
Mean of 'expected' variation in crowding	3.047	0.298		

Notes: See notes for Table 2.
Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

outcomes and in panel (B) we extend the analysis to consider outcomes related to child health (after birth).

Relating the point estimates in panel (A) of Table 4 to the mean range in level of crowding, we observe that an additional three admitted births result in a very small ($3 \times 0.05 = 0.15$ percentage point) difference in the probability of complications at birth.[32] Zooming in on complications that may be the result of staff shortage, we study the probability of mild and serious lacerations. While we find a significant and negative impact of crowding on mild lacerations, we do not find an effect of crowding on severe lacerations.[33] Given that lacerations of very mild form may be subject to staff assessment, we cannot rule out that crowding impacts their registrations.

Considering other relevant birth outcomes, our estimates for both the probability of the child's APGAR score being low and the probability of the mother experiencing post-birth complications are very small and do not suggest an impact of temporary crowding on these outcomes. Focusing on severe maternal post-birth complications, we even find a small negative effect of crowding (an estimate that implies roughly a 1.5 percent decrease in the probability of severe complications for our absolute measure of crowding). These last findings are different from results in Avdic et al. (2018), who find that hospital mergers increase mothers' probability of experiencing post-birth trauma, a finding that they attribute to potential crowding at merged wards. These differences may be due to (at least) two factors. First, our inside-ward variation in crowding may be less drastic and disruptive than a ward merger. Second, we do not find an impact of crowding on the probability of experiencing an unscheduled (emergency) CS. We find decreased procedure use on crowded days, which may reduce the need for follow up treatments due to side effects of procedures such as pain relief. This difference may be particularly important for maternal postnatal health.

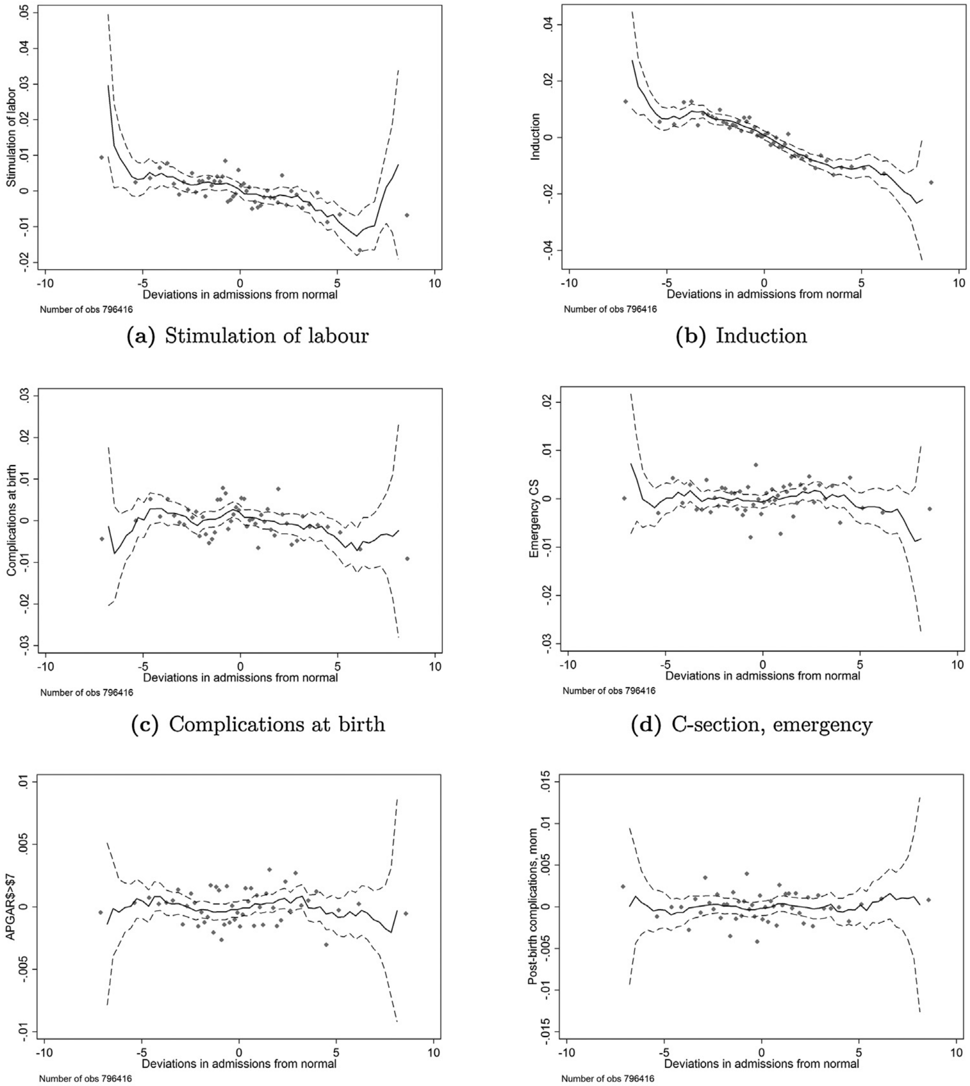
In panel (B) of Table 4, we extend our analyses to post-birth child health outcomes measured as health care usage at either the GP or at the hospital (admissions).[34] Across

at birth. However, we confirm the main patterns in our findings for post birth complications (for severe lacerations).

32 Similarly, a 30 percentile rank variation in crowding results in a $0.29 \times 0.5 = 0.15$ percentage points difference in the probability of birth complications.

33 Recall that lacerations are excluded from our overall complications measure.

34 We have also considered the number of nights spent at the neonatal care unit. We find no significant impacts of crowding at this margin and results are available on request.



(a) Stimulation of labour (b) Induction

(c) Complications at birth (d) C-section, emergency

(e) APGAR >7 (f) Post-birth complications

Fig. 2. The effect of the number of daily admissions on procedure use and health outcomes, local linear regressions. *Notes*: The plots show the relationships between the residualized *y*-variable and the residualized number of admissions to maternity wards. Each marker contains two percent of observations and plots the mean of the y-variable against the mean of the *x*-variable. The line represents the local linear regression, with a bandwidth of one.

specifications, we find very small and mostly precise estimates that suggest no important longer-run impact of temporary crowding on the health care usage of children in our sample. As in panel (A) the effect sizes are very similar across treatment measures once the variability in crowding is taken into account.

Finally, we have considered the impact of crowding on the probability of the birth being a stillbirth, resulting in a perinatal death (including the first week of life) and the probability of a first-year death.[35] As shown in Appendix Table A.6, we do not find any large impact of crowding on these rare and severe health outcomes. Estimates are very small and thus do not support an impact of (temporary) crowding at Danish maternity wards for our general population of (non-scheduled) births.

In additional robustness analyses we confirm that our results are not driven by ward mergers (Appendix Table A.7 with estimates based on stable wards only and excluding wards that merge throughout the sample period). Further our findings are unchanged when we measure crowding based on the day of admission as well as the day prior to admission (Appendix Table A.8).[36] While point estimates

[35] Results for perinatal deaths including the first two weeks of life are very similar and available on request.

[36] Appendix Table A.7 presents results for two crowding measures only based on absolute number of admissions (to ease comparison to the main specification): A two day average measure of crowding and changes in crowding between the day of admission and the day prior to admission.

Table 5
Heterogeneity: The effect of crowding on selected health outcomes and use of procedures, 2000–2014.

	Main	Gest. age		Parity		Hospital size	
	(1)	<41w (2)	≥41w (3)	=1 (4)	>1 (5)	<p50 (6)	>p50 (7)
Stimulation of labor	−0.120***	−0.113***	−0.103**	−0.172***	−0.110***	−0.087**	−0.124***
	(0.018)	(0.025)	(0.043)	(0.056)	(0.021)	(0.034)	(0.014)
		[0.824]		[0.231]		[0.295]	
Induction	−0.225***	−0.180***	−0.281***	−0.287***	−0.215***	−0.176***	−0.268***
	(0.023)	(0.019)	(0.044)	(0.063)	(0.025)	(0.022)	(0.027)
		[0.003]		[0.059]		[0.001]	
Complications at birth	−0.049***	−0.060***	0.005	−0.090	−0.042***	−0.032**	−0.044**
	(0.012)	(0.017)	(0.036)	(0.063)	(0.010)	(0.014)	(0.020)
		[0.096]		[0.371]		[0.731]	
Complications at birth: Laceration degree 3 or 4	0.007	0.015	−0.012	0.013	0.007	0.001	0.016**
	(0.008)	(0.010)	(0.017)	(0.014)	(0.009)	(0.018)	(0.007)
		[0.130]		[0.733]		[0.310]	
APGAR>7	−0.007	0.001	−0.010	−0.042*	−0.001	0.007	−0.019**
	(0.008)	(0.009)	(0.011)	(0.023)	(0.008)	(0.013)	(0.008)
		[0.412]		[0.024]		[0.038]	
Post-birth complications, mom	−0.001	0.010	−0.028*	0.005	−0.002	−0.001	0.003
	(0.006)	(0.009)	(0.016)	(0.016)	(0.006)	(0.009)	(0.008)
		[0.061]		[0.730]		[0.816]	
Post-birth complications – severe, mom	−0.014***	−0.006	−0.033***	−0.026*	−0.012***	−0.010	−0.014**
	(0.004)	(0.007)	(0.012)	(0.014)	(0.003)	(0.008)	(0.006)
		[0.077]		[0.372]		[0.769]	
Observations	796,416	577,158	217,031	200,871	595,545	361,702	434,714

Notes: Each cell presents point estimates from a separate regression for the impact of the number of admissions. Column (1) is based on the full sample, columns (2) and (3) are for children born below and above 41 completed weeks of gestation, columns (4) and (5) are for first-born and higher parity samples, columns (6) and (7) are for small and large hospitals, respectively (split at the median). P-values for the test of equal coefficients across subgroups are in square brackets. Standard errors are clustered at the hospital level and presented in parenthesis. For further details see notes for Table 2.
Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

and significance change marginally, our main conclusions hold across the different definitions of sample and crowding measure.

In sum, our estimates for the effects of temporary crowding on health at birth have the same sign across different measures of crowding. While our large sample results in precise estimates, the size of the estimates does not indicate large health effects and suggests that wards are able to accommodate to the observed variation in daily admissions without health risks for a general population of mothers and their infants.

As our findings suggest no or very few health effects on more crowded days, our results for inductions may indicate that a decreased use (or delay) of marginal inductions is not hurtful in this population of births (a small decrease in maternal severe post-birth complications may suggest the opposite even). Inductions have been shown to be correlated with more complicated progression of labor and (in some studies) with the increased use of emergency CS. As we show below, we find that the probability of experiencing an induction decreases on crowded days for both pregnancies prior to and after completed week 41 (which is a relevant cut-off in most Danish hospitals for considering an induction for safety reasons). Thus, our results suggest that crowding may delay and potentially prevent non-medically indicated inductions.

4.3. *Are effects asymmetric or heterogeneous?*

To assess whether our linear model appropriately captures the underlying relationship between temporary crowding and our outcomes, Fig. 2 plots the relationship between our residualized treatment variable and residualized outcome measures. As the figures show, the linear specification appears to be appropriate for all considered outcomes. This finding suggests that there is no "threshold" for the effects of crowding, at least for the variation that we observe in our data.

Finally, we assess the heterogeneity in our reported results along three dimensions using the absolute level of crowding as the treatment variable.[37] As Table 5 illustrates, overall we see limited evidence for heterogeneous impacts of crowding along the dimensions that we consider. First, in columns (2) and (3) of Table 5 we split the sample by gestational age (below full 41 weeks or not). While most coefficients are similar across these two groups, the effect of crowding on the probability of inductions is significantly higher for births after week 41. In columns (4) and (5) we split the sample by parity. The effect of crowding on the probability of induction is largest for first-born children (marginally significant). Finally, in columns (6) and (7) we split the sample by maternity ward size. The effect of crowding on the probability of an induction is significantly larger in large wards. There is some indication for a

In both columns we interpret estimates as the effect of an additional admission.

[37] We only report the results for our main outcomes—additional results are available on request.

negative effect on the probability of having an APGAR score >7 in large wards. Again, this estimate is very small at the relevant mean.

5. Conclusion

While we have solid evidence for the benefit of medical care for at-risk births in the short and long run, we lack knowledge on the impact of variability of care for a more general population of births. This paper has studied the impact of exogenous shocks to maternity wards—-unexpected variation in the number of daily admissions–on the inside-ward change in procedure use for this group of patients and their health outcomes. Rather than exploiting variation across hospitals, we have isolated residual variation in daily admissions net of maternity ward, year, season, day of week and ward × year fixed effects. Using Danish administrative data, we have assessed several relevant margins of procedure use and health.

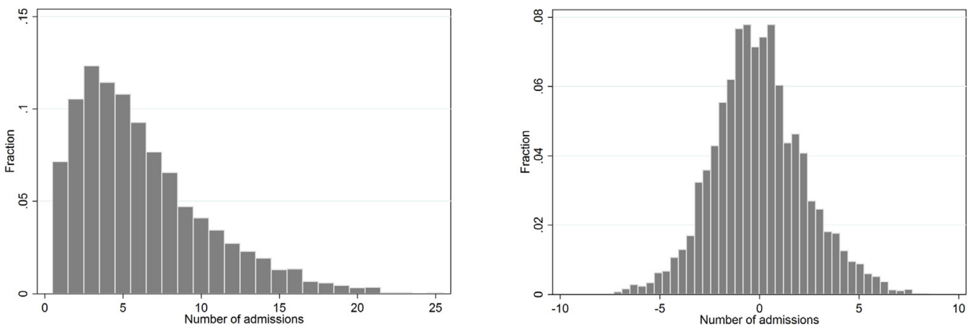
Importantly, our results do not indicate large negative impacts on health at birth and in the short-run due to variation in maternity ward crowding for a generally healthy population of mothers and their infants. This result echoes earlier findings for at-risk newborns and is in line with other causal estimates for the effects of crowding on patient health from other settings. However, as opposed to earlier work, we document that maternity wards adapt their allocation of procedures and care also for a general population of births (i.e. a relatively healthy patient group): Due to temporary crowding, they allocate fewer procedures to mothers during birth and admit them later during labor. At the same time, we document that crowding does not impact the handling of complications during labor when measured as the probability of having an emergency CS. These changes of allocation of care do not seem to impact child health but may even lead to fewer severe post-birth complications for mothers.

Our findings emphasize the benefits of collecting rigorous evidence on the impact of crowding across different settings and patient groups in the health care system. This evidence can inform policies about the importance of crowding for medical care decisions and patient health and likely leads to country- and setting-specific recommendations. Importantly, exploiting temporary variation in crowding, our study is not informative about the optimal level of maternity ward care. Furthermore, given our identifying variation and the scheduling of the vast majority of complicated births as caesarean sections, our results do not carry over to at-risk births. However, and important for the prioritization of resources at the maternity ward, our main findings show that Danish maternity wards can buffer the impact of crowding at the observed levels without important health consequences for a general population of mothers and newborns.

Authors' contributions

Jonas Maibom, Hans Henrik Sievertsen, Marianne Simonsen and Miriam Wüst: Conceptualization, Methodology, Data curation, Writing, Reviewing and Editing.

Appendix A. Additional figures and tables



(a) Number of admissions, 2010 (b) Residualized admissions, 2010

Fig. A.1. Distribution of the variation in the number of daily admissions to all Danish hospital wards, based on admissions in the year 2010.

Table A.1
Summary statistics, means, standard deviations and distribution measures.

	Mean	SD	*N*	P10	Median	P90
N. adm. same day	8.36	5.29	796,416	2.00	7.00	16.00
N. adm same day, no planned CS	7.57	4.71	796,416	2.00	7.00	14.00
Crowding percentile	0.60	0.27	796,416	0.20	0.64	0.95
Relative relative to median	1.26	0.62	796,416	0.60	1.17	2.00
Female	0.49	0.50	796,416	0.00	0.00	1.00
Gestational age	278.94	13.26	794,189	266.00	281.00	292.00
Birth after week 41 (over term)	0.27	0.45	794,189	0.00	0.00	1.00
First-born child	0.46	0.50	783,762	0.00	0.00	1.00
Birth weight	3525.75	561.48	789,713	2870	3544	4200
Mother income (thousands)	178.63	100.31	773,173	64.94	172.27	288.84
Mother western origin	0.89	0.31	773,173	0.00	1.00	1.00
Mother with university degree	0.13	0.34	796,416	0.00	0.00	1.00
Mother with higher education	0.23	0.42	796,416	0.00	0.00	1.00
Mother disability pension	0.00	0.06	796,416	0.00	0.00	0.00
Mother enrolled in edu	0.05	0.22	796,416	0.00	0.00	0.00
Father income (thousands)	248.85	170.84	765,675	88.67	234.19	402.44
Father western origin	0.89	0.31	765,675	0.00	1.00	1.00
Father with university degree	0.14	0.34	786,673	0.00	0.00	1.00
Father with higher education	0.17	0.38	786,673	0.00	0.00	1.00
Father disability pension	0.01	0.08	786,673	0.00	0.00	0.00
Father enrolled in edu	0.02	0.15	786,673	0.00	0.00	0.00
Pregnancy complic., indicator	0.31	0.46	796,416	0.00	0.00	1.00
N. of schel. CS on day of adm.	0.79	1.34	796,416	0.00	0.00	3.00
Complications at birth	0.57	0.49	796,416	0.00	1.00	1.00
Emergency CS	0.12	0.33	796,416	0.00	0.00	1.00
APGAR>7	0.98	0.15	796,416	1.00	1.00	1.00
APGAR>9	0.91	0.28	796,416	1.00	1.00	1.00
Post-birth complications, mom	0.05	0.22	796,416	0.00	0.00	0.00
Hospital nights at birth	3.47	6.90	791,290	1.00	2.00	5.00
Discharge on the day of birth	0.36	0.48	796,416	0.00	0.00	1.00
Readmitted first 28 days	0.05	0.23	792,754	0.00	0.00	0.00
Readmitted first year	0.22	0.42	791,772	0.00	0.00	1.00
Readmitted second year	0.16	0.37	791,772	0.00	0.00	1.00
Contacts with gp first month	0.70	1.31	792,754	0.00	0.00	2.00
Contacts with gp first year	13.30	13.01	791,772	1.00	10.00	29.00
Contacts with gp second year	7.76	9.90	791,772	0.00	5.00	19.00
Stimulation of labor	0.28	0.45	796,416	0.00	0.00	1.00
Induction	0.19	0.39	796,416	0.00	0.00	1.00
Neonatal care admission	0.08	0.27	796,416	0.00	0.00	0.00
Nights at neonatal care unit	0.82	5.03	796,416	0.00	0.00	0.00
Death during first year	0.01	0.08	796,416	0.00	0.00	0.00
Perinatal deaths: incl. first 14d	0.00	0.07	796,416	0.00	0.00	0.00
Perinatal deaths: incl. first 7d	0.00	0.07	796,416	0.00	0.00	0.00
Stillbirth	0.00	0.05	796,416	0.00	0.00	0.00
Indicator: Epidural	0.24	0.43	192,691	0.00	0.00	1.00
Indicator: Skin-to-skin	0.76	0.42	192,691	0.00	1.00	1.00
Waiting time, epidural (min.)	36.58	53.66	41,421	0.00	25.00	70.00
Time from admission to birth (min.)	634.27	954.93	182,524	50.00	330.00	1490.00
Time birth to skin-to-skin (min.)	42.92	37.01	129,434	7.10	35.23	95.68

Notes: Parental covariates are measured in the calendar year two years prior to child birth. The median, p10 and p90 values are (following Statistic Denmark guidelines) calculated as the average over five observations around the true value. Note that, in our analyses, we set missing values for included covariates to zero and include an indicator variable for missing values for each of the covariates.

Table A.2
Variation in crowding measures in the analysis sample.

	Mean	SD	P25	P50	P75	P90
Range absolute	3.447	2.944	1.000	3.000	5.000	7.000
Range absolute (residualized)	3.047	2.507	1.064	2.276	4.141	6.382
Range percentile	0.328	0.235	0.141	0.289	0.495	0.676
Range percentile (residualized)	0.298	0.214	0.126	0.260	0.440	0.609

Notes: The range in crowding is calculated as follows: For each actual admission we compute the difference between the most crowded and least crowded day, considering the actual day of admission as well as the day before and the day after the actual admission.

Table A.3
The effect of crowding rank on the admission day in the hospital and year on pre-determined characteristics.

	(1)	(2)	(3)	(4)	(5)	(6)	
Mother income	−1.632*	0.926	1.186*	1.189*	1.267*	1.346*	773,173
	(0.874)	(0.567)	(0.602)	(0.603)	(0.529)	(0.554)	
Mother uni. deg.	−2.042***	−0.293*	−0.129	−0.129	0.081	0.128	796,416
	(0.570)	(0.172)	(0.139)	(0.140)	(0.137)	(0.138)	
Mother age	−0.066	0.051*	0.064***	0.063***	0.031	0.038*	773,173
	(0.047)	(0.021)	(0.020)	(0.020)	(0.020)	(0.020)	
Father income	−3.011*	−0.445	−0.348	−0.337	−0.340	−0.166	765,675
	(1.522)	(0.936)	(0.914)	(0.914)	(0.926)	(0.922)	
Father uni. deg.	−1.857***	−0.060	0.050	0.052	0.230*	0.273*	786,673
	(0.537)	(0.138)	(0.133)	(0.132)	(0.126)	(0.124)	
Father age	−0.079*	0.012	0.024	0.023	0.003	0.009	765,675
	(0.043)	(0.030)	(0.029)	(0.029)	(0.026)	(0.026)	
Mother GP cont.	0.071	0.065*	0.114***	0.113***	−0.026	−0.028	775,943
	(0.073)	(0.035)	(0.033)	(0.033)	(0.033)	(0.034)	
Mother GP fees	5.771***	3.428***	0.611*	0.601*	−0.196	−0.172	775,943
	(1.174)	(0.845)	(0.329)	(0.330)	(0.363)	(0.361)	
Birth weight (gr.)	3.480	−3.024	−3.567	−3.446	−1.908	−1.778	786,530
	(4.188)	(3.565)	(3.563)	(3.571)	(3.369)	(3.333)	
Hospital FE		Yes	Yes	Yes	Yes	Yes	
Year FE			Yes	Yes	Yes	Yes	
Quarter of Year FE				Yes	Yes	Yes	
Day of week FE					Yes	Yes	
Hospital × year FE						Yes	

Notes: Each cell presents point estimates from a separate regression. For a description of the main analysis sample, see Section 2.2. The outcome variable for all regressions in a given row is denoted in the first column. Standard errors are clustered at the hospital level. See notes for Table 2 for further details.
Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table A.4
Robustness: The effect of crowding on transfers and procedure use; short sample (2011–2014).

	Absolute (1)	Percentile (2)	Mean of dep. var	*N*
Admitted to other hosp than first hosp	−0.013	−0.532**	18.186	191,746
	(0.015)	(0.245)		
Stimulation of labor	−0.175***	−2.010***	26.053	192,748
	(0.046)	(0.439)		
Induction	−0.316***	−3.957***	26.536	192,748
	(0.044)	(0.475)		
Emergency CS	−0.021	−0.169	12.834	192,748
	(0.025)	(0.329)		

Notes: See notes for Table 2.
Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table A.5
Robustness: The effect of crowding on birth outcomes and child health outcomes; short sample (2011–2014).

	Absolute (1)	Percentile (2)	Mean of dep. var	*N*
Comp. at birth	−0.008	0.073	85.964	192,748
	(0.025)	(0.202)		
Comp. at birth: Laceration degree 1 or 2	−0.069**	−0.985**	45.811	192,748
	(0.032)	(0.439)		
Comp. at birth: Laceration degree 3 or 4	0.016	0.122	3.235	192,748
	(0.011)	(0.144)		
APGAR>7	−0.005	0.023	97.516	192,748
	(0.015)	(0.172)		
APGAR>9	0.014	0.069	91.550	192,748
	(0.032)	(0.337)		
Post-birth complic., mom	0.010	0.028	6.392	192,748
	(0.018)	(0.198)		
Post-birth complic. – severe, mom	−0.009	−0.148	3.927	192,748
	(0.014)	(0.170)		
Hospital nights at birth	−0.002	−0.044	3.023	191,276
	(0.005)	(0.060)		
Neonatal care admission	0.003	−0.171	8.340	192,748
	(0.016)	(0.235)		

Table A.5 (*Continued*)

	Absolute (1)	Percentile (2)	Mean of dep. var	*N*
Readmitted first 28 days	−0.052*** (0.016)	−0.575*** (0.203)	6.725	191,893
Readmitted first year	−0.046* (0.024)	−0.715** (0.311)	25.512	191,710
Readmitted second year	−0.032 (0.026)	−0.273 (0.344)	16.667	191,710
Contacts with gp first month	0.001 (0.001)	0.008 (0.016)	0.887	191,893
Contacts with gp first year	−0.002 (0.009)	−0.100 (0.088)	8.609	191,710
Contacts with gp second year	−0.009* (0.005)	−0.047 (0.054)	3.148	191,710

Notes: See notes for Table 2 for further details.
Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table A.6
The effect of crowding on infant deaths, perinatal deaths and stillbirths (2000–2014).

	Absolute (1)	Percentile (2)	Mean of dep. var	*N*
Death in first year	0.007 (0.005)	0.083 (0.050)	0.583	796,416
Perinatal death (incl. first week)	0.005 (0.004)	0.072* (0.041)	0.464	796,416
Stillbirth	0.000 (0.002)	0.013 (0.023)	0.254	796,416
Mean of 'expected' variation in crowding	3.047	0.298		

Notes: See notes for Table 2. Deaths in first year is an indicator that is equal to one for all stillbirths and children dying during their first year of life. Perinatal deaths include stillbirths and deaths in the first week of life. Stillbirths are defined as deaths on the day of birth conditional on a gestational age of at least 170 days.
Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table A.7
Robustness: The effect of crowding on procedures, birth outcomes and child health outcomes, stable wards sample (2000–2014).

	Absolute (1)	Percentile (2)	Mean of dep. var	*N*
Admitted to other hosp than first hosp	−0.009 (0.016)	−0.381** (0.172)	11.195	403,960
Stimulation of labor	−0.083*** (0.019)	−0.808*** (0.252)	27.023	412,115
Induction	−0.228*** (0.030)	−2.331*** (0.273)	18.790	412,115
Emergency CS	0.002 (0.023)	0.118 (0.235)	12.159	412,115
Comp. at birth	−0.022 (0.014)	−0.072 (0.168)	54.181	412,115
Comp. at birth: Laceration degree 1 or 2	−0.082*** (0.020)	−0.791*** (0.263)	35.664	412,115
Comp. at birth: Laceration degree 3 or 4	0.017* (0.010)	0.227** (0.104)	3.288	412,115
APGAR>7	0.002 (0.010)	0.047 (0.096)	97.615	412,115
APGAR>9	0.019 (0.020)	0.112 (0.188)	90.998	412,115
Post-birth complications, mom	−0.011 (0.007)	−0.074 (0.095)	5.067	412,115
Post-birth complications – severe, mom	−0.020*** (0.006)	−0.225** (0.083)	2.888	412,115
Hospital nights at birth	0.003 (0.005)	0.022 (0.059)	3.549	409,417
Neonatal care admission	0.028* (0.013)	0.356** (0.157)	8.943	412,115
Readmitted first 28 days	−0.006 (0.011)	−0.035 (0.114)	5.123	410,194

Table A.7 (*Continued*)

	Absolute (1)	Percentile (2)	Mean of dep. var	*N*
Readmitted first year	−0.001	0.068	21.598	409,708
	(0.029)	(0.279)		
Readmitted second year	−0.029	−0.283	15.757	409,708
	(0.023)	(0.304)		
Contacts with gp first month	−0.000	−0.001	0.688	410,194
	(0.000)	(0.007)		
Contacts with gp first year	−0.013	−0.148	13.624	409,708
	(0.010)	(0.105)		
Contacts with gp second year	−0.011*	−0.095	8.037	409,708
	(0.005)	(0.076)		
Mean of 'expected' variation in crowding	3.063	0.299		

Notes: This table shows results based on analyses using a subsample with only stable maternity wards. A stable ward is defined as a ward that is never experiencing a change in the left vs. right mean of the average monthly number of admissions changing by more than 30 percent. The left mean includes all months up until a given month, the right mean includes months from the current month and onwards (we require at least 6 months of observations before using this rule). The results are similar for alternative cutoffs such as 20 percent or only excluding "unstable" wards only from the month where admissions change above or below the cutoff. See notes for Table 2 for further details.
Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table A.8
Robustness: The effect of crowding on procedures, birth outcomes and child health outcomes, alternative crowding measures (moving average or changes in daily admissions, 2000–2014).

	Moving Average (1)	Adm. Change (2)	Mean of dep. var	*N*
Admitted to other hosp than first hosp	0.009	−0.005	18.212	785,336
	(0.008)	(0.007)		
Stimulation of labor	−0.055***	−0.055***	28.055	796,416
	(0.013)	(0.015)		
Induction	−0.089***	−0.116***	18.612	796,416
	(0.016)	(0.012)		
Emergency CS	0.004	−0.003	12.022	796,416
	(0.010)	(0.010)		
Complications at birth	−0.026**	−0.019	57.084	796,416
	(0.012)	(0.012)		
Comp. at birth: Laceration degree 1 or 2	−0.042***	−0.023**	34.899	796,416
	(0.014)	(0.011)		
Comp. at birth: Laceration degree 3 or 4	0.001	0.005	3.164	796,416
	(0.006)	(0.004)		
APGAR>7	−0.006	0.001	97.642	796,416
	(0.005)	(0.005)		
APGAR>9	0.007	0.014	91.467	796,416
	(0.009)	(0.012)		
Post-birth complications, mom	−0.006	0.005	4.889	796,416
	(0.006)	(0.005)		
Post-birth complications – severe, mom	−0.009**	−0.004	2.632	796,416
	(0.004)	(0.003)		
Hospital nights at birth	−0.001	0.003	3.470	791,290
	(0.002)	(0.002)		
Neonatal care admission	−0.004	0.010	8.052	796,416
	(0.008)	(0.011)		
Readmitted first 28 days	−0.004	−0.011	5.409	792,754
	(0.006)	(0.007)		
Readmitted first year	−0.003	−0.008	22.439	791,772
	(0.011)	(0.011)		
Readmitted second year	−0.010	−0.007	16.249	791,772
	(0.012)	(0.011)		
Contacts with gp first month	0.000	0.000	0.700	792,754
	(0.001)	(0.000)		
Contacts with gp first year	−0.001	−0.008**	13.301	791,772
	(0.003)	(0.003)		
Contacts with gp second year	−0.003	−0.004**	7.756	791,772
	(0.003)	(0.002)		

Notes: This table shows results where the treatment is defined as the number of admissions of the day of admission including admissions from the previous day ("moving average" specification) or the difference in admissions between these two days (i.e. the daily change in admissions). See notes for Table 2 for further details.
Significance levels: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Appendix B. ICD diagnoses and operation codes

To measure birth and post-birth complications, we use diagnoses and operations registered in the Inpatient registry. The codes follow the ICD10 classification. **ICD codes defining "complications at birth"** In our aggregate measure of complications at birth we include diagnoses groups DO60-Do69 and DO71-DO75. To focus on complications that may reflect both severity and the impact of staff-handling, we single out and explicitly focus on a common yet important and closely-monitored complication: Lacerations of degree 1–4 (DO70). Thus we consider separately indicators for lacerations of degree one or two and of degree three or four. To avoid these complications, staff-involvement in the progression of the birth is vital.

ICD codes defining "post-birth complications" We create two measures of post-birth complications. First, an aggregate measure of post-birth complications. This measure is equal to one for all women having a diagnose of the groups DO85-DO90 and DO990A. We also create a summary measure of severe post-birth complications that is one if a mother has both a diagnoses from the groups listed above and an operation code in the period from birth to 90 days after birth (operation codes considered here are the groups KMW, KMB, KKCH00, KJFA70, KJFA80, KLCD00, KTAB30).

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