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ACCOUNTING FOR THE RISE IN C-SECTIONS: EVIDENCE FROM POPULATION LEVEL DATA

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Accounting for the Rise in C-sections: Evidence from Population Level Data
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ABSTRACT

Drawing on administrative records of nearly 4 million births in Canada as well as macro data from the US and Australia, we provide a comprehensive account of rising C-section rates. We explicitly consider the contributions of the changing characteristics of mothers, births, and physicians as well as changing financial incentives for C-section deliveries. These factors account for at most one-half of the increase in C-section rates. The majority of the remaining increase in C-sections over the period 1994-2011 occurred in the early 2000s. We overview the relative contributions that the Hannah Breech Trial and technological change may have played in this development.

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1 INTRODUCTION

Why are Caesarian section (C-section) births increasingly viewed as a public health care problem? First, C-section rates have been rising steadily over past decades in many developed countries. In Figure 1 we graph the rates of Caesarean births for selected countries of North America and Europe, and in Australia between 1995 and 2012. Across these countries, C-section rates have increased between 17 and 48 percent since 2000. Second, the World Health Organization (1985) has identified 15 percent as the highest C-section rate justifiable on medical grounds,[1] yet Gibbons et al. (2010) report that half of a sample of countries representing over 95 percent of global births had C–section rates exceeding this level. Note that the C-section rates in all six countries represented in Figure 1 are above 15 percent throughout the entire period. Third, over time, C-section deliveries have consumed a rising proportion of hospitals' surgical resources. For example, in both Canada and the US, C-sections have become the most common inpatient surgery (CIHI 2016a, Pfuntner et al. 2013).[2] Fourth, C-section rates have been found to vary across countries, within countries and across hospitals, suggesting that something more than the health of the mother and the child is at play defining the trends. Finally, C-sections are increasingly recognized as major surgery, posing significant, and perhaps in certain cases avoidable, risks for both mother and child (Card et al 2018, SOGC 2004).

[1] The guideline emitted by the WHO in 1985 stated: "Countries with some of the lowest perinatal mortality rates in the world have caesarean section rates of less than 10%. There is no justification for any region to have a rate higher than 10-15%." (WHO 1985) This guideline has been re-examined in 2015 and concluded that no optimal C-section rate could be identified, and that more evidence is needed to understand the health risks to mothers and babies of C-section rates over 30 percent (WHO 2015).

[2] C-sections totaled 100 963 surgeries in Canada in 2014-15. Knee replacements came second, with 60 607 occurrences. Over that same period, birth deliveries were responsible for nearly 370 000 inpatient stays, lasting on average 2.3 days. The second most important factor for inpatient hospitalization during that period were respiratory diseases, with nearly 88 000 occurrences (CIHI 2016a).

Among the reasons offered for the rise in C-sections rates, the trend to delay childbirth—the risk of complication during labor increases with maternal age—and the higher incidence of multiple births due to fertility treatments are leading medical based accounts. In addition, defensive medicine and risk avoidance—the risk of poor or catastrophic health outcomes for the mother and child and/or the risk of lawsuits in the rare event of failed vaginal delivery—on the part of health practitioners is also thought to contribute, fanned by new technologies such as continuous electronic fetal monitoring. Economic research on rising C-section rates has mostly focused on doctors' monetary incentives to perform the procedure. Finally, the convenience of C-sections is believed to appeal to both health professionals and mothers. It precludes long periods of labor and offers more predictability to doctors' and mothers' schedules.

Much of the previous research on the rise of C-sections focuses on a subset of these explanations and/or a selected sample of births. While this approach may be justified on the grounds of identification or data limitations, it lacks the context required to understand the relative roles that competing causes may play, or to assess how much of this overall rise can actually be explained by the factors proposed in the literature.

In this paper, we use Canadian population level data to investigate the salience of these competing explanations to rising C-section rates in Canada. Our administrative data provides detailed information on the characteristics of mothers and the delivery, which span many of the non-economic explanations enumerated above. Also, Canada provides an attractive forum for identifying any role of economic explanations—i.e., physician incentives. Obstetric care in this country is remunerated through fee-for-service agreements, and fees for Caesarean and vaginal deliveries vary substantially across provinces and over time.[3] The health system in Canada is public (single payer) and universal, and our administrative records allow us to consider the full population of hospital births within the country. We can therefore explore the roles of a variety of explanations of increasing Caesarean rates while obtaining findings that are not limited in scope or in nature by selection issues (either based on the patient or delivering physician types) present in some other systems. Finally, as documented in Figure 1, the rise in C-sections in Canada mirrors the rise in other developed countries, so our findings should have external validity for other developed countries facing.

Our investigation offers three main results. First, we find that variables capturing these various explanations of rising C-section rates are related to the choice of a birth delivery method in the expected ways. For example, C-section rates rise expectantly with maternal age and are higher in instances of, for example, fetal distress, multiple gestation, breech presentation and previous C-section.

Second, changes in the characteristics of mothers and deliveries together with changes in physician incentives account for at most half of the secular increase in C-section rates in Canada between 1994 and 2011. This is primarily the work of changes in characteristics, rather than changing incentives.

Third much of the remaining increase in C-section rates, net of changes in observables, occurs in the first half of the 2000s. This part of the increase can be roughly seen in Figure 2 for Canada, as well as in Figure 1 for the other countries, save Germany.

[3] In 2011-2012, more than 85 percent of Canadian physicians reported being mainly compensated by fee-for-service agreements (National Physician Survey 2013). The Canadian Institute for Health Information estimated the proportion of physician payments made in the form of fee-for-service compensation to be around 72 percent (CIHI 2016b).

In the final part of the paper we consider two leading accounts of a strong increase in C-section rates in the early 2000s. One is technological change, which has been widely cited as a possible cause of the increased practice of defensive medicine. A second is the publication of the results of the Hannah Term Breech Trial in late 2000. We do not find any evidence of a technological innovation in the early 2000s that might lie behind the sudden acceleration of C-section rates in this period. However, in Australia, the U.S. and Canada we find that the jump in the C-section rates for vertex births in the early 2000s echoes a jump in the C-section rate for breech births, which is widely attributed to the publication of the "Term Breech Trial" results (Hannah et al. 2000). While we lack the data to explicitly test ties between these two developments, the coincidence of the jumps in the rates for these different types of births points to possible spillover effects of the Trial. Given growing concerns over rising C-sections rates, this finding presents an important question for future research.

2 PREVIOUS RESEARCH

Several studies have investigated the contribution of mother/birth characteristics to the rising number of C-section deliveries (c.f Lauer et al. 2010, Taffel et al. 1987, Anderson and Lomas 1984). Others have investigated the relationship between a variety of financial/physician incentives and C-section rates (c.f Gruber and Owings 1996, Gruber et al. 1999, Alexander 2017).

Another explanation of rising C-section rates is changing patient preferences. Some media reports have claimed that an increasing proportion of mothers requests a C-section for aesthetic reasons, for fear of experiencing prolonged labor or for scheduling convenience. Testing this hypothesis is challenging; in Canada, for example, data on maternal requests for C-sections has not been collected consistently across provinces or over time. The few existing studies argue that explore mothers' preferences suggest that they could only play a marginal role in explaining the high rates of primary C-sections across the country (e.g. Canadian Health Services Research Foundation 2012, Hanley et al. 2010, Declercq et al. 2007, Gamble 2007).

In parallel, the medical and legal literatures have described how tort laws, initially adopted to deter negligence, have intensified the recourse to unnecessary medical acts and contributed to a culture of defensive medicine (c.f. Carrier et al. 2010, Currie and MacLeod 2008, Baicker et al. 2007, Kim 2007, Keeler and Brodie 1993, Lawthers et al. 1992). However, these investigations tend to focus on the U.S. tort laws, and cannot explain why C-sections have been rising in contexts with different legal environments.

Still another explanation for high C-section rates is technological change in health professionals' practice (Currie and MacLeod 2017, Clemens and Gottlieb 2014). Finally, there is very little evidence-based support in the literature for the hypothesis that physicians opt for C-section deliveries for reasons of scheduling convenience or demand for leisure (e.g. Fabbri et al. 2016, Lefevre 2014, Brown 1996).

3 The Canadian Health Care System

Canadian health care is a universal, single payer system that operates at the provincial level and is financed both by general provincial taxes and by fiscal transfers from the federal government. In the period we study, most physician services were remunerated according to fee-for-service agreements, in which physicians are responsible for billing the provincial health insurance plan for each procedure they perform at a fee administratively fixed by provincial authorities for a predetermined period (typically corresponding to a fiscal year). Even in those cases where doctors were paid by alternate arrangements such as capitation agreements, births were generally reimbursed by fee-for-service. Fees did not evolve in response to the relative movements of the demand and supply for different medical services. Physicians are, moreover, precluded by provincial legislation aligned with the Canada Health Act from billing their patients in addition to the fees they receive from the public insurer. Finally, over our study period, the Canadian health care system did not provide an opportunity for physicians to choose between privately and publicly insured patients, or to self-select into remuneration agreements for obstetric care.[4]

Another important feature of the Canadian health care system relevant to this study is that physicians are effectively insulated from any impact of tort liability (Flood and Thomas 2012). This is significant, because as explained in the previous section, an explanation of "defensive medicine" has been used to account for some of the increase in the use of C-section in other countries. Because Canadian physicians are substantially reimbursed by provincial governments for malpractice insurance premiums, and are defended by the (historically very successful) Canadian Medical Protective Association in the event of a court proceeding, the risks of financial—as opposed to the reputational—costs of malpractice are unlikely to play a significant role in Canadian C-section trends.

Finally, most (but not all) births in Canada are delivered in hospitals, and they can be handled by different types of healthcare providers. General practitioners and family physicians are trained to provide obstetric care, including intrapartum care, although these represent only one (often marginal) component of their varied practice. They also have the option to refer their

[4] Changes in the fees in each province are typically induced by external scientific assessments of changes in the relative level of effort or skills required to perform different medical acts, caused for example by technological change, modifications in medical protocols or in the training for certain areas of practices. Changes in fees may also reflect political considerations as the formal negotiation process involves the provincial government and the provincial medical association (or its designated tariff committee). However, the objective of these negotiations is mostly to determine the amount of the global envelope attributed to physician remuneration, rather than to determine the relative movements in specific fees.

patients to an OB/GYN, for example for higher risk pregnancies or if they decide to opt out of obstetric practice completely.

4 DATA AND DESCRIPTIVE STATISTICS

Our main source of data on birth deliveries is the Discharge Abstract Database (DAD), administered by the Canadian Institute for Health Information (CIHI), which covers the universe of administrative discharge abstracts from acute inpatient facilities in all Canadian provinces but Quebec. Our sample covers the administrative records for all hospital births between April 1994 and March 2011 in the remaining nine provinces.[5]

The data provides some demographic characteristics for each mother, such as her age at delivery and her province of residence. It also contains detailed clinical information including the date of her admission and discharge, the day of the week and time of the birth.

Most importantly, the data lists, for each mother during our study period, diagnoses made and interventions performed by physicians in acute care facilities prior to, during and after the delivery using the International Classification of Diseases codes, adapted for Canada (ICD-9-CM and ICD-10-CA)[6], the Canadian Classification of Health Interventions (CCI) and the Canadian Classification of Diagnostic, Therapeutic and Surgical Procedures (CCP). With this information on the medical records, we can identify the factors that are medically known to be associated with higher risks of Caesarean deliveries, such as multiple pregnancy, non-vertex presentation, etc. (e.g.

[5] Deliveries not happening in a hospital represent a marginal fraction of all births in Canada. For 2002-03, CIHI reports that 99 percent of births were delivered in acute care facilities (CIHI 2006), with a slight decline to 98.5 percent by 2010. Unlike other provinces, facilities in Quebec do not directly provide CIHI with all discharge abstracts, which can only be accessed following a different protocol. Canadian territories are also excluded from our analysis. Our birth records also exclude the years 1994 for Newfoundland and Labrador and Nova Scotia, and the years 1994-1997 for Prince Edward Island for data availability reasons.

[6] ICD-9-CM codes were gradually replaced by ICD-10-CA codes by some provinces starting from 2001. From 2004 onwards, all provinces reported the diagnostics to CIHI using ICD-10-CA. Manitoba is the latest province to have completely transitioned.

NICE 2012, PHAC 2008, SOGC 1986). From the hospital records, we can also extract details on the health conditions of the infant at birth (weight, gestational age, etc.), as well as the mode of delivery for the birth (vaginal or C-section).

Finally, the administrative records provide the necessary information to identify the specialty of the physician most involved in the mother's inpatient stay for the birth delivery.[7] We assign a type of healthcare provider to each birth based on the most responsible provider identified on the mother's record: GP (either family physician or general practitioner), OB/GYN (either obstetrician/gynaecologist or gyne-reproductive specialist) or midwife.[8] In the small number of cases where the most responsible provider is not identified as being one of these types (0.69 percent of cases), we turn to the specialty of the other providers identified as responsible for the mother's care without being the most responsible.[9]

We exclude from our main estimating sample all deliveries that are assigned to a midwife (2.5 percent of all births), since these providers have different remuneration agreements and compensation parameters. Including these births does not alter our results in an important way

[7] We note that the most responsible physician identified on a mother's chart is not necessarily the physician who proceeded to deliver the baby; it rather corresponds to the physician responsible for most of the care during the mother's inpatient stay at delivery (or associated with the care justifying the longest portion of the stay). While there is not a one-to-one mapping between the physician delivering the birth and the most responsible physician, it is reasonable to assume that the latter in most cases is involved in the choice of a delivery method. Furthermore, information on the most responsible physician is available for almost all observations in our data (one notable exception is Manitoba between 1994 and 2000, and for approximately one third of births in that province between 2001 and 2003, since hospitals in that province used an older reporting system for those early years).

[8] Laws recognizing the status of midwives have been adopted during the 1990s and 2000s by different provinces (for example, regulation was introduced in 1994 in Ontario, in 1998 in British Columbia and Alberta, 2008 in Saskatchewan, etc. Newfoundland and Labrador still had not adopted regulation at the end of our sample period in 2010). The increase in the share of births delivered by midwives between 1994 and 2010 represents both an increase within provinces as the profession and services offered by midwives gained popularity and an increase in the number of provinces recognizing midwifery as a profession within the health care system of midwifery. Like GPs and OB/GYNs, midwives are often responsible for the pre- and post-partum care of the mother and baby.

[9] In the cases where this procedure is not successful (0.4 percent of all births), we assign GP as a physician type for cases where the most responsible physician is listed as either a public health physician or a practitioner in family medicine, and we assign OB/GYN where the most responsible provider is from another relevant specialty (for a few cases, our OB/GYN category therefore more loosely means "physician specialist").

(results are available upon request). We also discard all records for mothers younger than 14 years old or older than 65 years old. Our final sample consists of 4,084,755 maternal birth delivery records.

We obtain information on the fees paid in each fiscal year to physicians for vaginal deliveries and C-sections from provincial ministries of health and medical associations. Those amounts correspond to the information listed on the fee schedules published for physician billing purposes in the fee-for-service remuneration system. As previously mentioned, those schedules are administered at the province-level, and physician compensation for different procedures vary not only through time, but also across provinces. We obtain annual information on fees for the period 1994 to 2010 for most provinces with a few exceptions: Alberta for the periods 1994-96 and 1998-2000, and Prince-Edward Island for the period 1995-1997. [10]

The average C-section rate for all births in our main estimating sample is 24.74 percent, but varies through time and across provinces (see Table 1 and Table A1). Excluding all Caesarean deliveries for cases of previous C-section, fetus breech presentation and multiple pregnancies, the rate falls to 14.03 percent. Table 2 provides the average maternal and pregnancy characteristics in the sample and compares the mean of each variable across delivery outcomes. Mothers are on average 29 years of age at delivery, and mothers delivering by C-section are generally older than mothers delivering vaginally (aged 30.28 versus 28.62). Underlying this difference is that women older than 40 are overrepresented in the C-section group (4.3 percent versus 2.2 percent). This is

[10] For each combination of a province and a fiscal year, we use the payment associated with the fee codes describing standard vaginal deliveries and C-sections. To ensure comparability, those payments are stripped of the fees associated with ancillary procedures. Certain provinces list slightly different fees for GPs and OB/GYNs; we therefore allocate to each birth the appropriate fee measures given the physician type associated with the birth using the procedure described above. The estimated parameter on the fee variable is very similar to the reported results when we average the GP and OB/GYN fees for each procedure, or when we use only the fees listed for OB/GYNs or only the fees listed for GPs.

likely due, in part, to the fact that pregnancy later in life is associated with specific risks and complications during labor (Joseph et al. 2005).

The proportion of deliveries performed on weekends is significantly lower for C-sections than for vaginal deliveries, which might simply be due to hospitals' constraints on the availability of operating rooms for planned surgical procedures, or might attest to the scheduling convenience of C-sections from a physician's perspective. Finally, C-section deliveries are associated with longer inpatient stays (4.09 against 2.26 days) and with a (five times) higher probability of exceptional postpartum complications leading to long-term hospitalization (one month or more).

Table 3 presents the C-section rates for riskier births (corresponding to either cases of previous C-section, fetus breech presentation or multiple pregnancy), and for lower-risk births (vertex singleton births for which the mother had no previous C-section). The C-section rate for lower-risk births rose by 58 percent (or nearly 6 percentage points) over the period, while the rate for riskier births rose by 25.2 percent (or a little more than 16 percentage points). Because vertex singletons represent 83 percent of all births throughout the period covered by our analysis, they make the greater contribution to the overall increase in the C-section rate. Figure 2 maps the evolution of the C-section rates between 1994 and 2010. It identifies the years between 2000 and 2005 as a period of significant growth in the C-section rates, in aggregate and for higher- and lower-risk births alike.

In Figure 3 we graph the evolution of some of the variables capturing leading accounts of upward march of the C-section rate: the rate of pregnant women with a previous history of C-section, the proportion of multiple births, average maternal age and the ratio of the fee paid for a C-section relative to the fee paid for a vaginal delivery. The increase in the rate of pregnant women with a previous history of C-section over time is a mechanical consequence of the rise in the caesarean section rate. The rate of repeat C-section is 77.88 percent at the national level in our data, which can partly be explained by the fact that a previous C-section increases the risks of uterine rupture and placenta previa in subsequent pregnancies (NICE 2014, ACOG 2013, Shearer 1993).[11] The trends in the proportion of multiple births over the population of births are relatively flat, suggesting that they are not a significant contributor to the increase in the C-section rate. Maternal age increased steadily in our sample from 28.4 in 1994-95 to 29.5 in 2010-11. This pattern is observed in all provinces, and occurred in tandem with the increase in the C-section rate. Leon et al. (2011) report that in 2008, nearly a third of first-time mothers were older than 34. Finally, across provinces between 1994-95 and 2010-11, the fee billed by a physician for a C-section delivery was approximately 21 percent higher on average than the fee billed for a vaginal delivery. However, the period was marked by significant heterogeneity in the fee ratio both across provinces and over time.

Of all births delivered by a physician recorded in our sample, 69.37 percent had an OB/GYN as the most responsible provider of care for the mother during the delivery. Figure 4 shows that this proportion was relatively constant at around 62 percent into the mid 1990s, started to increase around 1997, and then plateaued beginning in 2000 to land at more than seventy-three percent in 2010. Of all OB/GYN assigned births, 31 percent were delivered by C-section; for GP assigned births, that proportion falls to 10 percent. As shown in Figure 5, although more pronounced for OB/GYNs, the increase in C-section rate is common to both types of providers. The differences in trends across provider types is somewhat in line with the observation that

[11] However, we note that various policy statements of the Society of Obstetricians and Gynaecologists of Canada (SOGC) during the period covered by our study rejected the idea that pregnancies following a Caesarean section should automatically lead to subsequent surgical deliveries. The relative risks associated with vaginal birth after a Caesarean remain debated; Young et al. (2018) find evidence that, despite adverse events being rare in both cases, elective C-sections following a previous Caesarean are associated with lower risks of maternal and neonatal mortality and morbidity than attempted vaginal deliveries.

OB/GYNs were generally more likely to deliver riskier births by the end of the study period (see appendix Table A2). Given these patterns, we examine how our observable characteristics affect the probability of C-section for OB/GYNs and GPs separately below.

5 EMPIRICAL STRATEGY

Our main estimating equation is:

$$CSection_{ipth} = \alpha + Z'_{pt}\,\beta + X'_{ipth}\,\phi + \gamma\,Trend_p + \delta_t + \mu_h + \varepsilon_{ipth} \qquad (1)$$

where *Csection* is a binary variable indicating if a birth i in province p, fiscal year t and hospital h was delivered by C-section. Z is a vector of time varying characteristics at the provincial level, X is a vector of time varying characteristics at the birth delivery level, and δ and μ are fiscal year and province or hospital fixed effects respectively.[12] Standard errors are clustered at the hospital level.

Included in Z is the ratio of C-section to vaginal delivery fees for the physician in charge. We also include a measure of provincial GDP and changes in population size, a control indicating the status of midwives in the province, as well as measures of provincial total health care expenditure per capita and provincial total expenditure on capital in health care per capita.

X captures an extensive set of maternal health conditions and characteristics related to the pregnancy. These include indicators for pre-term delivery, multiple birth, breech presentation of the fetus, previous C-section, a set of dummy variables for maternal age and for the day of the week and the month on which the mother was admitted to the hospital, as well as variables indicating if the newborn was large or small for gestational age at delivery, and for any disproportion (of the mother or the fetus) or problems of the placenta (including placenta previa)

[12] In specifications where hospital fixed effects are not included, we include a vector of province fixed effects.

likely to complicate the delivery process. We also control for health conditions of the mother associated with risks during the pregnancy and delivery process, such as hypertension (pre-existing or pregnancy-related), pre-eclampsia or eclampsia, antepartum hemorrhage, diabetes (pre-existing or pregnancy-related), and obesity. As discussed in section 4, some of these characteristics, in addition to having an impact on the choice of a birth delivery method, have followed specific trends throughout the period considered. Finally, we also control for problems arising during the labor and delivery (including issues related to the umbilical cord), such as fetal stress or distress, maternal stress or distress and obstructed labor[13] [14], and include an indicator variable specifying if the provider most responsible for the mother's care during the inpatient stay for the delivery was an OB/GYN.

We observe anonymized physician identifiers on most discharges for the period 2001 through 2010. These might be important if we suspect changes in the population of physicians, who may have been trained differently, to play a role in the evolution of delivery outcomes. They can also help understand if changes in the fee incentive variable leads to dynamic sorting of physicians practicing obstetrics, and provide some additional context in which to interpret physician responses to financial incentives. For example, physicians more sensitive to fee incentives may be responsible for a higher proportion of births when C-section fees are relatively high. We, therefore, also present estimates of equation (1) adding physician fixed effects for this restricted period.

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[13] While these are often noted as indicators of a potential C-section delivery, we note that they may ex post be added to patients' charts by physicians to justify a C-section that may have been performed for other reasons, for example convenience or the presence of other incentives (the *coding creep* phenomenon describes in, for example, Gruber and Owings 1996, Carter, Newhouse, and Relles 1990). Given their potential contribution to the rise in C-section, we include these controls in our preferred specification, but note that our results are robust to excluding them (results available upon request).

[14] Our results are also robust to including a control for the use of forceps or ventouse suction cup (vacuum extraction) during the delivery and/or a control for labor induction.

6 RESULTS

6.1 Base Results

Estimates of equation (1) for our main sample of births are presented in the first three columns of Table 4. In the first column are the results for the characteristics of the birth and the fee variable, conditioning on fixed effects for province, (fiscal) year of birth and single year of maternal age. The remaining province level controls are added in the second column of the table, while in the third column we add hospital fixed effects. Most birth-level characteristics have the expected impact. The estimates for three factors known to be important predictors of Caesarean births, multiple gestation, previous C-section and fetus breech presentation, are large, positive and strongly statistically significant. In particular, fetus breech presentation and a previous Caesarean increase by, respectively, slightly more than 57 percentage points each the probability of a C-section delivery, all else equal. Other important contributors are disproportion, which increases by nearly 65 percentage points the probability of a Caesarean delivery, and disorders related to the placenta (such as placenta previa), which increase it by more than 20 percentage points. The estimates for hypertension or (pre)eclampsia, obesity, diabetes, antepartum hemorrhage, fetal distress and obstructed labor are also positive and statistically significant, as are the indicators for small or large size for gestational age. The impacts associated with each of these variables are remarkably stable across the specifications.

The coefficient estimates associated with the full set of maternal age dummies, presented in Figure 6 indicate an increasing probability of C-section with age primarily starting in the mid 30s.[15] This is firstly the mechanical implication of maternal age on potential complications in

[15] Figure 6 presents the estimates corresponding to column 3 of Table 4. However, the estimates present the same pattern when province-level controls and hospital fixed effects are excluded from the empirical specification.

antepartum and intrapartum care, for example in the form of dystocia (Leon et al. 2011). Since a subset of intrapartum complications cannot be precisely accounted for as individual control variables, the age dummies could be picking up some of this impact.

For the most part, province-level characteristics are not significant predictors of a C-section birth. One exception is per capita capital expenditures in the healthcare sector, which is positively associated with the probability of a C-section. This relationship may reflect the introduction of new technologies that have been offered as an explanation of rising C-section rates; for example the availability of electronic monitors for fetal surveillance during labor or other regional differences that change over time. While not statistically significant, the overall expenditure per capita on health care is negatively correlated with the event of a C-section birth. This last relationship could for example be coherent with the probability of C-section being reduced when more resources are invested to improve the ratio of non-physician personnel in hospitals (for example to improve the ratio of nurses per patient which could help monitoring labor), or when more resources are invested in preventive or pre-natal care. We note that our results on both health expenditures and capital expenditures in the healthcare sector are in line with the cross-country estimates presented by the World Health Organization (Lauer et al. 2010).

The estimate for the fee incentive variable indicates that the birth delivery method does not strongly respond to changes in the relative compensation for a C-section compared to a vaginal delivery. The coefficients presented in columns (2) and (3) imply that raising physicians' remuneration for a C-section by 100 percent relative to the baseline fee of a vaginal delivery might increase the probability that a physician opts for Caesarean by 0.6 to 1.1 percentage points, but those estimates are not statistically different from zero. This result contrasts with some of the findings in previous literature, mostly focused on the U.S. system. It is important to note that we do obtain significant estimates of fee variables (with similar magnitudes) if we exclude birth level controls and hospital fixed effects. However, such restrictions undermine the value of our population-level, comprehensive approach, which differs most from previous literature looking at the effects of prices on physician decisions. [16] [17]

In addition to clustering standard errors at the hospital level, we allow for the potential serial correlation of the error terms within each province in our baseline specification. When clustered at the province-level, the statistical significance of most controls which vary at the province-year level is reduced, but the inference does not change in a material way. Doing so, our number of clusters however decreases to 9, such that we might still over-reject the null hypothesis on individual coefficients, even if a province is the right unit to cluster over. To correct for this, we obtain p-values using a wild cluster bootstrap procedure (Cameron et al. 2008), which suggest a further reduction in the significance of most province-year varying controls (results available from the authors on request).

In column 4 we present the estimates adding physician fixed effects for the restricted sample for which physician IDs are available. This modification has a negligible impact on the estimates of most of our variables of interest, with the exception of provincial capital expenditures, which is attenuated, and the fee variable, which is now negative (suggesting that composition

[16] The estimates for the fee variable are modestly larger but still statistically insignificant conditioning on province specific trends rather than the provincial level controls—see appendix Table A3. We have also estimated a version of equation (1) using the difference in fees for C-section and vaginal deliveries rather than their ratio, and obtained very similar results. These results are available from the authors on request.

[17] Evidence from the U.S. suggests that the gap in C-section rates between Medicaid and non-Medicaid patients is (rather largely) influenced by financial incentives (Gruber et al. 1999), and that such incentives also drive a difference in the C-section rates of Medicaid salaried versus fee-for-service physicians (Alexander 2017). With a single population of physician all remunerated similarly and the full population of births (rather than a Medicaid subsample), our account of physician responses to financial incentives for Caesareans in the Canadian context does not lead to similar conclusions, with much weaker and not statistically significant responses (more in the line of those obtained by Grant (2009) in the U.S. when accounting for state-specific trends).

effects within the population of physicians as remuneration parameters change might matter), but statistically insignificant.

Given that the share of complicated births delivered by OB/GYNs has increased over our sample period, we next estimate equation (1) for the GP and OB/GYN samples separately. The results are presented in columns 5 and 6, and reveal that the estimates on birth-level characteristics remain relatively stable, with the OB/GYN coefficients mostly larger that GP ones. This could because specialists are more comfortable with both types of birth deliveries, and are more likely to adapt their choice of procedure to various characteristics of the mother or of the pregnancy.

Finally, we also estimate a specification in which we take a more agnostic approach to important provincial level factors and replace the province level variables with province-specific time trends. The resulting estimates for the other control variables, reported in appendix Table A3, are very similar to those in Table 4.

6.2 The Overall Contribution of Observable Characteristics on Rising C-section Rates

The signs of the parameter estimates for most of the variables representing the various accounts of the rise in the C-section rate are consistent with their hypothesized effect and so could play a role in the rising C-section rate over the sample period. To evaluate their contribution, we report in Table 5 the estimates of the year effects from specifications in columns 1 through 3 and 5-6 in Table 4. We also add a column "0", which presents the estimates of the year fixed effects from a model with no other added control variables. In column 0 the overall increase in the C-section rate is 12 percentage points, comparable to the overall increase reported in Table 3. Comparing this result to the estimates in columns 1-3 indicates that our controls for birth and province level factors can account for 39 to 49 percent of the overall increase in the C-section rate.

Therefore, somewhat more than half of the increase in the C-section rate over the period remains unaccounted for.

Another message of the estimates in columns 1-3 is that the vast majority of this residual increase in the C-section rate over the period occurs between 2000 and 2005, echoing the patterns observed for most countries reported in Figure 1. In column 1 it is roughly 4 of the almost 7 percentage point residual increase, while in column 3 it is effectively the entire increase. In this latter specification, all the year effects prior to 2000 are statistically insignificant, and we cannot reject the hypotheses that most of the estimates either pre- 2000 are jointly equal nor that the estimates from 2005 on are equal. The coefficients associated with each of the years between 2000 and 2005, which are characterized by an increasing pattern, are however generally statistically different from each other. We note that these results hold when replacing the province-level controls with province-specific time trends (Table A3), and when including both our set of province-level controls and such trends.[18]

The abrupt increase in C-section rates in the early 2000s suggests some event is at play. In general, like changes in the birth, mother, province and physician characteristics included in our model, changes in some omitted variable are more likely to be gradual, inconsistent with the "trend break" evident in Table 5. For example, while it is plausible that successive cohorts of physicians have become less comfortable with assisted vaginal birth, or have developed different preferences over the two methods of delivery, it is unlikely that the effect of such changes would manifest as a discrete break in the C-section rate. A more promising story would be a corresponding break in

[18] We also note that the year effects estimated from a sample composed exclusively of more complicated births (multiple gestation, breech presentation of previous C-sections) suggest that nearly two thirds of the total increase in C-section for those categories is captured by the year effects from 2000 to 2005 (results available upon requests).

the fee schedule, but our results do not support this conclusion. We therefore look for some event in the early 2000s that may lie behind the pattern we find in the year effects.

7 What Else Might Explain the Jump in C-sections From 2000 Onwards

What caused the C-section rate to jump upwards starting around 2000 and level off after 2005? We see two main alternative explanations: 1) the publication of results from the Term Breech Trial (Hanna et al. 2000), and 2) a technological change in intrapartum care.

7.1 The Impact of the Term Breech Trial

The high-profile "Term Breech Trial" (Hannah et al. 2000), based on a cross-country randomized trial, concluded that planned C-section was safer for mothers and infants than vaginal deliveries in cases of breech presentation at term. The original results from the trial were published in October 2000 and the Society of Obstetricians and Gynaecologitss of Canada (SOGC) published new recommendations for breech births founded on this research in March 2001.

While the Trial and subsequent announcements of national health professional associations in various countries specifically targeted breech births in their recommendations for C-section, there is evidence from a number of nations suggesting possible spillover effects of this discovery on a wider set of births. In Figure 7 we report the growth rate of C-section deliveries in Australia between 1995 and 2005, separately for singleton term breech and vertex births. The underlying data are population records of term singleton births taken from Table 1 in Sullivan et al. (2009). In 2001, there is a very clear impact of the Term Breech Trial on the growth of C-section deliveries for breech births, but there is also a very clear corresponding spike in the growth rate of C-section deliveries for vertex births. The Royal Australian and New Zealand College of Obstetricians and

Gynaecologists issued a statement in February of 2001 stating the higher risk in planned vaginal breech deliveries than in planned C-section deliveries for breech births as per the Trial results (Sullivan et al. 2009, p. 458).

In Figure 8 we examine the rates of growth of C-section deliveries in the US. To construct this figure, we use data on term births from the public-use U.S. microdata natality files, constructed by the National Center for Health Statistics using information abstracted from all birth certificates registered in the 50 U.S. states and the District of Columbia between 1995 and 2005. Here we see a (albeit smaller) spike in the growth of C-sections for singleton term breech births in 2001 and a corresponding spike in the growth of C-sections for singleton term vertex births between 2000 and 2003.[19]

Finally, in Figure 9 we present C-section growth rates for Canada in comparable form to the graphs for Australia and the U.S. Very similar patterns are observed. Between 1999—the year before the Trial was published—and 2002, the unadjusted C-section rate for singleton term breech deliveries rises from 78.8 percent to 94.5 percent. Importantly, we observe the corresponding spikes in the growth rate of C-section beyond breech births.

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[19] An interesting feature of the US data is the significant deceleration in the growth rate of C-sections for breech births starting in 2005, which also coincides with the tapering of the increasing pattern observed for Canada in the year effects presented in Table 5. A proximate cause of a decline in the growth rate for breech births is the publication of follow up results and commentary on the Term Breech Trial research in this period. A follow up study published in 2004 (Whyte et al. 2004) found no difference in the mortality or neurodevelopment of children born by vaginal or C-section delivery at selected Trial sites. A few months later, an observational study of births in France and Belgium found little difference in neonatal outcomes between breech births delivered by C-section and planned vaginal delivery (Goffinet et al. 2006). Finally, a series of articles (e.g., Glezerman 2006, Kotaska 2004, Hauth et al. 2002) questioned the methodological soundness of the Trial and the external validity of the results. In June 2006, the ACOG officially modified its recommendation for the delivery of breech presentations (ACOG 2006), the new recommendation deferred to the clinician's specific experience. The deceleration of the growth in C-sections for singleton term breech births in Figure 8 is such that the level of these deliveries in fact falls in the data by over 10 percentage points between 2004 and 2007. Note also, we observe a deceleration in the growth of C-section delivery for vertex births starting in this same year. Extending the data set until 2010, the growth rate in C-sections for breech presentations is negative until 2007. Over this same interval, the growth rate in the C-section rate for vertex births falls from 5.5 percent in 2004 to 1.5 percent in 2008.

Relative to the patterns for the other two countries these responses are slightly more "spread out" through time. We note that the Term Breech Trial was led by a team of Canadian researchers, and that at least some local facilities may have had early notice of the results, thus also contributing to the gradual increase observed in Figure 9. Another factor contributing to the gradual response to the trial in Canada, is that the effects of the Term Breech Trial played out differently across provinces. While there are national associations of various medical specialties in Canada, health services are organized and funded at the provincial level and doctors are governed by provincial level practice associations. In their study investigating the impact of the Term Breech Trial across Canadian health care facilities, Daviss et al. (2010) note some significant heterogeneity in the responses of the maternity centers surveyed. For example, 11 of 20 centers amongst the largest in the country, reported it did not become required protocol to perform C-sections for breech presentations after the publication of the study. In three of the eight centers where it did become protocol, qualification criteria applied. Similarly, reactions to follow up criticism of the Trial's results and external validity was mixed (e.g. Whyte et al. 2004). By the Fall of 2004, 35 percent of the hospitals in the sample changed their internal practices (or had the intention to do so) in response to the publication of studies reassessing the safety of vaginal breech birth, while 55 percent had no intention to make any changes. In contrast, 65 percent of hospitals mentioned having seen a marked increase in the rate of C-section for breech presentations in the aftermath of the publication of the Trial in 2000, 30 percent having seen some increase and 5 percent having seen no increase during the same period.

The mechanisms that might have facilitated a fall out effect of the Trial on vertex births could include that an official recommendation of C-section, albeit targeted at cases of term breech presentation, went some way to alleviate any concerns about the safety of the procedure.

Alternatively, the recommendation of C-section delivery for breech births could have necessitated the provision of staff and physical infrastructure that could not be rationalized based on the incidence of breech presentations alone (which roughly represent 4 percent of hospital physician assisted births in our sample). Therefore, these resources became ready and available to facilitate the advancement of C-sections for other births.

7.2 Technological Changes

The second possible explanation for the trend break around 2000 is some breakthrough in the technology associated with birth delivery, which could have increased the incidence of C-sections. Perhaps the technology most commonly cited in discussions of "excess" C-sections is electronic fetal heart rate monitoring (EFM), primarily used to detect risks of fetal compromise (e.g. fetal hypoxia leading to acidosis) during labor. As the interpretation of the additional insights produced by EFM is not always conclusive, the rate of false positives when predicting bad outcomes with this technology is known to be high (ACOG 2005, Thacker et al. 2001). For these reasons, it is possible that recourse to electronic fetal monitoring may have led to increased, unnecessary interventions during deliveries, especially by risk averse doctors.

There however appears to be little evidence that the availability of EFM changed discretely in the early 2000s, and that it would drive the pattern we observe in Table 5. First introduced to obstetric practice in 1968 and increasingly used in the 1970s and 1980s, electronic fetal heart rate monitoring equipment was available in almost three quarters of Canadian hospitals by the early 1990s, and almost all women were monitored with this technology at some point during labor before 2000 (SOGC 1995). In the US, the prevalence of EFM also rose more quickly between

1980 and 1998 (from 45 percent to 64 percent) than between 1992 and 2002 (from 74 percent in to 85 percent) (ACOG 2009).

In Appendix B we document in more detail the changes in guidelines influencing the use of fetal monitoring. We also survey the introduction of complementary and substitute technologies such as ST waveform analysis, near infrared spectroscopy and fetal pulse oximetry. Our conclusion is that changes in guidelines associated with EFM, and the availability of and recommendations targeting related or complementary technologies are also unlikely to explain the patterns observed in Table 5. Indeed, these other technological innovations and the development of new software or models might plausibly be expected to reduce (rather than increase) the incidence of C-sections, and are not susceptible to have caused a discrete increase in Caesareans in the early 2000s. Furthermore, to the extent that these technologies would likely have increased the recourse to Caesareans by facilitating the identification of fetal distress, the estimated year effects should be net of this effect in columns 1 to 5 of Table 5, since we directly control for fetal distress in the regressions.

7.3 Other Guidelines and Directives From Medical Societies

A final factor to consider in trying to explain the break in the trend presented in Table 5 is any change to directives concerning alternatives to C-sections. The May 2000 policy statement of the Society of Obstetricians and Gynaecologists of Canada on attendance at labor and delivery seems most relevant (SOGC 2000). Updating a statement originally published in August 1995 and published again in an amended version in September 1996 (SOGC 1996), it suggested, among other things, that all hospitals have a responsibility to maintain the adequate equipment and staff to perform C-sections, especially in case of emergency, and recommended that C-sections be performed without delay when the clinical progress of labor justifies it. It also highlighted that physicians bear responsibility when choosing to delay the recourse to C-sections, and should report the reasons for such a decision on the patient's chart. According to this last recommendation, we would expect the inclusion of risk factors in our empirical model to at capture the impact of this directive on the choice of a birth delivery method.

Ultimately we do not have the data to directly test the Breech Trial and technological change alternatives. What is clear is that there was a discrete break in the trend of C-sections for both vertex and non-vertex births at the beginning of the 2000s. Our overview of the alternatives does not identify a discrete technological event in the early 2000s, perhaps making some spillover from the Breech Trial a more likely cause. Given widespread concern over the high proportion of births by C-section, the exact reasons for this development are an important topic for future research.

8 CONCLUSION

In this paper, we use unique features of the Canadian health care system— universal, single-payer, fee-for-service remuneration—to better understand the competing causes of the dramatic rise in C-sections over the 1990s and 2000s. Our empirical approach rests on an institutional context that allows us to use detailed data on the entire population of births, and to evaluate the contributions of birth, physician and environmental characteristics.

Changes in characteristics of the mothers and births, the move towards more deliveries by OB/GYNs and the changing relative prices of C-section and vaginal deliveries account for roughly half of the increase in C-sections (and their effects are remarkably stable across various specifications). The residual increase in C-section deliveries, representing over half the overall increase during the period, primarily occurred in the early 2000s.

We investigate two possible explanations of this latter development. We can find no evidence of a technological innovation that might account for the observed trend break in the C-section rate. We do find that the accelerated growth rate for all C-sections coincides with the publication of the Hannah Breech Trial, which focused on term breech births. We document a coincident increase in the growth rates of C-sections for both breech and vertex births in data from Australia, the US and Canada. We lack the data to explicitly connect these two developments and so a resolution awaits future study, but our investigation does suggest that spillovers from the Term Breech Trial may have had an influence on the changes in the number of C-sections.

C-sections represent, by far, the main cause of surgery in many countries. Our findings constitute an insightful basis for policy initiatives that would seek to improve the efficiency in the allocation of resources within the health care system and the broader impacts of dissemination of new best-practices.

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Table 1: Total observations for fiscal years 1994 to 2010, by province

	All births			Births not corresponding to cases of breech, multiple births or previous C-sections		
	Births	**Vaginal deliveries**	**C-sections**	**Births**	**Vaginal deliveries**	**C-sections**
Newfoundland and Labrador	76,544	55,705	20,839	64,612	54,128	10,484
Prince Edward Island	17,954	12,854	5,100	14,794	12,326	2,468
Nova Scotia	145,170	109,793	35,377	121,687	104,280	17,407
New Brunswick	128,174	95,274	32,900	107,936	91,698	16,238
Ontario	2,264,754	1,715,091	549,663	1,882,295	1,627,003	255,292
Manitoba	130,421	103,548	26,873	109,374	97,262	12,112
Saskatchewan	164,725	131,511	33,214	139,300	123,957	15,343
Alberta	469,997	349,299	120,698	386,724	330,502	56,222
British Columbia	687,018	500,970	186,047	565,177	474,962	90,215
Canada	**4,084,757**	**3,074,046**	**1,010,711**	**3,391,899**	**2,916,118**	**475,781**

Notes: The sample restricted to births recorded in the hmdb/dad files between fiscal years 1994 to 2010, from mothers between 14 and 65 years of age, whose birth was assisted by a physician (general practitioner or specialist), for whom price data on birth delivery method is available and for which information on the specialty of the most responsible physician is available. Data for Alberta includes fiscal years 1997, and 2001 to 2010. Data from Newfoundland and Labrador and Nova Scotia includes fiscal years 1995 to 2010. Data from Saskatchewan and Prince Edward Island includes fiscal years from 1998 to 2010. Data from Manitoba includes fiscal years 2001 to 2010 (with partial population of births between 2001 and 2002 due to some hospital not providing information on physician types). No data from Quebec is included.

Table 2: Means of main variables in the sample of births by physicians

	All	Vaginal Delivery	C-section
C-section birth	24.74	0	100
Maternal age	29.03	28.62	30.28
Maternal age > 40 years	0.027	0.022	0.043
Maternal age > 35 years	0.170	0.150	0.231
Multiple gestation	0.016	0.009	0.037
Previous C-section	0.121	0.036	0.380
Breech presentation	0.045	0.010	0.150
Pre-term delivery	0.105	0.051	0.084
Prolonged gestation	0.103	0.105	0.099
Disproportion	0.035	0.004	0.130
Obstructed labor	0.088	0.058	0.178
Fetal distress and umbilical cord problems	0.265	0.260	0.283
Antepartum hemorrhage	0.004	0.004	0.006
Disorders of the placenta	0.026	0.018	0.051
Maternal obesity	0.006	0.004	0.013
Maternal diabetes	0.045	0.037	0.070
Hypertension and (pre) eclampsia	0.060	0.049	0.094
Induced labor	0.220	0.234	0.178
Small for gestational age	0.017	0.034	0.023
Large for gestational age	0.022	0.017	0.035
Week-end delivery	0.228	0.249	0.164
OB/GYN	0.694	0.635	0.872
GDP per capita ($2002, k)	38.63	38.47	39.11
Gov expenditure on health care capital per capita ($2002)	118.50	116.16	125.65
Gov expenditure on health care per capita ($2002, k)	2.524	2.502	2.593
Length of stay (days)	2.710	2.257	4.089
Stay > 1 month (/10,000)	0.002	0.001	0.005
Observations	**4,084,755**	**3,074,046**	**1,010,711**

Notes: The sample restricted to births recorded in the hmdb/dad files between fiscal years 1994 to 2010, from mothers between 14 and 65 years of age, whose birth was assisted by a physician (general practitioner or specialist), for whom price data on birth delivery method is available and for which information on the specialty of the most responsible physician is available.

Table 3: Contribution of different types of births to the rise in C-section, 1994 to 2010

Panel A: OB/GYNs and GPs only

	1994	2010
Panel A: C-section rate by birth type (%)		
Vertex singletons without a previous C-section	10.23	16.21
Multiple births, breech and previous C-sections	66.19	82.84
All births	18.37	29.31
Panel B: Share of all births (%)		
Multiple births, breech presentations and previous C-sections	14.55	19.65

Panel B: OB/GYNs, GPs and Midwives

	1994	2010
Panel A: C-section rate by birth type (%)		
Vertex singletons without a previous C-section	10.19	15.52
Multiple births, breech presentations and previous C-sections	66.10	81.94
All births	18.30	28.12
Panel B: Share of all births (%)		
Multiple births, breech presentations and previous C-sections	14.51	18.97

Table 4: Probability of C-section birth: Impact of birth- and province-level characteristics – with full set of birth-level characteristics and province characteristics

	Baseline Specification			Physician IDs	Physician type	
					OB/GYN	GP
	(1)	(2)	(3)	(4)	(5)	(6)
Most responsible provider is OB/GYN	0.109***	0.109***	0.156***	0.002		
	(0.008)	(0.008)	(0.011)	(0.009)		
Breech presentation (care or obstruction)	0.580***	0.580***	0.576***	0.595***	0.565***	0.610***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.015)
Multiple gestation	0.109***	0.109***	0.105***	0.108***	0.104***	0.090***
	(0.009)	(0.009)	(0.008)	(0.010)	(0.009)	(0.018)
Previous C-section	0.582***	0.582***	0.572***	0.599***	0.593***	0.394***
	(0.007)	(0.007)	(0.007)	(0.010)	(0.007)	(0.019)
Preterm birth	0.003	0.003	0.004	-0.001	0.004	0.001
	(0.004)	(0.004)	(0.004)	(0.003)	(0.004)	(0.005)
Hypertension or (pre)eclampsia	0.113***	0.113***	0.110***	0.111***	0.118***	0.074***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.005)
Diabetes mellitus	0.043***	0.042***	0.045***	0.043***	0.048***	0.028***
	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)
Obesity	0.104***	0.105***	0.117***	0.119***	0.118***	0.090***
	(0.017)	(0.017)	(0.014)	(0.011)	(0.012)	(0.021)
Antepartum hemorrhage	0.040***	0.040***	0.038***	0.031***	0.035***	0.053***
	(0.008)	(0.008)	(0.007)	(0.009)	(0.008)	(0.010)
Placenta disorders (previa, etc.)	0.209***	0.209***	0.209***	0.206***	0.227***	0.130***
	(0.011)	(0.011)	(0.010)	(0.013)	(0.011)	(0.019)
Large fetus for gestational age	0.091***	0.090***	0.102***	0.123***	0.127***	0.042***
	(0.014)	(0.014)	(0.012)	(0.014)	(0.013)	(0.011)
Small fetus for gestational age	0.077***	0.077***	0.079***	0.074***	0.089***	0.041***
	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)	(0.005)
Disproportion	0.648***	0.648***	0.644***	0.662***	0.644***	0.625***
	(0.009)	(0.009)	(0.010)	(0.011)	(0.011)	(0.016)
Obstructed labor (any)	0.172***	0.172***	0.169***	0.159***	0.170***	0.163***
	(0.009)	(0.009)	(0.009)	(0.010)	(0.011)	(0.012)
Maternal distress/stress in labor/delivery	-0.018	-0.020	-0.014	-0.001	-0.019	-0.000
	(0.023)	(0.023)	(0.015)	(0.015)	(0.018)	(0.013)
Fetal distress/stress incl. umbilical cord problem	0.057***	0.057***	0.065***	0.069***	0.073***	0.050***
	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)
Recognition of midwifery		-0.005	-0.003	-0.004	0.005	0.003
		(0.005)	(0.005)	(0.007)	(0.007)	(0.006)
Change in population		-0.001	-0.002	-0.002	-0.003	-0.002
		(0.003)	(0.003)	(0.002)	(0.003)	(0.003)
GPD per capita		-0.000	-0.000	0.000	0.000	-0.000
		(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
Provincial exp on capital in health care per capita		0.117***	0.107***	0.060*	0.149***	0.045
		(0.030)	(0.030)	(0.033)	(0.041)	(0.032)
Provincial expenditure on health care per capita		-0.014	-0.012	-0.009	-0.014	-0.025**
		(0.009)	(0.010)	(0.008)	(0.014)	(0.011)
Financial incentive (CS/VD)	0.040	0.011	0.006	-0.032	0.009	0.014
	(0.025)	(0.027)	(0.032)	(0.022)	(0.028)	(0.013)
Hospital fixed effects			✓		✓	✓
Physician fixed effects				✓		
Observations	4,084,757	4,084,755	4,084,755	2,601,061	2,833,505	1,251,250

Notes: All specifications include a full set of maternal age fixed effects, day of the week fixed effect for the day of admissions, month of admission fixed effects, province fixed effects and year fixed effects. All amounts are in 2002 dollars (k) using the all-item consumer price index published by Statistics Canada (CANSIM Table 306-0020). Provincial health expenditure (total and on capital) are for each fiscal year and from the National Health Expenditure Database published by the Canadian Institute for Health Information (Series F-nhex2017). Population counts are taken on July 1st of each year per province, as published by Statistics Canada (CANSIM Table 051-0001). Expenditure-based GDP is from Statistics Canada (CANSIM Table 384-0002). Results in column 4 are obtained on a sample of observations between years 2001 to 2010 for which physician identifiers are available. Standard errors, in parenthesis, are clustered at the province-year level for columns 1-2, at the hospital level for columns 3-5. The coefficient on the fee variable for a specification corresponding to column (3) but on a sample corresponding to that used in column 4 is 0.001 (0.046). Significance levels: *** = 1%; ** = 5% and * = 10%.

Table 5: Probability of C-section birth: Estimates of year effects from main specification – with full set of birth-level characteristics and province characteristics

	No controls	Baseline specification			Physician type	
					OB/GYN	GP
	(0)	(1)	(2)	(3)	(5)	(6)
Year FE: 1995	0.003*	-0.000	-0.001	-0.003	-0.002	-0.004*
	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)	(0.002)
Year FE: 1996	0.011***	0.003	0.002	-0.000	0.002	-0.003
	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)
Year FE: 1997	0.014***	0.005	0.003	0.000	0.003	-0.002
	(0.002)	(0.003)	(0.004)	(0.003)	(0.004)	(0.003)
Year FE: 1998	0.022***	0.007*	0.008*	0.003	0.006	-0.002
	(0.003)	(0.004)	(0.004)	(0.003)	(0.004)	(0.004)
Year FE: 1999	0.030***	0.013***	0.013*	0.006	0.011**	0.003
	(0.003)	(0.004)	(0.007)	(0.004)	(0.005)	(0.005)
Year FE: 2000	0.047***	0.023***	0.024***	0.017***	0.025***	0.011**
	(0.003)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)
Year FE: 2001	0.064***	0.033***	0.034***	0.027***	0.036***	0.022***
	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.006)
Year FE: 2002	0.076***	0.044***	0.045***	0.037***	0.048***	0.028***
	(0.003)	(0.004)	(0.006)	(0.006)	(0.007)	(0.007)
Year FE: 2003	0.090***	0.053***	0.055***	0.046***	0.058***	0.036***
	(0.002)	(0.004)	(0.006)	(0.006)	(0.008)	(0.007)
Year FE: 2004	0.099***	0.062***	0.065***	0.055***	0.068***	0.041***
	(0.002)	(0.005)	(0.007)	(0.007)	(0.009)	(0.008)
Year FE: 2005	0.108***	0.067***	0.072***	0.061***	0.077***	0.042***
	(0.002)	(0.005)	(0.008)	(0.008)	(0.011)	(0.010)
Year FE: 2006	0.109***	0.068***	0.074***	0.063***	0.079***	0.044***
	(0.002)	(0.005)	(0.008)	(0.008)	(0.012)	(0.010)
Year FE: 2007	0.115***	0.069***	0.076***	0.064***	0.078***	0.047***
	(0.002)	(0.005)	(0.009)	(0.009)	(0.013)	(0.011)
Year FE: 2008	0.119***	0.069***	0.076***	0.063***	0.078***	0.046***
	(0.003)	(0.005)	(0.010)	(0.010)	(0.015)	(0.013)
Year FE: 2009	0.119***	0.067***	0.073***	0.061***	0.076***	0.047***
	(0.003)	(0.005)	(0.010)	(0.011)	(0.016)	(0.013)
Year FE: 2010	0.122***	0.067***	0.075***	0.062***	0.076***	0.048***
	(0.003)	(0.005)	(0.012)	(0.012)	(0.018)	(0.014)
Fee incentive and birth controls		✓	✓	✓	✓	✓
Province characteristics			✓	✓	✓	✓
Hospital fixed effects				✓	✓	✓
Observations	4,084,755	4,084,755	4,084,755	4,084,755	2,833,505	1,251,250

Notes: Includes a full set of province fixed effects and year fixed effects, as well as a dummy variable for OB/GYN (except columns 4 and 5). Birth and province controls correspond to those in Table A3 (part 1). Standard errors, in parenthesis, are clustered at the province-year level for columns 0 to 2, and at the hospital level for columns 3 to 5.
Significance levels: *** = 1%; ** = 5% and * = 10%.
F-statistics from column (3): Test that the year effects for 1995 to 1999 jointly equal has a p-value 0.22 (F stat of 01.45), and decreases to 0.00 (F= 6.78) when testing the equality of the year effects for 1995 to 2000. Tests that each pair of years between 2000 and 2005 are jointly equal has a p-value of 0.00 (F=22.10) and testing the equality of the coefficients for each pair of these years yields p-values of at most 0.002 (for 2004-2005); Year effects for 2005-2010 are jointly equal has a p-value of 0.66 (F=0.65).

Figure 1: Evolution of C-section Rates for Selected Countries, 1995-2012

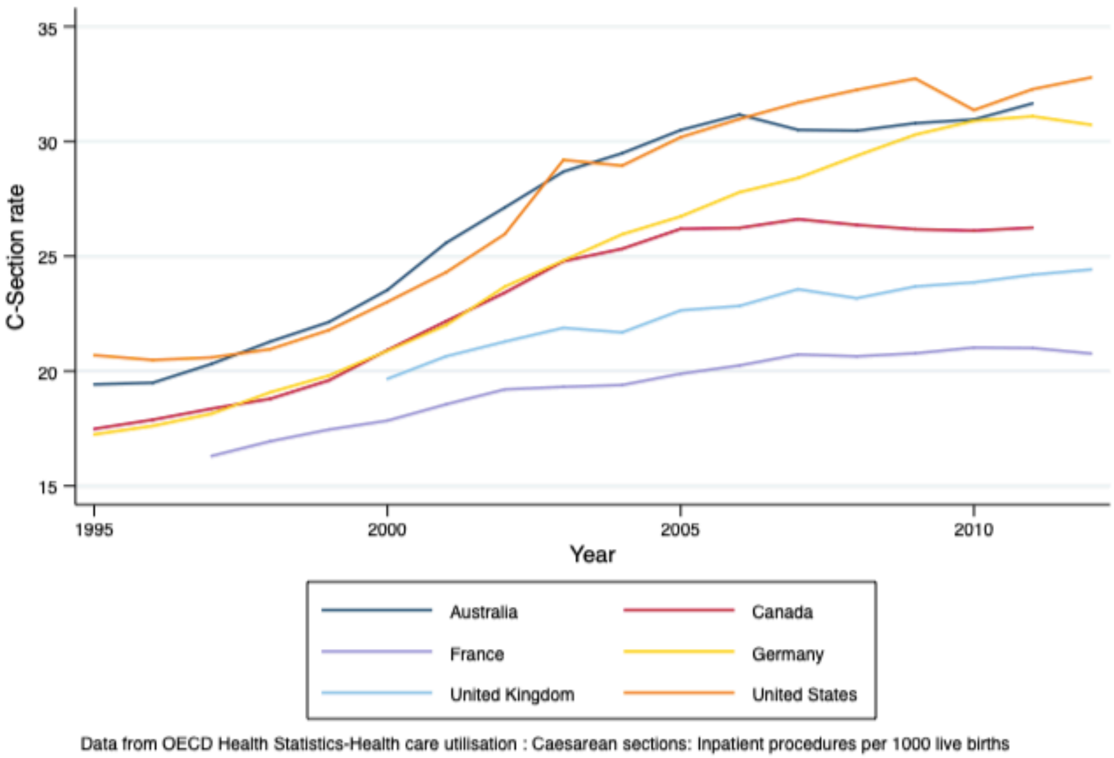


Figure 2: Evolution of C-Section Rates by Presentation, 1994-2010

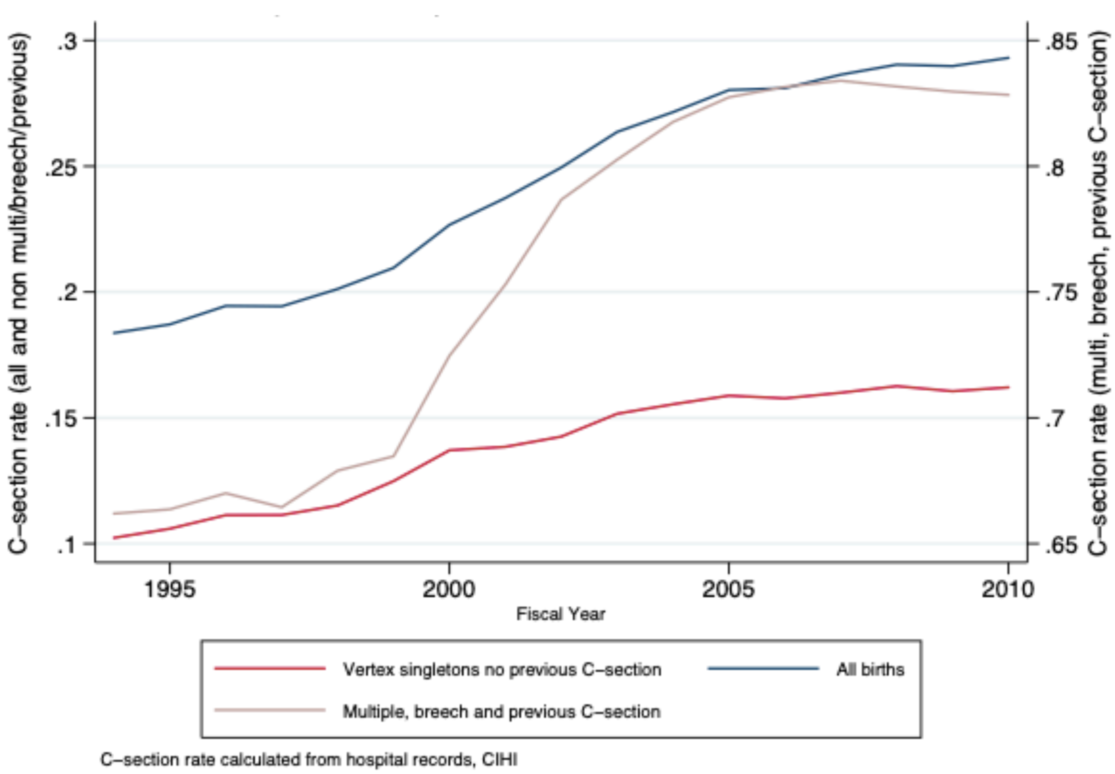


Figure 3: Evolution of Selected C-section Risk Factors, 1994-2010

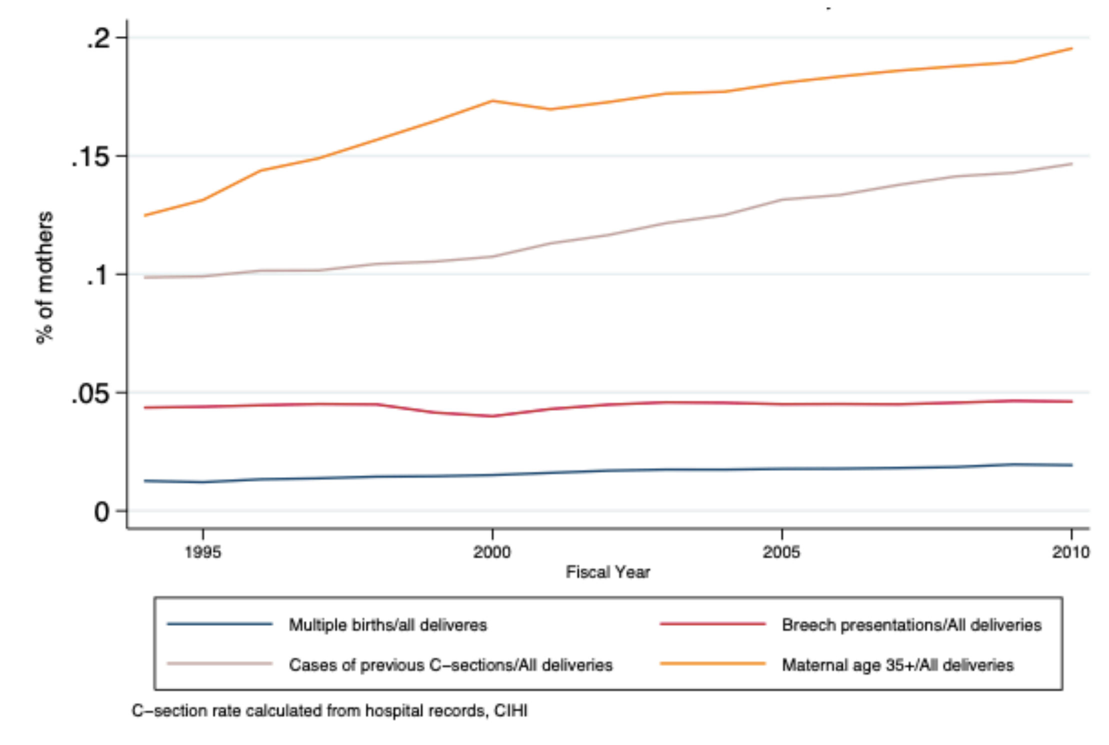


Figure 4: Evolution of the Share of Births by Type of Most Responsible Provider

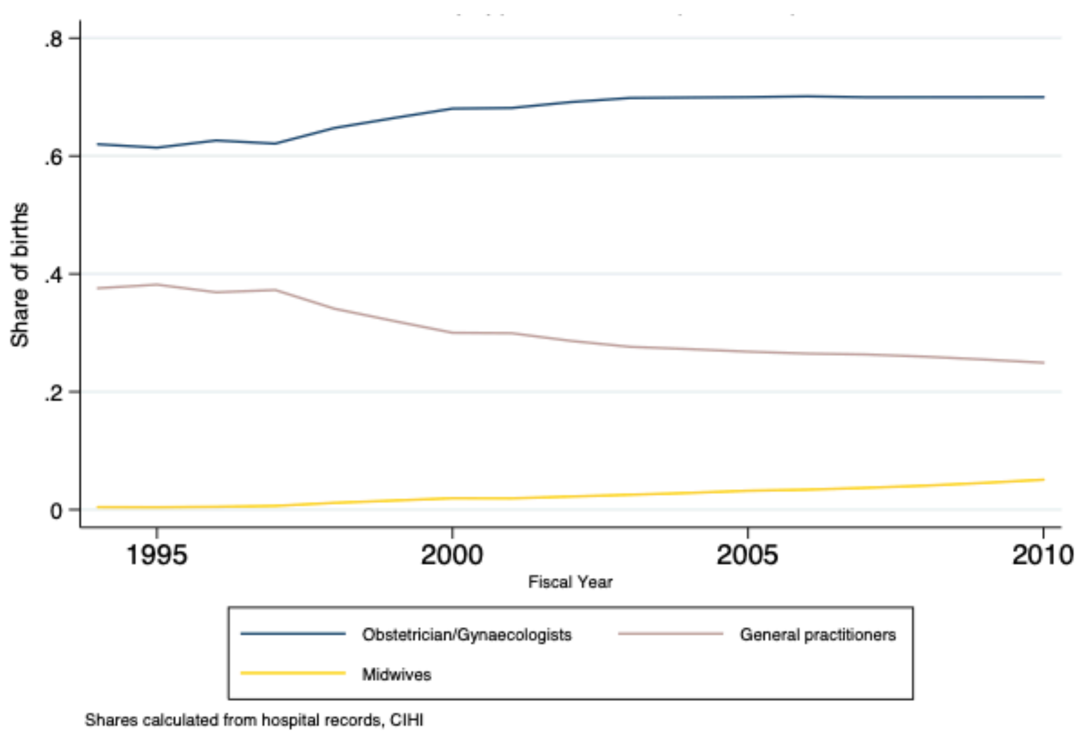


Figure 5: Evolution of C-section Rates by Type of Most Responsible Provider

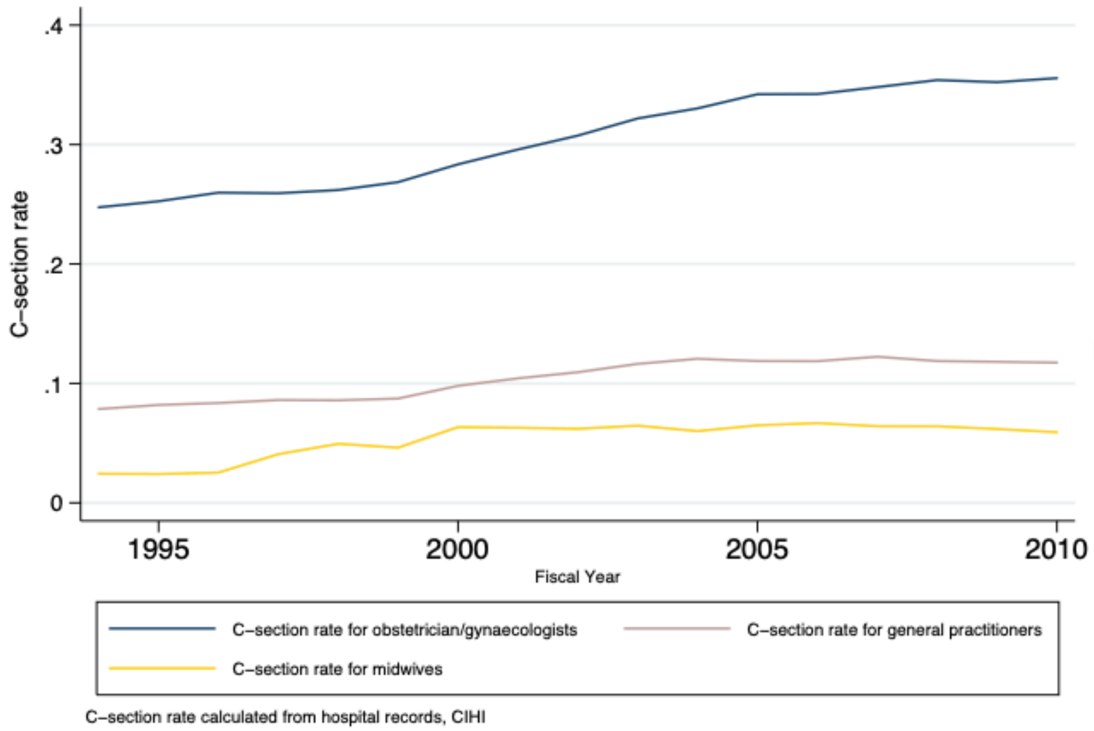


Figure 6 : Effects of Maternal Age at Birth on Probability of C-section

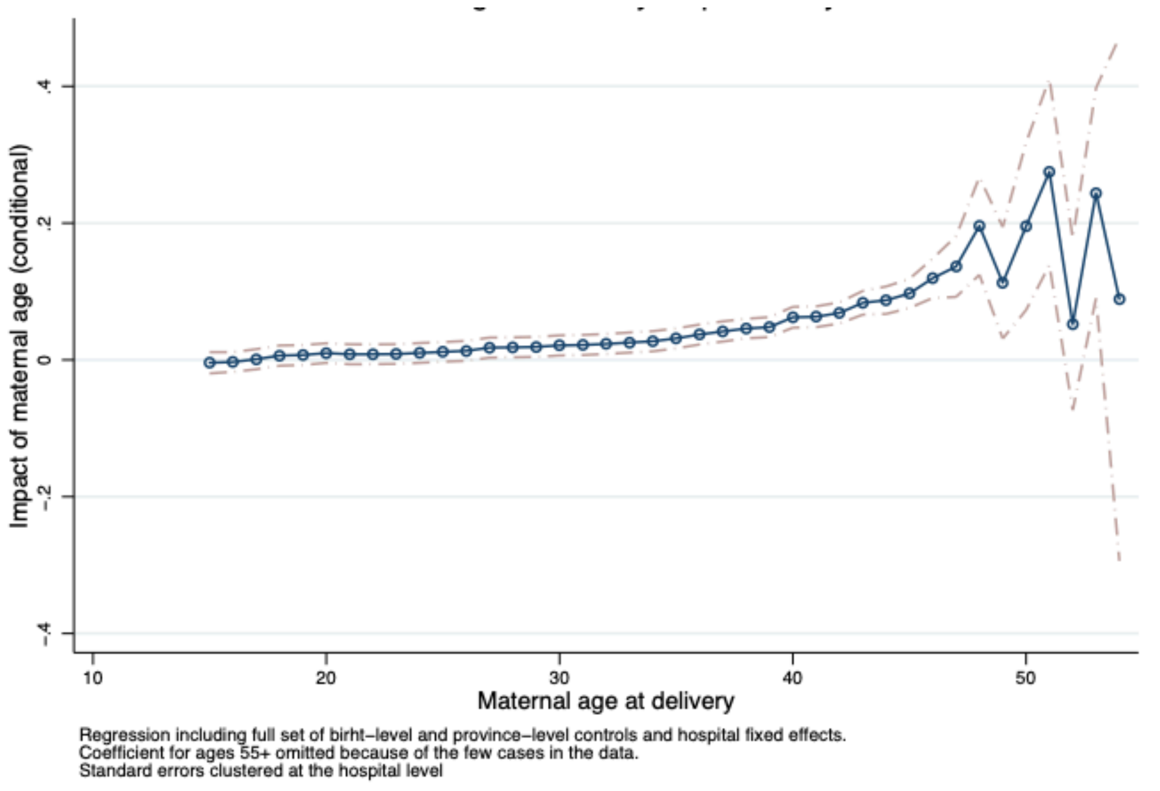


Figure 7: Growth in C-section Rate Between 1995-2005 in Australia, by Presentation Type

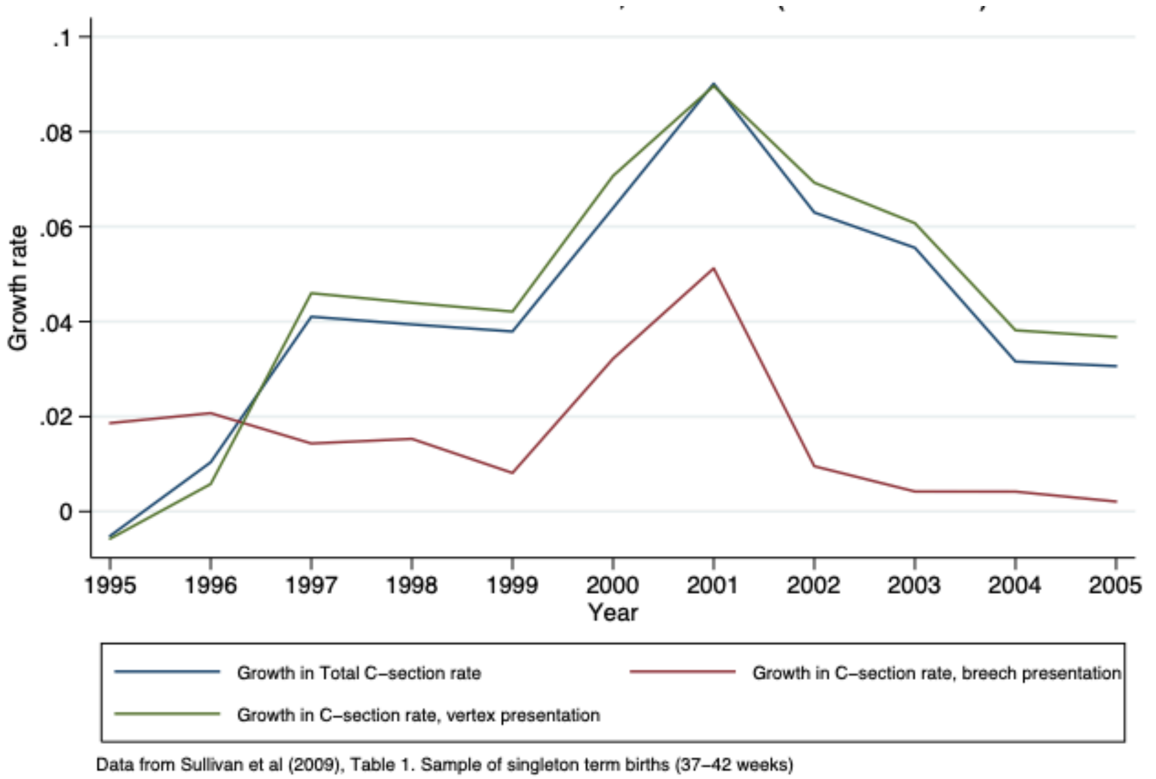


Figure 8: Growth in C-section Rate Between 1995-2005 in the US, by Presentation Type

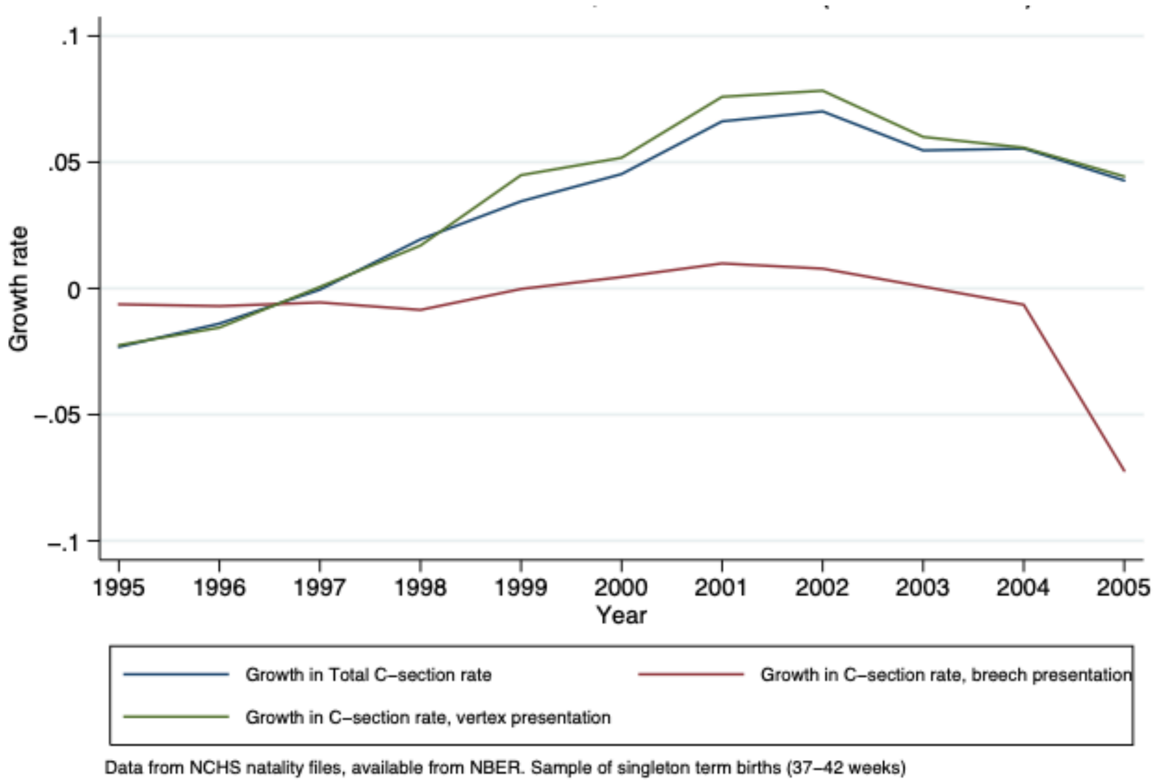
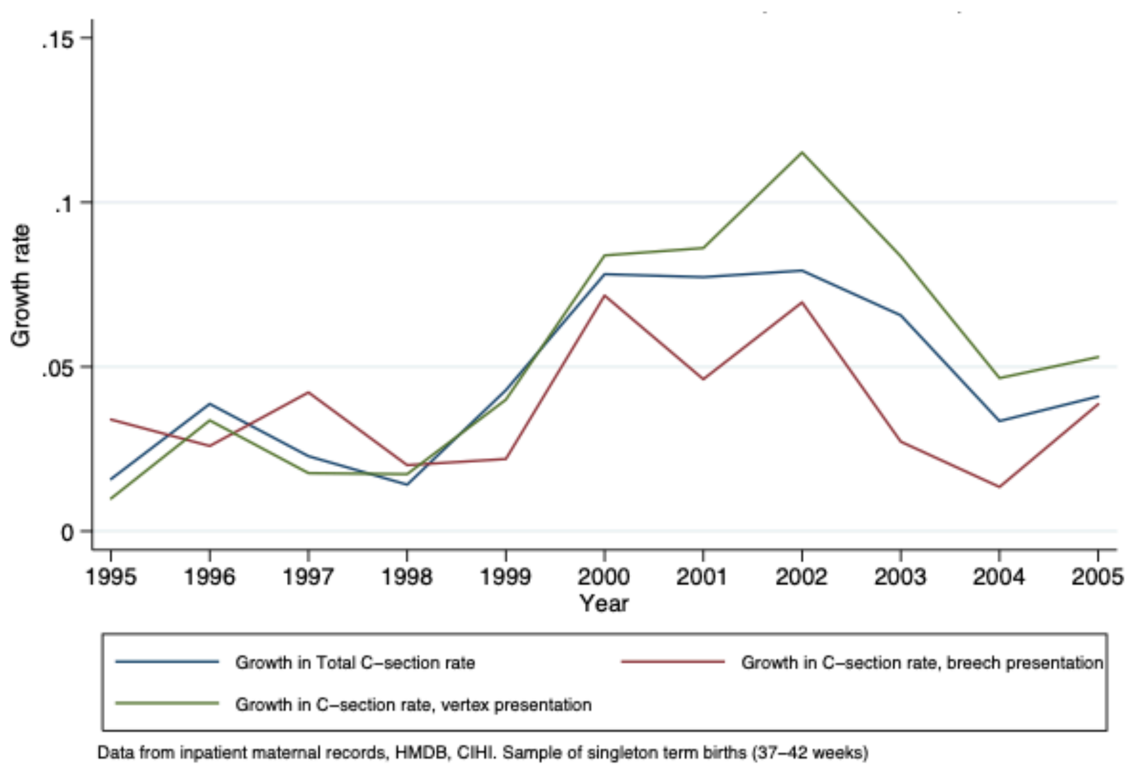


Figure 9: Growth in C-section Rate Between 1995-2005 in Canada, by Presentation Type



APPENDIX

Appendix A: Supplementary Tables

Table A1: Description of variations in annual C-section rates for fiscal years 1994 to 2010, by Canadian province

	C-section rate (%) All births			**C-section rate (%)** Births not corresponding to cases of breech presentations, multiple births or previous C-sections		
	Average	Annual Min	Annual Max	Average	Annual Min	Annual Max
Newfoundland and Labrador	27.495	20.895	32.485	16.457	11.439	20.216
Prince Edward Island	28.502	21.921	33.309	16.781	12.345	21.629
Nova Scotia	24.609	18.796	27.962	14.475	10.658	16.816
New Brunswick	25.893	20.433	29.229	15.223	11.104	17.354
Ontario	24.386	17.4495	30.124	13.688	9.636	16.447
Manitoba	20.482	18.550	21.995	11.058	10.178	11.910
Saskatchewan	20.086	16.417	23.013	10.976	8.567	13.267
Alberta	25.371	16.631	28.259	14.414	9.421	16.076
British Columbia	27.353	20.611	34.054	16.207	11.844	20.686
Canada	**24.743**	**18.373**	**29.306**	**14.027**	**10.232**	**16.259**

Table A2: Birth-level characteristics by physician type

	GP		Midwives		OB/GYN	
	Sample average	Change 1994-2010	Sample average	Change 1994-2010	Sample average	Change 1994-2010
C-section birth	10.34	3.74	6.07	2.48	31.11	11.03
Maternal age at delivery	28.176	0.525	29.935	-0.76	29.402	1.185
Maternal age > 40 years	1.693	0.985	2.432	-0.501	3.122	2.139
Maternal age > 35 years	13.014	3.888	18.357	-3.096	18.768	7.632
Multiple birth	0.298	-0.096	0.231	-0.081	0.223	0.718
Previous C-section	5.421	1.096	4.929	1.48	15.027	4.865
Breech presentation	1.536	-0.479	0.907	-0.586	5.755	-0.132
Pre-term delivery	3.187	0.458	2.599	0.723	7.168	2.317
Prolonged pregnancy	11.183	6.358	10.763	5.19	9.977	4.109
Disproportion	2.216	-0.788	1.592	-0.335	4.123	-3.163
Fetal distress and umbilical cord problems	24.140	12.487	12.890	11.179	27.588	9.188
Hemorrhage	0.376	-0.251	0.165	-0.263	0.460	-0.084
Placental disorders	1.616	0.057	1.081	-0.213	3.059	0.065
Maternal obesity	0.407	0.346	0.233	0.205	0.734	1.203
Maternal diabetes	3.181	1.387	1.147	1.332	5.145	3.834
Hypertension and (pre) eclampsia	4.440	0.66	2.309	0.502	6.710	1.235
Induction of labor	19.518	7.661	11.462	3.183	23.173	4.115
Small for gestational age	1.493	0.231	0.745	-0.04	2.621	0.349
Large for gestational age	2.145	0.275	1.565	-2.726	2.160	0.144
Week-end delivery	24.223	-0.313	26.478	-1.802	22.144	0.05
Length of stay (days)	2.433	-0.675	1.524	-0.022	2.833	-0.729
Stay > 1 month (/10,000)	0.055	0.027	0.006	0	0.213	-0.078
Observations	**1,251,252**		**105,400**		**2,833,505**	

Table A3: Probability of C-section birth: Impact of birth- and province-level characteristics – with full set of birth-level characteristics and province specific time-trends

	Baseline Specification			Physician IDs	Physician type	
					OB/GYN	GP
	(1)	(2)	(3)	(4)	(5)	(6)
Most responsible provider is OB/GYN	0.109***	0.109***	0.156***	0.002		
	(0.008)	(0.008)	(0.011)	(0.009)		
Breech presentation (care or obstruction)	0.580***	0.580***	0.576***	0.595***	0.565***	0.610***
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.015)
Multiple gestation	0.109***	0.109***	0.105***	0.108***	0.104***	0.090***
	(0.009)	(0.009)	(0.008)	(0.010)	(0.009)	(0.018)
Previous C-section	0.582***	0.582***	0.572***	0.598***	0.593***	0.394***
	(0.007)	(0.007)	(0.007)	(0.010)	(0.007)	(0.019)
Preterm birth	0.003	0.003	0.004	-0.001	0.004	0.001
	(0.004)	(0.004)	(0.004)	(0.003)	(0.004)	(0.005)
Hypertension or (pre)eclampsia	0.113***	0.113***	0.110***	0.111***	0.118***	0.074***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.005)
Diabetes mellitus	0.043***	0.042***	0.045***	0.043***	0.048***	0.028***
	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)
Obesity	0.104***	0.105***	0.117***	0.120***	0.119***	0.090***
	(0.017)	(0.017)	(0.014)	(0.011)	(0.012)	(0.020)
Antepartum hemorrhage	0.040***	0.039***	0.037***	0.031***	0.034***	0.052***
	(0.008)	(0.008)	(0.007)	(0.010)	(0.008)	(0.010)
Placenta disorders (previa, etc.)	0.209***	0.209***	0.209***	0.206***	0.227***	0.130***
	(0.011)	(0.011)	(0.010)	(0.013)	(0.011)	(0.019)
Large fetus for gestational age	0.091***	0.090***	0.102***	0.123***	0.127***	0.042***
	(0.014)	(0.014)	(0.012)	(0.013)	(0.012)	(0.011)
Small fetus for gestational age	0.077***	0.077***	0.079***	0.074***	0.089***	0.041***
	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)	(0.005)
Disproportion	0.648***	0.648***	0.644***	0.662***	0.644***	0.625***
	(0.009)	(0.009)	(0.010)	(0.011)	(0.011)	(0.016)
Obstructed labor (any)	0.172***	0.172***	0.169***	0.159***	0.170***	0.163***
	(0.009)	(0.009)	(0.009)	(0.010)	(0.011)	(0.012)
Maternal distress/stress in labor/delivery	-0.018	-0.020	-0.014	-0.001	-0.018	0.000
	(0.023)	(0.023)	(0.016)	(0.015)	(0.018)	(0.013)
Fetal distress/stress incl. umbilical cord problem	0.057***	0.057***	0.065***	0.069***	0.073***	0.050***
	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)
Financial incentive (CS/VD)	0.040	0.023	0.018	0.020	-0.026	0.009
	(0.025)	(0.027)	(0.033)	(0.022)	(0.021)	(0.013)
Hospital fixed effects			✓		✓	✓
Physician fixed effects				✓		
Province specific time trends		✓	✓	✓	✓	✓
Observations	4,084,755	4,084,755	4,084,755	2,601,061	2,833,505	1,251,250

Notes: All specifications include a full set of maternal age fixed effects, day of the week fixed effect for the day of admissions, month of admission fixed effects, province fixed effects and year fixed effects. All amounts are in 2002 dollars (k) using the all-item consumer price index published by Statistics Canada (CANSIM Table 306-0020). Results in column 4 are obtained on a sample of observations between years 2001 to 2010 for which physician identifiers are available. Standard errors, in parenthesis, are clustered at the province-year level for columns 1-2, at the hospital level for columns 3-6.
The coefficient on the fee variable for a specification corresponding to column (3) but on a sample corresponding to that used in column 4 is 0.042 (0.038)
Significance levels: *** = 1%; ** = 5% and * = 10%.

Table A3 (continued): Estimates of year effects from main specification – with full set of birth-level characteristics and province specific time-trends

	No controls	Baseline specification			Physician type	
					OB/GYN	GP
	(0)	(1)	(2)	(3)	(4)	(5)
Year FE: 1995	0.003*	-0.000	-0.002	-0.004*	-0.001	-0.002
	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)	(0.002)
Year FE: 1996	0.011***	0.003	0.001	-0.001	0.005	0.001
	(0.002)	(0.003)	(0.003)	(0.003)	(0.004)	(0.003)
Year FE: 1997	0.014***	0.005	0.000	-0.001	0.008	0.002
	(0.002)	(0.003)	(0.004)	(0.004)	(0.005)	(0.004)
Year FE: 1998	0.022***	0.007*	0.002	0.001	0.012*	0.004
	(0.003)	(0.004)	(0.005)	(0.005)	(0.006)	(0.005)
Year FE: 1999	0.030***	0.013***	0.007	0.005	0.021***	0.008
	(0.003)	(0.004)	(0.006)	(0.006)	(0.007)	(0.005)
Year FE: 2000	0.047***	0.023***	0.018***	0.015**	0.036***	0.014***
	(0.003)	(0.004)	(0.006)	(0.006)	(0.008)	(0.005)
Year FE: 2001	0.064***	0.033***	0.027***	0.024***	0.048***	0.022***
	(0.004)	(0.004)	(0.007)	(0.007)	(0.009)	(0.007)
Year FE: 2002	0.076***	0.044***	0.037***	0.034***	0.061***	0.028***
	(0.003)	(0.004)	(0.007)	(0.007)	(0.010)	(0.008)
Year FE: 2003	0.090***	0.053***	0.047***	0.044***	0.073***	0.035***
	(0.002)	(0.004)	(0.007)	(0.007)	(0.011)	(0.008)
Year FE: 2004	0.099***	0.062***	0.056***	0.051***	0.084***	0.039***
	(0.002)	(0.005)	(0.008)	(0.008)	(0.012)	(0.010)
Year FE: 2005	0.108***	0.067***	0.061***	0.058***	0.093***	0.039***
	(0.002)	(0.005)	(0.008)	(0.008)	(0.013)	(0.009)
Year FE: 2006	0.109***	0.068***	0.061***	0.058***	0.095***	0.039***
	(0.002)	(0.005)	(0.009)	(0.009)	(0.014)	(0.010)
Year FE: 2007	0.115***	0.069***	0.063***	0.059***	0.097***	0.041***
	(0.002)	(0.005)	(0.009)	(0.010)	(0.015)	(0.010)
Year FE: 2008	0.119***	0.069***	0.062***	0.059***	0.099***	0.038***
	(0.003)	(0.005)	(0.010)	(0.011)	(0.016)	(0.010)
Year FE: 2009	0.119***	0.067***	0.060***	0.057***	0.098***	0.039***
	(0.003)	(0.005)	(0.011)	(0.011)	(0.017)	(0.011)
Year FE: 2010	0.122***	0.067***	0.060***	0.057***	0.099***	0.038***
	(0.003)	(0.005)	(0.012)	(0.012)	(0.019)	(0.011)
Fee incentive and birth controls		✓	✓	✓	✓	✓
Province specific time trends			✓	✓	✓	✓
Hospital fixed effects				✓	✓	✓
Observations	4,084,755	4,084,755	4,084,755	4,084,755	2,833,505	1,251,250

Notes: Includes a full set of province fixed effects and year fixed effects, as well as a dummy variable for OB/GYN (except columns 4 and 5). Birth and province controls correspond to those in Table 4. Standard errors, in parenthesis, are clustered at the province-year level for columns 0 to 2, and at the hospital level for columns 3 to 5.
Significance levels: *** = 1%; ** = 5% and * = 10%.
F-statistics from column (3): Test that the year effects for 1995 to 1999 jointly equal has a p-value 0.27 (F stat of 1.30), and decreases to 0.00 (F= 7.63) when testing the equality of the year effects for 1995 to 2000. Tests that each pair of years between 2000 and 2005 are jointly equal has a p-value of 0.00 (F=30.53) and testing the equality of the coefficients for each pair of these years yields p-values of 0.00; Year effects for 2005-2010 are jointly equal has a p-value of 0.51 (F=0.85).

Appendix B: Changes in Fetal Monitoring Guidelines and Related Technologies

If the availability of electronic fetal monitoring or related technologies did not change discretely at the new millennium, changes in the guidelines influencing its use could have contributed to the pattern we observe in the early 2000s. While professional associations in Canada, the U.S. and Australia/New Zealand did issue bulletins concerning the use of intrapartum fetal monitoring in this period (e.g. SOGC 2002a-b, ACOG 2001, RANZCOG 2002), they did not in general promote a more aggressive recourse to this procedure, but rather counselled more conservative interpretation of its output. For example, the Canadian 2002 practice guidelines on fetal health surveillance in labor, which replaced the guidelines published in 1995 noted that, “Over the past two decades, research has challenged the clinical value of electronic fetal heart rate monitoring” (SOGC 2002a). Noting that EFM had not systematically been proven to improve outcomes, but had been associated with an increase in obstetrical interventions, the new guidelines recommend EFM for cases of augmented or induced labor, increased risks of cerebral palsy, perinatal death or neonatal encephalopathy and presence of abnormal fetal heart rate features unresponsive to resuscitation measures. They also reiterate the appropriateness of intermittent auscultation (IA) over EFM for low-risk/healthy pregnancies.

Similar recommendations were issued during the same period in the United States, as well as in Australia and New Zealand, three jurisdictions in which we observe an acceleration of the increase in C-section rates in the early 2000s. In the U.S., the 4th and the 5th editions of the Guidelines for Perinatal Care, published in 1997 and in 2002, highlight that in most cases, EFM is not preferred to intermittent auscultation performed at specific intervals, as the former is associated with a higher rate of false positive cases of fetal distress leading to unnecessary C-section deliveries (AAP and ACOG 1997, AAP and ACOG 2002). In 2002, the Royal Australian and New

Zealand College of Obstetricians and Gynecologists also published guidelines that advised caution when using EFM (RANZCOG 2002). Based on reports from enquiries within their jurisdictions and findings from the literature, they also called for education programs to be rolled out to help practitioners use the technology, and interpret and report the data it produces. We note that the Royal College of Obstetricians and Gynaecologists, in the United Kingdom, also published related recommendations in 2001 (RCOG 2001).

It also seems unlikely that a rise in the use of newer technologies developed or refined in the 1990s (such as ST waveform analysis combined with conventional cardiotocography, near infrared spectroscopy, fetal pulse oximetry) to complement EFM and facilitate the interpretation of its output lies behind the rapid rise in C-section births from 2000. Indeed, new guidelines in the early 2000s generally refrained from recommending the use of such technologies. For example, the US Food and Drug Administration gave, in May 2000, its conditional approval to a new device to help assessing fetal oxygen status during labor (fetal pulse oximetry), which was regarded as a major technological progress related to EFM since its introduction in obstetrics (Simpson and Porter 2001, Dildy 2011). Following the publication of results from early randomized control trial (e.g. Garite et al. 2000)[20], the ACOG to publish a committee opinion in September 2001 in which it refrained from formally endorsing the use of the device, arguing that it might increase the cost associated with deliveries without improving outcomes for patients (ACOG 2001). Records of deliberations of the FDA Obstetrics and Gynecology Devices Approval Advisory Panel suggest that the publication of this opinion and the interruption of active marketing efforts by the company producing the device contributed to limiting the use of the device (FDA 2003). In Canada, the

[20] Garite et al. (2000) found that the combination of fetal pulse oximetry and electronic fetal monitoring reduced C-section rates in cases of non-reassuring fetal status at delivery compared to electronic fetal monitoring alone. However, they found no impact on the total rate of C-sections among trial participants.

device had been approved in the late 1990s, before the observed break in the C-section trend, on the basis that it might help reduce recourse to unnecessary C-section in cases of non-reassuring fetal heart rate patterns. However, both the 1995 and the updated 2002 SOGC guidelines on EFM refrained from recommending its use until further research was conducted (SOGC 1995, SOGC 2002a-b). Given the barriers to its diffusion and the mixed conclusions of several trials (e.g. Bloom et al. 2006), it is therefore not clear that fetal pulse oximetry might have contributed to the rapid acceleration in C-section rates observed in the early 2000s.

The STAN system (combining ST segment and T-wave analysis) is another technology which a wave of trials in the 2000s suggested could help better understand EFM data and reduce occurrences of unnecessary C-sections for deliveries starting with a normal initial heart rate (Bloom et al. 2016). However, many of those trials were conducted later in the 2000s, and they are unlikely to be relevant to changes in the C-section rate as early as 2000-2002. Moreover, most trials were conducted in Europe, and North American authorities voiced scepticism about the external validity of the findings in different contexts (Bloom et al. 2016). While the FDA approved the STAN system in 2005 and the Cochrane Library endorsed its use alongside EFM in 2006, further results from a U.S. RCT, published in 2015, did not support an impact of combining EFM with ST-segment analysis on C-section rates (Bloom et al. 2016). In Canada, the Society of Obstetricians and Gynaecologists also mentioned in its 1995 and 2002 clinical guidelines that the existing body of scientific evidence did not suffice to recommend the use of this technology (SOGC 1995, SOGC 2002a-b). Overall, even if these trials had had for an impact to increase the use of ST segment analysis in Canada and in the US, the results from existing RCTs suggest that it could have reduced or left unchanged (not increased) recourse to C-section as a delivery method.

Other technological innovations of this period and related to improvements in the mathematical models, software and devices used to gather and interpret fetal heart rates include an algorithm developed in 2000 by Lai and Shynk to detect maternal and fetal heartbeat separately. However, despite the development of a series of mathematical models aimed at improving EFM data extraction and analysis, the most prevalent method used, averaging, had not changed by the end of the 2000s (Hasan et al. 2009). Note that the 2002 Canadian guidelines stated that the, "use of computer-based algorithms alone to interpret fetal heart rate patterns is not recommended as a standard of care at the present time" (SOGC 2002a).

References – Appendix B

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