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ARTICLE

Physician behaviour, malpractice risk and defensive medicine: an investigation of cesarean deliveries

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Abstract

Analyzing whether physicians use cesarean sections (c-sections) as defensive medicine (DM) has proven difficult. Using natural experiments arising out of Oregon court decisions overturning a state legislative cap on non-economic damages in tort cases, we analyze the impact of patient conditions on estimates of DM. Consistent with theory, we find heterogeneous impacts of tort laws across patient conditions. When medical exigencies dictate a c-section, tort laws have no impact on physician decisions. When physicians have latitude in their decision making, we find evidence of DM. When we estimate a model combining all women and not accounting for patient conditions (such as models estimated in previous studies) we obtain a result which is the opposite of DM, which we call offensive medicine (OM). The OM result appears to arise out of a bias in the difference-in-differences estimator associated with changes in the marginal distributions of patient conditions in control and treatment groups. The changes in the marginal distributions appear to arise from the impact of tort law on the market for midwives (substitutes for physicians for low-risk women). Our analysis suggests that not accounting for theoretically expected heterogeneity in physician reactions to changes in tort laws may produce biased estimates of DM.

Key words: Cesarean section; defensive medicine; Simpson's paradox; tort law

1. Introduction

Defensive medicine (DM) concerns physicians undertaking unnecessary procedures out of fear of a medical malpractice lawsuit (positive DM) or avoiding certain patients out of fear of lawsuits (negative DM). Physicians consistently state that their fear of malpractice litigation affects their decisions when interacting with patients (e.g. Grant and McInnes, 2004; Reyes, 2010; Montanera, 2016). Despite these stated fears, finding evidence of DM has proven difficult (Reyes, 2010; Seabury *et al.*, 2014).

The Obstetrics and Gynecology (OBGYN) medical specialty, generally, and physicians' use of cesarean sections (c-sections), specifically, have been a popular object of empirical analyses because use of c-sections is thought to be especially responsive to malpractice liability (Dubay *et al.*, 1999; Kim, 2007). Birth is a medical procedure in which the damages arising out of a bad outcome (such as fetal or maternal death or injury) can be especially high. Adding to the risk of malpractice claims, many plaintiffs file suit for the failure to perform a timely c-section rather than the failure to perform a c-section in the first instance (Kravitz *et al.*, 1991). As a result, the OBGYN practice is one of the medical specialties for which average payouts in malpractice cases is high, where jury verdicts can exceed malpractice insurance coverage, and for which tort reform might have a discernible impact (Dubay *et al.*, 1999; Seabury *et al.*, 2014). If DM exists, we might be more likely to find evidence of it in physicians performing c-sections.

Despite the expected greater likelihood of observing DM in the context of physicians performing c-sections, empirical analyses have spanned the spectrum of possible results, with findings of modest evidence of DM (Dubay *et al.*, 1999; Dranove and Watanabe, 2009; Esposito, 2012), no evidence of tort law affecting physician decisions to perform a c-section (Kim, 2007; Sloan and Shadle, 2009), and evidence of the opposite of DM (Currie and MacLeod, 2008; Shurtz, 2014) or what might be called 'offensive medicine' (OM). Studies have also identified various factors which, if not accounted for, may bias DM estimates. Brown (2007) finds that failure to account for small area variation in physician practice affects estimates of physicians performing c-sections as DM. In the context of the impact of tort reform on malpractice insurance markets, Grace and Leverty (2013) find that not accounting for the permanence of tort reforms may affect estimates of those impacts. Cano-Urbina and Montanera (2017) note that a change in the coding of births may eliminate OM findings.

We explore measuring whether physicians perform c-sections as DM in the context of natural experiments arising out of 1996 Oregon Court of Appeals and 1999 Oregon Supreme Court rulings that a state-enacted cap on non-economic damages in tort lawsuits was unconstitutional. Importantly, the Oregon Supreme Court ruling effectively increased the costs of physician error, increasing the incentive for DM. To test the effect of tort reform on physicians undertaking DM by performing c-sections, we focus strategically on the Portland-Vancouver MSA, which spans Oregon and Washington states. We consider (i) how accounting for maternal and fetal conditions (patient conditions), or failing to account for them, affects estimates of DM, and (ii) the impact of market-level effects of the change in tort law on estimating DM.

Economic theory and intuition suggest that a change in tort law should have heterogeneous (across patient conditions) impacts on physician decisions to perform c-sections. We do not necessarily expect a change in tort law to affect physician decision making uniformly across patient conditions. Given that the tort of medical malpractice is defined with reference to the standard of practice in the medical community, a physician with a patient who has had a prior c-section will face a different standard of practice than a physician presented with a low-risk patient. We would not necessarily expect physicians with such different points of reference to react to a change in negligence tort law in the same fashion. In addition, we would expect the medical risks associated with patient conditions to dominate over concerns about malpractice liability when a physician is faced with a patient whose fetus has a medically severe condition such as, for example, cord prolapse. In such a case, a change in tort laws will likely have a nominal effect on a physician's medical judgment. The importance of these reference standards and of medical risks to physician decision making is supported by research indicating that medical norms may have a greater influence on physician behavior than economic incentives in some circumstances (Lin and Yang, 2006). Finally, economic theory also implies such heterogeneous impacts (e.g. Currie and MacLeod, 2008) for similar reasons. We analyze the possibility of such heterogeneous impacts in the context of the Currie and MacLeod (2008) theoretical model of physician decision making.

The heterogeneity in physician responses to changes in tort laws has implications for uncovering and measuring DM. It implies that we would expect the changes to affect a narrower group of mothers, those mothers for whom physicians have wider latitude in deciding whether a vaginal or c-section birth is appropriate. We would not expect the changes to affect situations in which a c-section is dictated medically (such as when a fetus has cord prolapse). Investigators should, therefore, focus on the patient conditions in which physician discretion is greatest when looking for evidence of DM. Those would be situations in which a patient poses lower medical risks.

Empirical analyses have generally not measured the impacts of changes in tort law on physicians performing c-sections for different patient conditions. In some cases, studies have included dummy variables for patient conditions in regressions (e.g. Currie and MacLeod, 2008; Shurtz, 2014).[1] An exception is Kim (2007) who, in the context of the impact of malpractice risk on physician decision making, presents econometric estimates of the probability of having a c-section for sub-groups of mothers, including (1) mothers who did not have a prior c-section, (2) mothers with a prior c-section, (3) breech births, (4) mothers with gestational diabetes, (5) plural births and (6) mothers having less than a high school diploma. He finds no impact of malpractice risk on physician decision making for these groups. We differ from his analysis in that we tie the patient conditions on which we focus to a theoretical model of physician decision making that is presented in Currie and MacLeod (2008).

We estimate separate models for women presenting with conditions which range from lower to higher medical risk. Specifically, we focus on (i) 'low-risk' women, (ii) 'low-risk, first-birth' women, (iii) women with plural births and (iv) women who have had a prior c-section. We also separate women with birth complications into two broad risk categories (those with c-section rates above 50% and those with c-section rates below 50%) to determine whether regression results for these sub-groups are consistent with our findings for the foregoing sub-groups. When we estimate our econometric model separately for the different sub-groups of women we find heterogeneous impacts of the change in law consistent with intuition and the Currie and MacLeod (2008) model. Specifically, we find that the change in tort law increased c-section rates for low-risk women, and low-risk, first-time women, with the impact on women presenting with complications with c-section rates below 50% being positive but statistically insignificant. We also find that the change in tort law did not affect c-section rates for women with plural births and women with a prior c-section. When we estimate a model which combines all of these women into one group (and does not distinguish among them), as has typically happened in the literature, we obtain an OM result: that c-section rates decreased after the removal of the cap on damages. When we add dummy variables for patient conditions, the OM result disappears and we find no effect for the change in tort law.

We explore these divergent results in terms of the market-level effects of the change in Oregon tort law. It has been noted that, when measuring the treatment effect of a change in policy, the market-level (general equilibrium) effects arising out of the change can produce misleading estimates of a policy's impact (Abbring and Heckman, 2007: 5285). For example, Heckman *et al.* (1998b) focus on the general equilibrium price effects of a tuition subsidy policy. They 'find that general-equilibrium impacts of tuition on college enrollment are an order of magnitude smaller than those reported in the literature on micro-econometric treatment effects' (Heckman *et al.*, 1998b: 385).

We frame our analysis of market-level effects in the context of studies by Heckman *et al.* (1998a, 1999) who identified possible biases which might arise when using the difference-in-difference (DD) estimator to measure a treatment effect in the presence of an unobserved variable. Using the Heckman *et al.* (1998a) framework, we identify a bias which arises from differences in the marginal distributions of patient conditions in the treatment and control groups and changes in those distributions over time. We then relate those changes to market-level effects of the Oregon court decisions. We find that the changes in distributions appear to be driven by the impact of the Oregon Supreme Court decision on the market for midwives (possible substitutes for physicians). Noting that midwives' practices are more flexible than those of physicians in the sense that midwives can deliver a baby at a mother's home, the change in tort law in Oregon caused midwives to move their services to the less costly alternative (Washington) after the change in law. More midwives working in Washington resulted in fewer low-risk women using physicians there and more

[1]Currie and MacLeod (2008) included a dummy variable for plural births in their primary regression and estimated models for mothers with preventable and non-preventable birth complications. They did not, however, calculate separate estimates for mothers presenting with difference conditions. Their primary focus was a model which combined women with varying conditions. Shurtz (2014: 13, n. 12) included a dummy variable for a mother who presented with certain risks, such as a prior c-section, breech birth, obesity and early onset labor but, again, did not obtain separate estimates for different conditions and did not differentiate the conditions.

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low-risk women using physicians in Oregon, thereby changing the underlying marginal distributions of patient conditions facing physicians in both areas.

As a final matter, our analysis extends the observations of Grace and Leverty (2013) regarding the impact of the permanence of changes in tort laws on measuring the impact of those laws on economic outcomes, and Currie and MacLeod (2008) and Shurtz (2014) regarding 'lead effects' of changes in tort laws. There was an approximate 3-year period of uncertainty regarding the constitutionality of the cap on non-economic damages created by the 1996 Oregon Court of Appeals decision declaring the cap unconstitutional (the 'Appellate Period'). We obtain separate DD estimates for the Appellate Period and the period after the Oregon Supreme Court decision in 1999. Our analysis provides a specific example of a 'lead' effect, which to our knowledge no one has done before. Our regression results are consistent with the Currie and MacLeod (2008) theoretical model of physician decision making, which implies that physician responses during the Appellate Period should not be as strong as the responses after the Oregon Supreme Court declared the cap unconstitutional. Although generally statistically insignificant, our regression results for the Appellate Period are consistent in direction and magnitude with this theory.

This paper is organized as follows. We first discuss the natural experiments upon which we focus. We then relate the theoretical model of physician decision making in Currie and MacLeod (2008) to our empirical analysis. We follow with an analysis of the biases which may arise when using the DD estimator. We then present our econometric model, data and regression results. In light of these results, we review evidence suggesting that failure to account sufficiently for patient conditions in our econometric analysis produces biases in estimates of the impact of the change in tort law on physician use of c-sections. We find that the general equilibrium effects of the change in tort law produce biases, with the market for midwives being important to those effects. We conclude thereafter.

2. The legal setting

In 1987, the Oregon legislature enacted a statute which imposed a $500,000 cap on non-economic damages in tort lawsuits [OR Rev Stat §18.560(1) subsequently renumbered 31.710(1)]. Non-economic damages include damages for which an individual did not incur a direct, out-of-pocket cost, such as damages for pain and suffering. On 9 October 1996, the Oregon Court of Appeals found that the cap violated the Oregon Constitution (Lakin *et al.* vs Senco Products, Inc. 144 OR App 52, 925 P.2d 107). The Court of Appeals decision was appealed to the Oregon Supreme Court. On 15 July 1999, the Oregon Supreme Court upheld the Court of Appeals decision, rendering the cap unconstitutional (Lakin *et al.* vs Senco Products, Inc. 329 Ore. 62, 987 P.2d 463).

3. Theoretical model of physician decision making

We adapt the Currie and MacLeod (2008) theoretical model of physician decision making to our analysis. Currie and MacLeod (2008) model a physician's decision to perform a medical procedure. Physician utility is

$$U(\alpha, s, p, law) = B(\alpha, s, p) - H(s, p, law) \times \alpha \tag{1}$$

where 's' represents a patient's condition, 'law' represents the existing tort law, 'p' represents either not using the procedure (NP) or using the procedure (P), α is a medical 'error rate' chosen by the physician, $B(\bullet)$ is benefits to the physician and $H(\bullet)$ is the physician's expected malpractice liability. A patient's condition may vary from $s = 0$ (a patient with no medical conditions or difficulties) to $s = S$ (a patient with the most severe conditions). In the context of a pregnancy, a patient's condition includes maternal and fetal conditions. In terms of our analysis, we might think of a low-risk woman as having a low s, a woman with a plural pregnancy as having a mid-level value of s, a

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woman with a prior c-section as having a higher s and, for example, a situation in which the fetus presents with an umbilical cord prolapse which cannot be managed through manipulation as one of the highest conditions. In the present context, 'no procedure' is a vaginal birth (v) and the procedure is a c-section (cs). Physician benefits from performing (not performing) a procedure 'include the intrinsic reward from treating the patient, any pecuniary rewards from treatment, and the opportunity cost of care, α' (2008: 805).

For a given set of tort laws and a given value of p, the physician first chooses the optimal error rate for each possible patient condition. The physician then chooses a c-section if their optimal utility from performing a c-section ($U^*(\alpha^*_{cs},\ s,\ law,\ cs)$) is greater than their optimal utility from a vaginal birth ($U^*(\alpha^*_v,\ s,\ law,\ v)$) and vice-versa. If we assume that as s increases the increase in optimal utility associated with a c-section is greater than the increase (or decrease) in their optimal utility associated with a vaginal delivery and if we assume that when $s = 0$ the optimal utility from a vaginal birth exceeds the optimal utility from a c-section there will be a critical cutoff value of s ($\bar{s}$) above which a c-section is chosen and below which a vaginal birth is chosen. We may represent the physician decision in terms of the difference in their utility between a c-section and vaginal birth: $\Delta U(s, \text{law}) = U^*(\alpha^*_{cs},\ s,\ law,\ cs) - U^*(\alpha^*_v,\ s,\ law,\ v)$. A physician chooses a c-section when $\Delta U(s, \text{law}) \geqslant 0$. Patient condition $\bar{s}$ is the patient condition where $\Delta U(s, \text{law}) = 0$. Letting 'Law' refer to the tort law before the Oregon court decisions and 'Law′' to the tort law after an Oregon court decision, we may represent the impact of a change in law as $\Delta U(s, \Delta law) = [\Delta U(s, Law') - \Delta U(s, Law)]$.[2]

The Currie and MacLeod (2008) model implies that the impact of a change in tort law on physician use of c-sections depends on relative optimal error rates of a procedure (e.g. a c-section) at $\bar{s}$ and of not using the procedure (e.g. a vaginal birth) at $\bar{s}$. If the error rate of the procedure is greater than the error rate of not using the procedure, an increase in expected malpractice liability associated with, say, the removal of a cap on damages will result in a *decrease* in use of the procedure. If the opposite is true with respect to the optimal error rates at $\bar{s}$, we would observe an increase in the physician's use of c-sections.

Whether the optimal error rate of a c-section is less than (or exceeds) the optimal error rate of a vaginal birth for the woman with the $\bar{s}$ condition depends on how the optimal error rates of c-sections and of vaginal births vary as s increases and on their relative magnitudes. Generally, we view the error rate for c-sections as relatively stable across values of s because the medical risks associated with a c-section are relatively stable across maternal and fetal conditions (Ecker and Frigoletto, 2007; Yang *et al.*, 2009). Although the c-section procedure is not without risk, it is widely perceived among physicians as effective at minimizing the severe birth injuries that invite litigation (Yang *et al.*, 2009). In fact, a common saying among obstetricians is that 'no one gets sued for doing a c-section' (Lake, 2012).[3] On the contrary, we might expect the error rate for vaginal births to increase dramatically as we move from low values of s to high values of s. Consider, for example, the error rate associated with having a vaginal delivery when a fetus is deprived of oxygen (which could lead to cerebral palsy). In such a case, the

[2]Although we focus primarily on the impact of tort laws on physician choice of a c-section across patient conditions, several other factors may affect a physician's utility associated with performing a c-section. C-sections providing greater reimbursement for physicians than vaginal births (Brown, 1996) will increase physician utility for a c-section. Because c-sections are more predictable and faster than a vaginal delivery, physicians who demand leisure may prefer them (Brown, 1996). Since vaginal births may take a longer time than c-sections, physicians may also prefer c-sections because they are able to attend to more patients (Brown, 1996). Finally, cesarean delivery on maternal request has been identified as a factor in the decision to perform a c-section (Coleman *et al.*, 2009). In the context of our model of physician decision making, a patient's preferences for a c-section may increase a physician's utility associated with a c-section (at least for low-risk women). For all of these factors, when the utility associated with a c-section increases, the marginal patient condition ($\bar{s}$) at which physician's utility for a c-section is greater than their utility for a vaginal birth will decrease, thereby increasing the number of c-sections performed.

[3]In analyzing medical malpractice claims data, Kravitz *et al.* (1991: 2090) observed that '[m]any more obstetrical claims were associated with nonperformance or delay in performing cesarean section than with unnecessary or inappropriate cesarean section (31 vs 3%)'.

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risks to the fetus are high, especially relative to the risks associated with a c-section, a procedure meant to address such potentially dire outcomes. These observations suggest that it is likely that the optimal error rate for a vaginal birth is greater than the optimal error rate for a c-section at $\bar{s}$. For our purposes, an important aspect of the Currie and MacLeod (2008) model is that it implies heterogeneous impacts of a change in tort law across patient conditions. In discussing their model, Currie and MacLeod (2008) observe '[o]ur model predicts that doctors should have less discretion over high-risk births so that tort reforms should have smaller effects in these cases' (814). Specifically, an increase in expected malpractice liability will have a greater impact on the probability that a woman with a lower value of s receives a c-section than on that probability for a higher s woman (if it has any impact on them). Stated in terms of our model, $\Delta U(s, \Delta\, law)$ is decreasing in s, where it may effectively equal zero at the highest s.

The result makes sense theoretically and intuitively. In terms of the theoretical model, a change in law will have little or no impact on physician utility in equation (1) at high s because medical concerns dominate economic incentives. Intuitively, when, for example, a physician is presented with a mechanical obstruction involving a baby with severe hydrocephalus, the medical risks to a fetus associated with a vaginal delivery are so high (prohibitively high) that a change in malpractice liability should not affect a physician's decision (to perform a c-section). At low values of s, on the contrary, a physician has greater discretion in performing a c-section because such medical risks are absent and we might expect a physician to be more responsive to changes in legal liability. In light of these observations, if the change in law increases expected malpractice liability we would expect $\Delta U(s, \Delta\, law)$ to be positive at low values of s, approaching zero as s increases.

Finally, the timing of Oregon court decisions regarding the cap on non-economic damages also provides an opportunity to obtain some insight into the impact of expected malpractice liability on physician decision making. During the 2-year, 9-month Appellate Period, the constitutional fate of Section 18.560 was uncertain. Under the foregoing model, the uncertainty associated with the Court of Appeals decision would increase a physician's expected medical malpractice liability cost but not by as much as the Oregon Supreme Court decision. Thus, if we observed an effect of the change in tort law arising out of the Oregon courts' decisions, we would expect the effect during the Appellate Period to be smaller, compared with the period after the Oregon Supreme Court decision.

4. Analysis of potential bias in the DD estimator

We use Heckman *et al.* (1998a) to identify the bias in the DD estimator which may arise out of changing marginal distributions of patient conditions in treatment and control groups. Assume that there are two legal regimes in the Portland area: the legal regime prior to the change in Oregon tort law and the legal regime after the change (the treatment). Let $y_1 = 1$ if a c-section was performed under the treatment and equal 0 otherwise, and $y_0 = 1$ if a c-section was performed when not subject to the treatment and equal 0 otherwise. Let $g = 1$ if a mother is in the treatment group (they live in Oregon) and equal 0 otherwise (they live in Washington state). A patient's condition (s) is the unaccounted-for variable. We have assumed that s lies on $[0, S]$ with cumulative distribution function $F(s)$.

We seek to estimate the (conditional on s) average effect of treatment on the treated ($\delta(s)$) by comparing outcomes in the treatment and control groups; i.e.

$$\Pr(y_1 = 1|g = 1, s) - \Pr(y_0 = 1|g = 0, s). \tag{2}$$

We can show that equation (2) equals

$$\delta(s) + B(s) \tag{3}$$

where $B(s)$ is a conditional bias term identified by Heckman, *et al.* (1998a: 1022).

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The conventional bias term, which does not condition on s, is $B = \Pr(y_0 = 1|g = 1) - \Pr(y_0 = 1|g = 0)$. We relate B to equation (3) by integrating across s. First, we define several terms. Let a ' $'$ ' mark designate the period prior to the change in law, with the absence of such a mark indicating the period after the change in law. Next, let

$$\Delta F(s|g)\mathrm{d}s = [F(s|g) - F'(s|g)]\mathrm{d}s, \textit{ and}$$

$$\Delta\frac{\partial \Pr(y_0 = 1|g = 0, s)}{\partial s} = \frac{\partial \Pr(y_0 = 1|g = 0, s)}{\partial s} - \frac{\partial Pr'(y_0 = 1|g = 0, s)}{\partial s}$$

In the Appendix, we show that for the DD estimator B equals

$$\int_0^S \Delta\frac{\partial \Pr(y_0 = 1|g = 0, \mathrm{s})}{\partial \mathrm{s}} \cdot [F(s|g = 0)\mathrm{d}s - F(s|g = 1)\,\mathrm{d}s]$$

$$-\int_0^S \frac{\partial Pr'(y_0 = 1|g = 0, \mathrm{s})}{\partial \mathrm{s}} \cdot \; [\Delta F(s|g = 1)\mathrm{d}s - \Delta F(s|g = 0)\mathrm{d}s] \tag{4}$$

Because the bias term can have any sign or be of any size, the estimated treatment effect may be greater or smaller than the actual effect, or it might have the opposite sign. Obtaining an OM result in the presence of DM is an example of the latter case. Such a situation will arise when equation (4) is negative and greater in absolute value than the average treatment effect (the expected value of $\delta(s)$). Elsewhere in the literature, such a result has been called Simpson's paradox (Samuels, 1993).

Because we have no *a priori* beliefs about the sign of $F(s|g = 0)$–$F(s|g = 1)$, we focus on the second component of equation (4). Since the probability of a c-section increases with s, $\partial \Pr'(y_0 = 1|g = 0, s)/\partial s$ is positive. Equation (4), thus, will be negative when $\Delta F(s|g = 1)\mathrm{d}s$ is positive and/or $\Delta F(s|g = 0)\mathrm{d}s$ is negative. The former is positive when there is more density at lower values of s in the period after the treatment (i.e. the density shifts left) for the treatment group. The latter is negative when there is more density at higher values of s in the period before the treatment. Furthermore, wider variation in c-section rates across patient conditions makes the bias larger.

5. Econometric model

We use a Probit model to represent a physician's decision to perform a c-section and model the impacts of the Oregon court decisions using the DD estimator. Since consistency of the DD estimator depends on a common trends assumption, we check whether our groups differ with respect to unobserved factors by estimating a Probit discrete factor model (Probit DFM). We account for different possible impacts of the court decisions by allowing the DD estimator to differ during the Appellate period and the period after the Supreme Court decision. Thus, we estimate the following model:

$$\begin{aligned} Y_{it} = &\beta_1 + \beta_2 Oregon_{it} + \beta_3 SCt_{it} + \beta_4 Oregon_{it} \times SCt_{it} \\ &+ \beta_5 Appellate_{it} + \beta_6 Oregon_{it} \times Appellate_{it} + \mathbf{X_{it}}\boldsymbol{\beta} + \lambda\mu_i + \varepsilon_{it} \end{aligned} \tag{5}$$

where Y_{it} equals 1 if a woman had a c-section (and equals 0 if they had a vaginal birth), $Oregon_{it}$ is a dummy variable which equals 1 if the birth was in Oregon, SCt_{it} is a dummy variable for a birth being in a month after the Oregon Supreme Court decision, $Appellate_{it}$ is a dummy variable

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for the birth occurring in a month during the Appellate period, $\mathbf{X}_{it}$ represent other independent variables in the analysis, μ_i is an unobserved variable with load factor λ and ε_{it} is a disturbance with a standard normal distribution.[4] We assume that μ_i has a discrete distribution with two points of support, one for each of the two groups. We assume that the points of support are {0, 1} and estimate their probabilities non-parametrically. We test for the presence of unobserved heterogeneity using the 'upward-testing approach' suggested by Mroz (1999).

6. Data and descriptive statistics

We use primarily data from the Natality Files. Our population is births in the Portland-Vancouver PMSA (PMSA 6440) between 1992 and 2002 which were attended by a medical doctor or by a Doctor of Osteopathy (we refer to them collectively as 'physicians'). Our data start in 1992 because Washington state (Clark county) was first incorporated into the PMSA in that year. A birth was associated with its State of occurrence.

We estimate the econometric model for sub-groups of women and for the Full Sample (all of the mothers together). We identify four primary sub-groups of women plus two other sub-groups which serve as a check on our results. Our 'low-risk' (low *s*) sub-group consists of women who had (1) a full term (i.e. between weeks 37 and 41 of the pregnancy), singleton birth, (2) not had a prior c-section and (3) none of maternal and fetal complications listed in the Natality Files.[5] The second sub-group is women in our low-risk group who were first-time mothers. These women face higher c-section rates than low-risk women who have had a prior birth. The third sub-group is women who had a plural birth and had not had a prior c-section. Since physicians are more likely to perform c-sections for these births, a physician's failure to use a c-section in this context exposes them to greater legal risks (Ecker and Frigoletto, 2007). In order to obtain a reasonable sample size, we combined women with no complications and women with complications. The fourth sub-group is women who have had a prior c-section, and have a full-term, singleton birth with no complications. Women with a prior c-section represent, to physicians, greater medical and legal risks. Finally, we separated the maternal and fetal complications reported in the Natality Files into those complications whose likelihood of having a c-section was less than 50% (we might think of these as being lower risk) and those complications whose likelihood of having a c-section was greater than 50%. The latter group includes women with seven different complications (cephalopelvic disproportion, breech birth, dysfunctional labor, cord prolapse, fetal distress, placenta previa and seizure during labor) for which the medical risks associated with a vaginal birth were high. The former group includes women with 23 different complications. We include these two groups as a test of consistency with results obtained for the sub-groups.

Table 1 identifies the total number of observations in our dataset and the number of observations in each of the six sub-groups analyzed. The low-risk group of women represents a large portion of the births in our sample. The percent of women in the group with a prior c-section is relatively small (10.8% of the Full Sample had a prior c-section), as is the percent of women

[4]Other independent variables include dummy variables for the mother (1) having less education than a high school diploma, (2) having more education than a high school diploma but no college degree, (3) having a college degree, (4) being married, (5) being Hispanic, (6) being African American and (7) being of another race. Age of the mother (in quadratic form) and a dummy variable for use of induction were also included, as were the average court-ordered payout in a medical malpractice case a given year and state (obtained from the National Practitioners Data Bank), the average medical malpractice insurance premium for an obstetrician/gynecologist in a given year and state, and dummy variables for years 1993 through 2002.

[5]Maternal complications included cardiac disease, herpes, hydramnios, hemoglobinopathy, chronic hypertension, pregnancy-associated hypertension, eclampsia, incompetent cervix, having had a previous infant who was more than 4000 g, previous pre-term or small-for-gestational-age infant, renal disease, Rh sensitization, uterine bleeding and other medical risk factors. The complications associated with delivery included febrile infant, meconium, premature rupture of membrane, abruptio placenta, placenta previa, other excessive bleeding, seizures during labor, precipitous labor, prolonged labor, dysfunctional labor, breech, cephalopelvic disproportion, cord prolapse, anesthetic complications, fetal distress and other complications of labor and/or delivery.

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Table 1. C-section rates for sub-groups analyzed

Group	Sample size	Portion of full sample	C-section rate
Full Sample	232,635		0.225
Low risk	91,665	0.39	0.033
Low risk, first time	37,746	0.16	0.055
Plural birth (no prior C-section, no complications)	7074	0.03	0.482
Complications: c-section probability < 50%	52,241	0.23	0.065
Complications: c-section probability > 50%	24,772	0.11	0.750
Prior c-section (full term, singleton, no complications)	10,847	0.05	0.670

Notes: Most of the observations in the Full Sample but not in one of the sub-groups analyzed were (i) women with no prior c-section, a singleton and non-full term birth and birth complications (n = 17,363), (ii) women with no complications and no prior c-section, who had a singleton, non-full term birth (n = 14,393) and (iii) women with a prior c-section and with complications who were having a singleton birth (n = 11,925).

Table 2. Mean values of maternal demographic variables

Variable	Oregon	Washington
Age (years)	27.8	26.7
Less than high school diploma	0.18	0.18
High school diploma	0.32	0.40
More than high school and less than a college degree	0.23	0.25
College degree	0.27	0.17
Hispanic	0.12	0.07
Race: African American	0.04	0.02
Race: Other	0.08	0.05
Married	0.74	0.73

with plural births. Table 1 also reports c-section rates for the sub-groups analyzed. Consistent with national statistics (Menacker, 2005; Lee *et al.*, 2011), the c-section rates across the sub-groups of women vary considerably.

Table 2 compares mean values of the maternal demographic variables in the two groups. Overall, the two groups of women are similar. Education rates differ somewhat, with the greater percentages of women in Oregon having a college degree and more women in Washington having a high school diploma. The difference in Hispanic origin is also notable.

As a final matter, Figure 1 reflects the trends in c-section rates in Washington and Oregon over the 11-year period of our analysis for the Full Sample. The overall rates suggest an upward trend in both states starting in the late-1990s.

7. Empirical analysis

7.1 Regression results

Table 3 presents regression results for sub-groups of women. Probit DFM results are reported when testing suggested the presence of unobserved heterogeneity. Otherwise, Probit results are reported. In light of the impact of nonlinearity on interpreting the marginal effect of interaction

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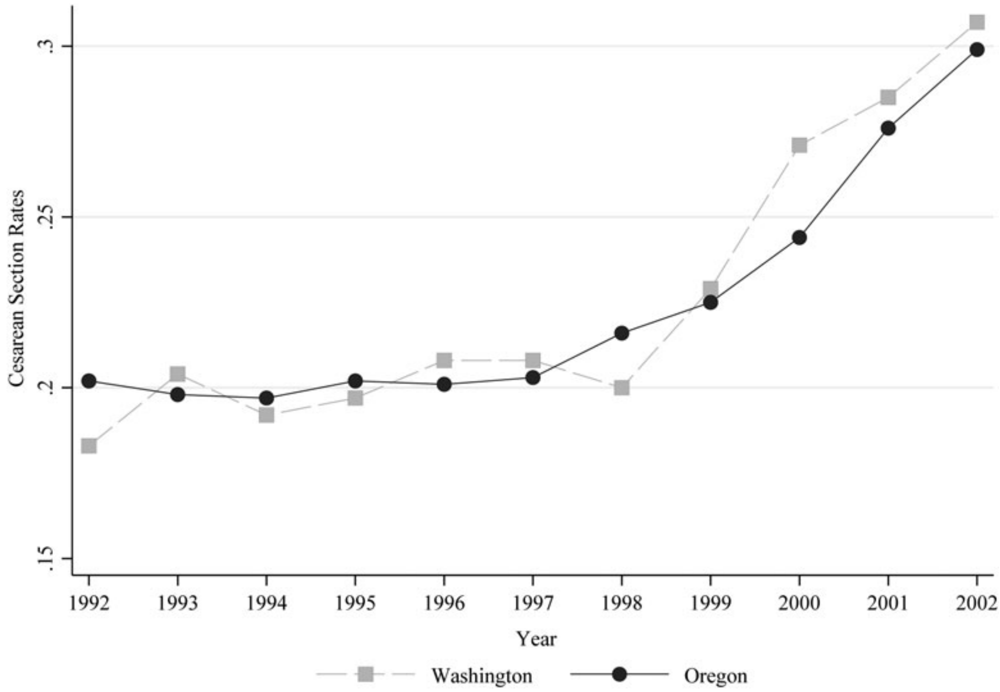

Figure 1. C-section rates for the Portland-Vancouver PMSA by state.

Table 3. DD estimate average partial effects for sub-groups of women

	Probit model		Probit DFM	
	Appellate period	Post-Supreme Court period	Appellate period	Post-Supreme Court period
Low risk	−0.002*	0.024***	0.008	0.025***
	(0.012)	(0.005)	(0.008)	(0.007)
Low risk, first time	0.011	0.041***	0.019*	0.047***
	(0.016)	(0.008)	(0.011)	(0.007)
Plural birth	0.021	−0.013		
	(0.094)	(0.081)		
Prior c-section	−0.092	0.014	−0.08	0.032
	(0.05)	(0.06)	(0.06)	(0.052)
C-section probability < 50%	0.010	0.018**	0.008	0.014
	(0.011)	(0.008)	(0.016)	(0.010)
C-section probability > 50%	−0.053	−0.09**		
	(0.036)	(0.03)		

Notes: The DD estimates were calculated using the results in Puhani (2012). Standard errors are in parentheses below parameter estimates. The standard errors for the average partial effects were calculated using the Delta method (Greene 2012: 698).
*Statistically significant (SS) 10% level of significance, two-sided test.
**SS 5% level of significance, two-sided test.
***SS 1% level of significance, two-sided test.

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Table 4. Probit DD estimate average partial effects for the Full Sample

Variable	Full Sample: no dummy variables	Full Sample: dummy variables
DD: Appellate period	−0.013	0.005
	(0.013)	(0.011)
DD: Post Supreme Court period	−0.035***	0.011
	(0.012)	(0.009)
Prior c-section		0.364***
		(0.002)
Plural birth		0.174***
		(0.003)
Full term		−0.032***
		(0.002)
Complications		0.238***
		(0.001)

Notes: Standard errors are in parentheses below parameter estimates.
***Statistically significant at 1% level of significance, two-sided test.

variables (see Ai and Norton, 2003), we calculate treatment effects using the results in Puhani (2012), who identifies the formula for calculating a treatment effect with the DD estimator in a Probit model. The effects in the Appellate period were generally statistically insignificant and positive. The Post-Supreme Court Period DD estimates for sub-groups reveal results consistent with the theoretical prediction that changes in tort laws will have greater effects on physicians presented with low-risk women. The average partial effects for low-risk mothers, and low-risk, first-time mothers were positive and statistically significant, suggesting the presence of DM for these women. On the contrary, the results suggest no effect for women with a prior c-section or a plural birth.

Turning to the regressions which served as a consistency check, the average partial effect of the Post-Supreme Court Period DD estimator is positive and statistically insignificant for mothers with complications whose c-section rates were less than 50%. The statistically significant negative effect for women with a complication whose c-section probability exceeds 50% is surprising. Our analysis in the next section provides insights into this result.

Table 4 includes regression results when we estimate the Probit model for the Full Sample. The second column of the table identifies the average partial effects of the DD estimates when we do not include patient condition dummy variables in the regression. The results suggest an OM result after the Oregon Supreme Court decision. The OM result disappears when we add dummy variables for the different conditions: the third column of the table. The sizes of the average partial effects for the patient condition dummy variables indicate that women with these conditions are notably different than women without the conditions.

Figure 2 presents 'standardized' average partial effects (the DD average partial effect for a sub-group divided by the unconditional c-section rate for the sub-group reported in Table 1) and their 95% confidence intervals. The condition of the patient is on the horizontal axis, from low risk (*s*) conditions on the left to higher risk conditions on the right. The point estimate for the Full-Sample regression (with no patient condition dummy variables) is reported as 'aggregate estimate'. The confidence intervals reflect large positive effects for lower-risk mothers, with those effects being indistinguishable from zero for higher-risk mothers.

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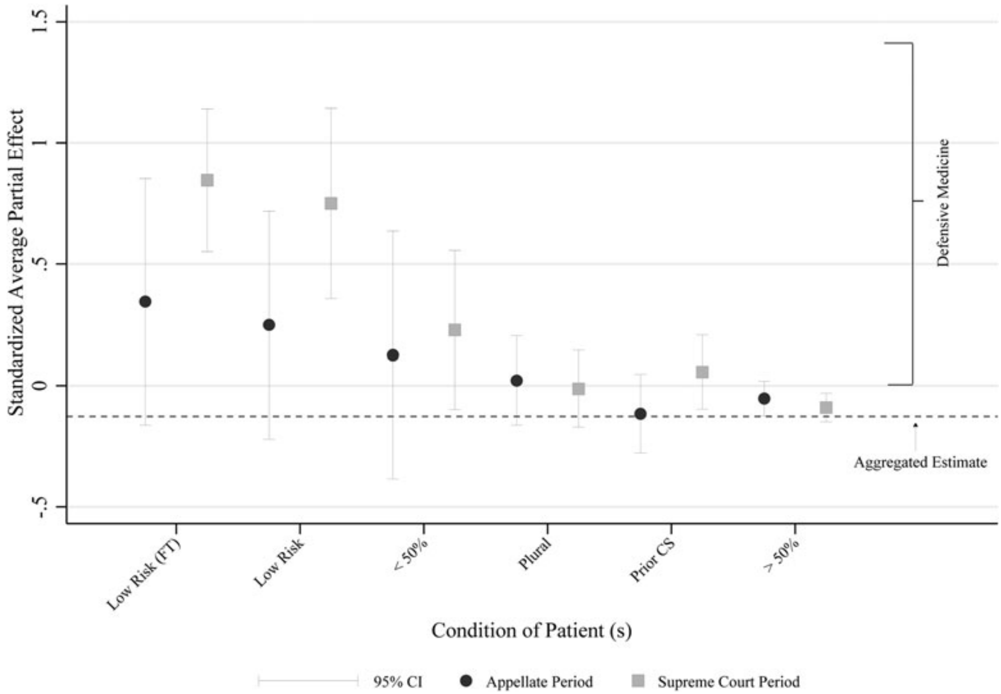

Figure 2. Standardized average partial effects for sub-groups of women.

7.2 Evidence suggesting bias in treatment effect estimates

We now analyze our regression results in light of our analysis of bias in Section 4. We note first that the variation in c-section rates across patient conditions from 3.3 to 75% presents a situation in which the $\partial Pr'(y_0 = 1|g = 0, s)/\partial s$ term in equation (4) is larger, making any bias in the DD estimates due to changing marginal patient conditions larger.

The distributions of patient conditions in Oregon and Washington over the time period considered changed in a manner consistent with Simpson's paradox (SP) (Samuels, 1993). The distribution did not change much in Oregon, while the distribution of conditions in Washington shifted toward higher s conditions. We summarize the changes in Figure 3, which identifies the relative changes in the distributions of certain conditions in Oregon and Washington over time. Specifically, the reported changes are

$$\Delta_s = \frac{P_{st}^{OR} - P_{s1}^{OR}}{P_{s1}^{OR}} - \frac{P_{st}^{WA} - P_{s1}^{WA}}{P_{s1}^{WA}}$$

where P_{st}^{i} is the probability that a patient in state i and period t presents with condition s. A positive value of Δ_s indicates that over time Oregon had a relatively larger percentage of patients with condition s than did Washington. Figure 3 indicates that Oregon had a greater relative percentage of low-risk patients over time, while Washington had relatively a greater percentage of the higher-risk patients with some type of complication. These are the types of shifts in distributions of conditions which can produce an SP result.[6]

We sought to gain further insight into the importance of the changes in the distributions of patient conditions to our regression results by estimating the Probit model for the Full Sample

[6]This type of analysis also applies to the statistically significant negative average partial effect of the Supreme Court DD estimate for women with a condition whose c-section probability exceeds 50%.

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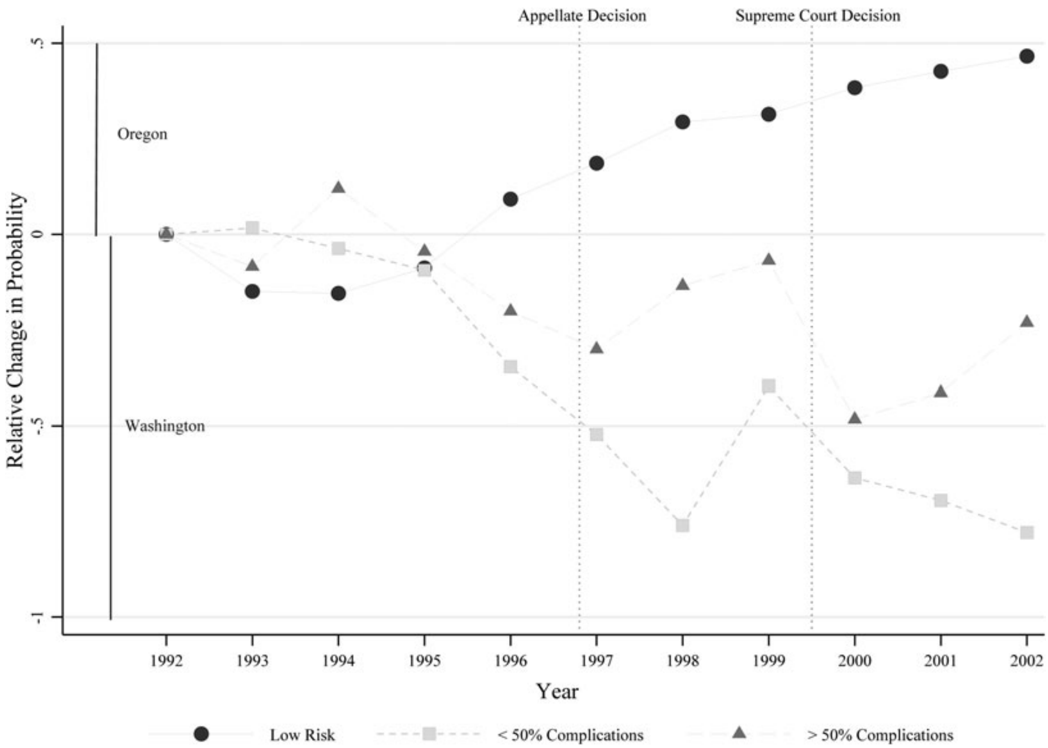

Figure 3. Relative changes in the marginal distributions of patient medical conditions in the Oregon and Washington parts of the Portland-Vancouver PMSA.

using narrower time frames. Narrowing the time frame examined minimizes the impact on regression results of changes in the distributions of conditions. The estimated average partial effects of the Supreme Court DD and the Appellate period DD estimators were statistically insignificant and close to zero for the (1997–2001), (1997–2002), (1998–2001) and (1998–2002) time frames.

The change in distribution of patient conditions in Washington over time suggested the possibility of bias in the DD estimates for sub-groups of women reported in Table 3 because of changes in our control group. For several reasons, we do not believe that the DD estimates are biased. First, since the DFM is supposed to capture the type of unobserved heterogeneity represented by a differing trends over time, our Probit DFM estimates being substantially similar to the Probit estimates suggests that such a bias is not present. Second, since most of the change in distribution of patient conditions in Washington involved mothers moving from the low risk group to the complications with less than a 50% probability of c-section group, we merged the two groups and estimated the Probit model for the merged group of mothers. The regression results were basically the same; the average partial effect of the DD estimate for the post Supreme Court period was positive and statistically significant and the average partial effect for the Appellate period was statistically insignificant and close to 0. Third, we thought that excluding midwife-attended births from our population might bias our results if midwife-attended births were more prominent in one state. We would expect midwives to attend low-risk births. To that end, we re-estimated the Probit model regressions with midwife births included in the sample. The regression results were substantially the same.

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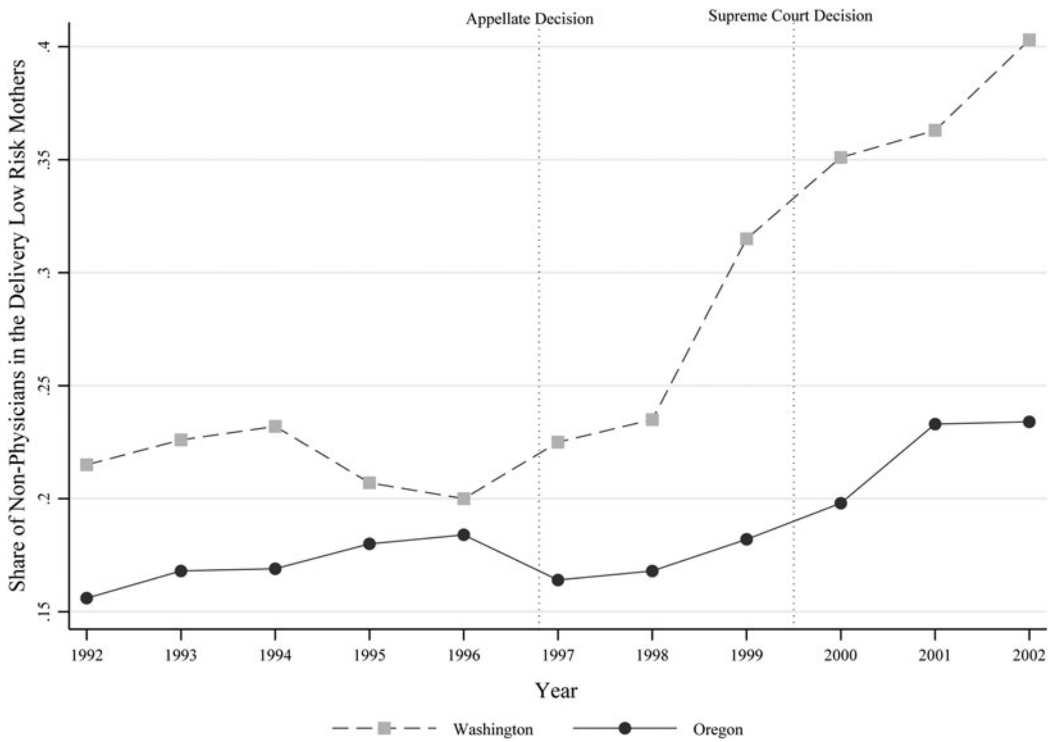

Figure 4. Share of deliveries of low-risk mothers attended by a midwife in the Oregon and Washington parts of the Portland-Vancouver MSA

7.3 Sources of changes in marginal distributions of patient conditions

As a final matter, we consider possible causes of the changes in the distributions of patient conditions in Washington and Oregon. Although our population continues to be births attended by a physician, we focus on the impact of midwives on the distributions of patient conditions which present to physicians. We focus on the role of midwives as substitute caregivers for low-risk births. We focus on low-risk births because midwives are generally restricted from attending higher-risk births. Low-risk births are the types of births for which a midwife is a substitute for a physician. The essence of our argument is that an increased supply of midwives will result in fewer lower-risk mothers using a physician, causing the distribution of patient conditions for births attended by a physician to shift with more mass at higher-risk patients. This dynamic occurred in the Oregon side of Portland. A decreased supply of midwives will have the opposite effect. This dynamic occurred in the Washington side of Portland.

These changes in the distributions of patient conditions in both states may have been endogenous in that they were a product of the Oregon Supreme Court decision. The Oregon Supreme Court decision increased the potential liability of medical caregivers in Oregon.[7] In response to the change in expected liability and costs of practice in Oregon, midwives in the Portland area may have shifted the focus of their practices to Washington. The increased supply of midwives in Washington and decreased supply of midwives in Oregon would produce the types of changes in the distributions of patient conditions observed in Section 6. One possible exogenous change in Washington might also have contributed to an increased supply of

[7]Washington had a cap on damages at the time (Avraham, 2014).

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midwives there. In 2000, the Washington legislature 'added licensed midwives to a Washington State law that require[d] private health insurers to provide direct access to health-care services for women' (Midwives Association of WA State, 2011).

Figure 4 identifies the share of deliveries of low-risk mothers which were attended by a midwife in Washington and Oregon between 1992 and 2002. In both states, there were no notable changes between 1992 and 1998. Between 1998 and 2002, the percentage increase in Washington was substantially larger. The percentage of low-risk births attended by a midwife in Oregon increased from 16.8 to 23.4% between 1998 and 2002 whereas in Washington the percentage increased from 23.5 to 40.3%. The changes in Washington between 1999 and 2002 suggest two separate impacts in that period. There was an increase between 1999 and 2001 (consistent with the Oregon Supreme Court decision) and a larger increase between 2001 and 2002 (consistent with the added effect of the change in Washington laws regarding health insurance policies covering midwifery).

8. Conclusions

The literature regarding the impact of tort law on physicians undertaking DM by performing an excessive number of c-sections has produced widely varying empirical results. Prior analyses have suggested that failure to account for various factors which might affect the impact of a change in tort law on physician decision making may bias estimates of those impacts. Economic theory and intuition suggest that a change in tort law should have heterogeneous impacts across patient conditions. Using natural experiments arising out of Oregon court decisions overturning a cap on non-economic damages in negligence tort cases, we find evidence of such heterogeneous impacts. Our analysis also suggests that failure to account for patient conditions in a regression analysis may produce misleading results arising out of market-level effects of the change in law. More broadly, our results suggest that measuring the effects of changes in tort laws on an agent's decision making using the DD estimator may not be straightforward. The responses having market-level effects combined with heterogeneous responses of the agent across an unaccounted-for variable produces a situation in which bias is likely and, as in our example, may produce an estimate which has the opposite sign of the treatment effect.

One factor which might affect our results is the possibility that attorneys alter the types of damages they seek when there is a cap on non-economic damages. In light of such caps, plaintiffs' attorneys may increase their requests for economic damages by providing more evidence of economic damages (Sharkey, 2005). Although there is nominal empirical evidence of such a 'crossover effect', to the extent that it was present in the Vancouver-Portland MSA during this period its presence would imply that our results understate the impact of removing the cap on non-economic damages on c-sections.

Ultimately, our empirical analysis counsels caution for researchers seeking to measure a treatment effect using micro-data sets which span a wide period of time. As the period covered by the panel increases, the likelihood that the effects of the treatment being measured have market-level effects increases, making bias in a DD estimate more likely.

In terms of public policy, our results provide some insight into the argument that high health care costs in the United States are due, in large part, to tort law. Our results suggest that tort law has a positive but limited impact on physician decision making. Our estimates suggest that tort law affects physician decisions for low-risk mothers (who comprise about 40% of the population of pregnant women) and that it increases physician use of c-sections by 2.5%. Assuming 4 million births in the USA in a given year (the approximate number of births in the United States in a year), there will be approximately 1.6 million low-risk mothers in a given year. A 2.5% increase in the likelihood of a c-section translates into an extra 40,000 c-sections in that year. With an approximate $12,000 difference between the cost of a vaginal birth with no complications and a c-section with no complications, the annual increase in birth-related health care costs due to

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DM equal $480 million.[8] Given total national childbirth costs in the USA (in 2013) of approximately $67 billion, the $480,000,000 excess cost equals 0.72% of total health care costs of birth. This is less than the Mello *et al.* (2010) more comprehensive estimate that the medical liability system cost is 2.4% of total health care spending and consistent with the Cutler and Ly (2011) observation that reform of the U.S. tort system will not have large cost-saving impacts.

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[8]The cost figures used in our example are based on (but not necessarily equal to) statistics which were obtained from the Health Care Utilization Project of the Agency for Healthcare Research and Quality.

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Appendix

The (conditional on s) average effect of treatment on the treated (ATET(s)) for a binary variable is defined as (Heckman, 1998a: 1021)

$$\delta(s) = \Pr(y_1 = 1|g = 1, s) - \Pr(y_0 = 1|g = 1, s) \tag{A1}$$

We observe

$$\Pr(y_1 = 1|g = 1, s) - \Pr(y_0 = 1|g = 0, s) \tag{A2}$$

Adding and subtracting $\Pr(y_0 = 1|g = 1, s)$ to equation (A2), we may represent it as

$$\begin{aligned} &\{\Pr(y_1 = 1|g = 1, s) - \Pr(y_0 = 1|g = 1, s)\} \\ &\quad + \{\Pr(y_0 = 1|g = 1, s) - \Pr(y_0 = 1|g = 0, s)\} = \delta(s) + B(s) \end{aligned} \tag{A3}$$

$B(s)$ is the (conditional on s) bias term identified by Heckman *et al.* (1998a: 1022).

The (unconditional on s) conventional bias term is

$$B = \Pr(y_0 = 1|g = 1) - \Pr(y_0 = 1|g = 0).$$

We relate B to equation (A3) by integrating across s:

$$B = \int_0^S \Pr(y_0 = 1|g = 1, s)\mathrm{d}F(s|g = 1) - \int_0^S \Pr(y_0 = 1|g = 0, s)\mathrm{d}F(s|g = 0).$$

Using the Heckman *et al.* (1998a: 1030) results and assuming the absence of non-overlapping support in s:

$$B = \int_0^S \Pr(y_0 = 1|g = 0, s)[\mathrm{d}F(s|g = 1) - \mathrm{d}F(s|g = 0)] + \int_0^S B(s)\mathrm{d}F(s|g = 1) \tag{A4}$$

Equation (A4) applies to a situation in which we compare the treatment and control groups in the period after the treatment. The DD estimator compares the two groups over the periods after the treatment and before the treatment. Representing the

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difference in observed probabilities before the treatment as $[\Pr'(y_0 = 1|g = 1,s) - \Pr'(y_0 = 1|g = 0,s)]$, the DD estimator is

$$[\Pr(y_1 = 1|g = 1, s) - \Pr(y_0 = 1|g = 0, s)] - [\Pr'(y_0 = 1|g = 1, s) - \Pr'(y_0 = 1|g = 0, s)] \tag{A5}$$

Expanding the first component of (A5) in square brackets by adding and subtracting $\Pr(y_0 = 1|g = 1,s)$, we get

$$[\Pr(y_1 = 1|g = 1, s) - \Pr(y_0 = 1|g = 1, s)] + [\Pr(y_0 = 1|g = 1, s) - \Pr(y_0 = 1|g = 0, s)] \tag{A6}$$

Incorporating (A6) into equation (A5), the latter becomes

$$\begin{aligned} &\delta(s) + \left[Pr(y_0 = 1|g = 1, s) - Pr(y_0 = 1|g = 0, s)\right] - \left[Pr'(y_0 = 1|g = 1, s) - Pr'(y_0 = 1|g = 0, s)\right] \\ &= \delta(s) + \left[B(s) - B'(s)\right] \end{aligned} \tag{A7}$$

Integrating the bias measure $[B(s) - B'(s)]$ over s, we get the conventional bias measure for the DD estimator:

$$\begin{aligned} B = &\left\{\int_0^S \Pr(y_0 = 1|g = 0, s)[dF(s|g = 1) - dF(s|g = 0)] + \int_0^S B(s)dF(s|g = 1)\right\} \\ &- \left\{\int_0^S \Pr'(y_0 = 1|g = 0, s)[dF'(s|g = 1) - dF'(s|g = 0)] + \int_0^S B'(s)dF'(s|g = 1)\right\} \end{aligned} \tag{A8}$$

Equation (A8) may be rearranged as follows:

$$\begin{aligned} B = &\left\{\begin{array}{l} \int_0^S \Pr(y_0 = 1|g = 0, s)[dF(s|g = 1) - dF(s|g = 0)] \\ - \int_0^S \Pr'(y_0 = 1|g = 0, s)[dF'(s|g = 1) - dF'(s|g = 0] \end{array}\right\} \\ &+ \left\{\int_0^S B(s)dF(s|g = 1) - \int_0^S B'(s)dF'(s|g = 1)\right\} \end{aligned} \tag{A9}$$

Equation (A9) has two components in curly brackets. Heckman *et al.* (1998a:1031) call the second component Selection Bias 'rigorously defined'. If the control group has been chosen appropriately, there will be no rigorously defined Selection Bias. We focus on this case.

Using integration by parts, $\int_0^S \Pr(y_0 = 1|g = 0, s) \cdot dF(s|g = 1)$ may be represented as

$$|_0^S \Pr(y_0 = 1|g = 0, s) \cdot F(s|g = 1) - \int_0^S \frac{\partial \Pr(y_0 = 1|g = 0, s)}{\partial s} \cdot F(s|g = 1)ds.$$

Since $F(0|g = 1) = 0$ and $F(S|g = 1) = 1$, it equals (Chiang, 1984: 453),

$$\Pr(y_0 = 1|g = 0, S) - \int_0^S \frac{\partial \Pr(y_0 = 1|g = 0, s)}{\partial s} \cdot F(s|g = 1)ds \tag{A10}$$

Applying this result to $-\int_0^S \Pr(y_0 = 1|g = 0, s) \cdot dF(s|g = 0)]$ and gathering the two results, we get

$$\begin{aligned} &\int_0^S \Pr(y_0 = 1|g = 0, s)\left[dF(s|g = 1) - dF(s|g = 0)\right] \\ &= \left\{\Pr(y_0 = 1|g = 0, S) - \int_0^S \frac{\partial \Pr(y_0 = 1|g = 0, s)}{\partial s} \cdot F(s|g = 1)ds\right\} \\ &-\left\{\Pr(y_0 = 1|g = 0, S) - \int_0^S \frac{\partial \Pr(y_0 = 1|g = 0, s)}{\partial s} \cdot F(s|g = 0)ds\right\} \end{aligned}$$

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$$= \int_0^S \frac{\partial \Pr\left(y_0 = 1|g = 0, s\right)}{\partial s} \cdot F(s|g = 0)\mathrm{d}s - \int_0^S \frac{\partial \Pr\left(y_0 = 1|g = 0, s\right)}{\partial s} \cdot F(s|g = 1)\mathrm{d}s$$
$$= \int_0^S \frac{\partial \Pr\left(y_0 = 1|g = 0, s\right)}{\partial s} \cdot [F(s|g = 0)\mathrm{d}s - F(s|g = 1)\mathrm{d}s].$$

Applying this result to the $\int_0^S Pr'(y_0 = 1|g = 0, s)[\mathrm{d}F'(s|g = 1) - \mathrm{d}F'(s|g = 0]$ part of equation (A9), the first component in equation (A9) equals

$$\begin{aligned} &\int_0^S \frac{\partial \Pr(y_0 = 1|g = 0, s)}{\partial s} \cdot [F(s|g = 0)\mathrm{d}s - F(s|g = 1)\mathrm{d}s] \\ &\quad - \int_0^S \frac{\partial \Pr'(y_0 = 1|g = 0, s)}{\partial s} \cdot [F'(s|g = 0)\mathrm{d}s - F'(s|g = 1)\mathrm{d}s] \end{aligned} \tag{A11}$$

Letting $\frac{\partial \Pr(y_0=1|g=0,s)}{\partial s} = \Delta \frac{\partial \Pr(y_0=1|g=0,s)}{\partial s} + \frac{\partial \Pr'(y_0=1|g=0,s)}{\partial s}$, equation (A11) may be represented as

$$\begin{aligned} &\int_0^S \Delta \frac{\partial \Pr\left(y_0 = 1|g = 0, s\right)}{\partial s} \cdot (F(s|g = 0)\mathrm{d}s - F(s|g = 1)\mathrm{d}s) \\ &+ \int_0^S \frac{\partial \Pr'\left(y_0 = 1|g = 0, s\right)}{\partial s} \cdot [(F(s|g = 0)\mathrm{d}s - F(s|g = 1)\mathrm{d}s) - (F'(s|g = 0)\mathrm{d}s - F'(s|g = 1)\mathrm{d}s)] \end{aligned} \tag{A12}$$

Letting $\Delta F(s|g = 1)\mathrm{d}s = [F(s|g = 1)\mathrm{d}s - F'(s|g = 1)\mathrm{d}s]$ and $\Delta F(s|g = 0)\mathrm{d}s = [F(s|g = 0)\mathrm{d}s - F'(s|g = 0)\mathrm{d}s]$, we may represent equation (A12) (which is equation (4) in the text) as

$$\int_0^S \Delta \frac{\partial \Pr\left(y_0 = 1|g = 0, s\right)}{\partial s} \cdot [\left(F\left(s|g = 0\right)\mathrm{d}s - F\left(s|g = 1\right)\mathrm{d}s\right]$$

$$- \int_0^S \frac{\partial Pr'\left(y_0 = 1|g = 0, s\right)}{\partial s} \cdot \; [\Delta F(s|g = 1)\mathrm{d}s - \Delta F(s|g = 0)\mathrm{d}s]$$

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