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# How much can hospital-level interventions improve maternal health? Evidence from state Perinatal Quality Collaboratives

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**Abstract**

Over the last 20 years, nearly all states have adopted Perinatal Quality Collaboratives (PQCs), which set guidelines for hospitals to provide higher standards of prenatal care. In this paper, I use individual-level natality data from 1989 to 2019 and a stacked difference in differences design comparing maternal and infant health outcomes in US states that have recently established a PQC to those that have not yet established one. Estimates indicate that PQCs decrease eclampsia, with the effect driven by Black mothers. Evidence also shows that PQCs reduce intensive care unit admissions for mothers.

**KEYWORDS**
infant health, maternal health, prenatal care

**JEL CLASSIFICATION**
I12, I18, J13

## 1 | INTRODUCTION

Despite advances in medical knowledge and technology, in 2018, the US had the third highest maternal death rate (OECD, 2022). The high maternal death rate is driven by deaths of Black mothers; notably, Black women have 2.5 times higher maternal mortality rates than non-Hispanic White women (Joseph et al., 2021). In response to the growing concern about maternal health, in recent years, states have established Perinatal Quality Collaboratives (PQCs). PQCs are networks of perinatal care providers and public health professionals within a state that provide hospital-level initiatives to improve maternal and infant health.[1] Common initiatives are those related to hypertension, early elective delivery, neonatal abstinence syndrome, and obstetric hemorrhage. While increasingly common, little is known about how such hospital-level interventions aimed at changing guidelines or standards of care affect patient outcomes. In this paper, I estimate the effects of PQCs on maternal and infant health outcomes.

**Abbreviations:** ACOG, American College of Obstetricians and Gynecologists; AIM, Alliance for Innovation on Maternal Health; CDC, Center for Disease Control and Prevention; EED, early elective delivery; ICU, intensive care unit; MMRC, Maternal Mortality Review Committee; NCHS, National Center of Health Statistics; PQC, Perinatal Quality Collaborative.

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To estimate these effects, I use individual-level National Center for Health Statistics (NCHS) Natality data from 1989 to 2019. I exploit the timing of state level implementation of state PQCs with a difference-in-differences estimation, accounting for the staggering adoption using a stacking method from Deshpande and Li (2019).

While the effects of PQCs are all marginally significant, I show that for Non-Hispanic Black mothers especially, PQCs decrease eclampsia.[2] For Non-Hispanic Black mothers, I find a 0.191 percentage point, 61%, decrease in eclampsia for non-first births. There is suggestive evidence of decrease in hypertension, which is only marginally significant for Non-Hispanic Black and Hispanic mothers giving birth for the first time. In addition, I find a reduction 0.082 percentage point, 45%, in intensive care unit (ICU) admissions for mothers and suggestive evidence of 0.031 percentage points, 31%, reduction in unplanned hysterectomies. While I cannot directly test why, there is a larger reduction in negative health outcomes for non-first births.

These results are especially important when considering how policy can improve maternal health. From 2014 to 2017, 6.6% of pregnancy-related deaths in the US were caused by hypertensive disorders, including eclampsia (CDC, 2020). In particular, eclampsia is associated with acute and long-run health complications. While initiatives that PQCs focus on differ across states, a common initiative is a “Severe Hypertension Initiative”. This type of initiative implement creating a standard protocol within a hospital for diagnosing and treating early warning signs of severe preelcampsia/eclampisa. These initiatives also include strategies to screen for structural and social drivers of health that may impact treatment plans and provide education to healthcare professionals and pregnant women on recognizing signs and symptoms.

Because state PQCs choose different initiatives, a limitation of this paper is that exact mechanisms driving the effects are difficult to determine. To address this limitation, I provide a patchwork of evidence and examples to discuss potential mechanisms. The decrease in eclampsia differs heterogeneously across maternal characteristics, with the magnitude of the decline being the largest for Non-hispanic Black mothers and mothers aged 30–44. The effects are driven by states with a Maternal Mortality Review Committee (MMRC), which reviews all maternal deaths in a state, suggesting complementary between PQCs and MMRCs.

Additionally, I test whether the adoption of PQCs affects infant health. Estimates indicate a 1.4 percentage point, 1.9%, decrease in the probability of an infant being born low birth weight. Estimates of PQCs on average birth weight, probability of very low birth weight, and early delivery outcomes are not statistically different from zero. I interpret this as suggestive evidence that PQCs improve maternal and infant health.

My research finds that PQCs affect maternal and infant health by reducing a leading cause of maternal mortality, eclampsia for Non-Hispanic Black mothers, suggesting that PQCs are an effective way to reduce maternal health disparities. These findings build on and contribute to the existing literature in several ways. First, I contribute to the maternal health economics literature by estimating the effects of state perinatal care *quality* for both mother and infant. Specifically, I focus on outcomes of preventable complications to maternal health that are primarily affected by hospital-level guidelines of perinatal care. Previous research reports that the effect of *quantity* of prenatal care alone on the infant is small. For example, by exploiting the change in Medicaid reimbursement rates for obstetric care, Sonchak (2015) finds the birth weight shift of an additional visit is not statistically different from zero for disadvantaged Black women and finds a 20 g increase for disadvantaged White mothers. Conway and Deb (2005) use the National Maternal and Infant Health Survey and two-stage least squares to find prenatal care results in a modest increase in birth weight of about 390–455 g for normal pregnancies. Kutinova and Conway (2008) and Yan (2016) study the effects of prenatal care utilization on the mother's health using outcomes like precipitous labor, hypertension, and placental abruption. Both papers find a decrease in these preventable outcomes with increased prenatal care utilization. My research expands on this literature by studying programs aimed at increasing the quality of prenatal care instead of the quantity or utilization of care.

Second, I created a new data set containing the establishment dates of each PQC. This data-set links information on PQCs to restricted individual-level natality data for all states. While existing work has studied the effects of single-state PQCs (Lee King et al., 2020; Main et al., 2017; Shields et al., 2017), I estimate the overall impact of PQCs nationally. In doing so, my findings have important policy implications on how states can improve maternal health.

## 2 | BACKGROUND ON PERINATAL QUALITY COLLABORATIVES

The Center for Disease Control and Prevention (CDC) defines PQCs as networks of perinatal care providers and public health professionals working to improve health outcomes for women and infants through continuous quality improvement. While the operational aspects differ by state, all PQCs have initiatives generally chosen by an advisory board of healthcare practitioners. Initiatives are often sourced from the American Alliance for Innovation on Maternal Health (AIM), an organization that creates initiative bundles to improve maternal health. State PQCs adopt these

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initiative bundles and implement them in their respective states. While all initiatives a state implements are not AIM bundles, they act as an important supplier of data-driven initiatives for PQCs. For example, the AIM Severe Hypertension bundle is used by many state PQCs. See Appendix A for the complete AIM Hypertension Bundle, which describes best practices for recognition, prevention, response, and reporting. Protocols include ensuring accurate measurement and assessment of blood pressure, screening for structural and social drivers of health that may impact treatment plans, standardized protocol with checklists, and post-event debriefs.

If a state adopts a PQC, birthing hospitals (sites) can choose to participate in PQC initiatives; however, not every birthing hospital in each state participates in the PQC initiatives. Although many, including Illinois, California, Florida, Maine, Maryland, Oklahoma, Washington, and West Virginia, have the majority (if not 100%) of birthing hospitals within their state participating. While participation is not universal, these states show that the state PQC broadly impacts the state. The number of participating sites is dynamic, and the longer a PQC is available in a state, the more sites may participate.[3] In addition, some states have differing site participation depending on the specific initiative.

States also may adopt MMRCs, which are separate organizations to improve maternal health. Forty-eight states, DC, New York City, Philadelphia, and Puerto Rico, have MMRCs (Guttmacher, 2021), many of which established the committees throughout the sample period, 1989–2019. These committees review all maternal deaths in a state, determine if they were preventable, and recommend best practices in maternal medicine. MMRCs publish reports with recommendations to prevent further deaths based on the contributing factors found from reviewing previous deaths (Review to Action, 2018). I explore the potential role of MMRCs and PQCs together and separately, detailed in Section 4.4.

Forty-three US states have PQCs, while eight other states are developing them as of 2021. Figure 1 shows a map of the staggered roll-out by state. Table 1 reports the years of establishment. While a few states established their PQCs in the 1970s and 1980s, most established them more recently. Because they are established at the state level, I can exploit the timing of their implementation to identify their causal effects.

The identification of causal effects relies on the randomness of the exact timing of PQC establishment. It is important to understand why states adopt PQCs to address possible sources of endogeneity. Next, I discuss how three states established their PQCs as evidence that states differ in which stakeholders initiated PQCs and the funding sources, suggesting there is randomness in the timing resulting from this heterogeneity in the establishing process. Massachusetts is an example of a state that established its PQC through direct collaboration between health care providers. The PQC in Massachusetts began due to conversations between neonatologists and the Department of Public Health. In fact, the first PQC meeting was held at the annual neonatology conference. The seed money was below 10,000 dollars and participation in leadership was voluntary (CDC, 2016).

Florida's PQC was launched with money from a March of Dimes grant, a national nonprofit supporting maternal and infant health, in collaboration with in-kind support from university faculty. Unlike Massachusetts and Florida, Illinois began its PQC with a grant through its state Medicaid program. The grant was large enough to hire a part-time coordinator (CDC, 2016). Importantly, each of the three states began with different stakeholders and with different funding, providing evidence that there is some level of randomness depending on a combination of funding sources and interest from stakeholders.

Another threat to identification is if PQCs are established with a bundle of other programs aimed at improving maternal and infant health that may be driving the results. This would be of particular concern if each initiative were funded and housed in the health department within a state where other health programs start. According to a 2016 survey of 32 state PQCs, 28% were housed in an academic institution, 18% were independent, 18% were in the state health department, 12% in a nonprofit, and 6% in each a state hospital association and a hospital or hospital system (Henderson et al., 2018). The heterogeneity in where PQCs are housed eases concerns of PQCs being bundled with other programs.

## 3 | EMPIRICS AND DATA

### 3.1 | Data

This section describes the data and the approach I use to estimate the causal effect of state PQCs on maternal and infant health. I use the National Center for Health Statistics individual-level Natality data from 1989 to 2019. The sample consists of singleton births where the birth order and state of delivery are recorded (National Center for Health

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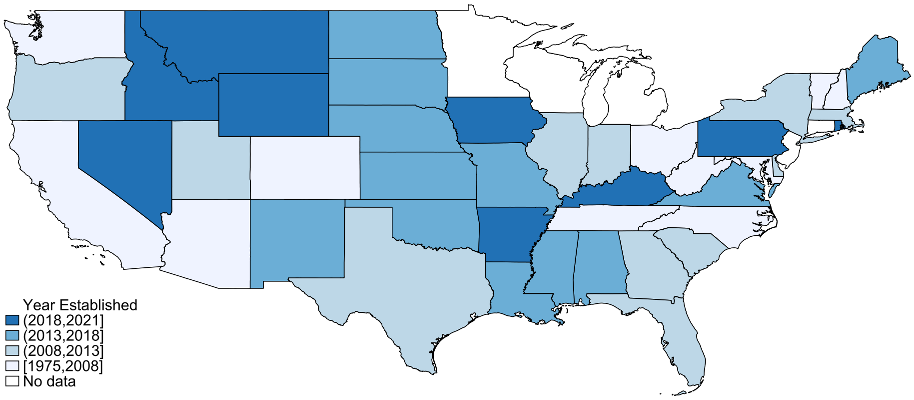


**FIGURE 1** PQC roll-out.

Statistics, 2021). The birth data has demographic information about the mother and includes race, age, and marital status. It also includes pregnancy risk factors, such as hypertension, eclampsia, and details from the birth log, such as the delivery method, gestation time, and birth weight. I collapse the data to the state-by-year-by-birth order level such that each cell contains the average for each state, year, and parity. Table 2 presents descriptive statistics of the outcomes of interest by birth order and race. Non-Hispanic Black mothers have more cases of hypertension and eclampsia, lower birth weight, and a higher probability of having a premature birth or cesarean prior to 39 weeks gestation. In addition, mothers giving birth for the first time are more likely to have hypertension and eclampsia, and infants are a slightly lower average birth weight.

Because first-time mothers differ from mothers who have given birth before and there are documented racial disparities in maternal health, I explore heterogeneity along these dimensions in my analysis. The outcomes of interest for this paper are eclampsia, gestational hypertension, premature birth, early cesarean, birth weight, probability of being low birth weight, and very low birth weight.[4]

As hypertension initiatives are common in PQCs and aim to reduce maternal morbidity associated with hypertension, studying the associated risky outcomes is particularly relevant.[5] Because hypertension is reported at the time of birth, it is important to identify and treat hypertension before the end of the pregnancy to reduce morbidity and mortality. Preventative measures can be taken in response to early warning signs, such as severe headaches, blurred vision, swelling of the hands and feet, and elevated blood pressure readings at prenatal care appointments. Preventative measures may be the result of education to pregnant women or health care providers, as many states' hypertension initiatives report maternal education and early warning signs as a part of the initiative. However, given the lack of specific information in the data on when during individual pregnancies hypertension and potential misreporting of hypertension, I interpret the results for hypertension cautiously (Howell, 2021).

In addition to a reduction in hypertension, the primary focus of these initiatives is to reduce the more severe outcomes that result from hypertension. While eclampsia is a rare outcome, affecting only 0.3% of births in the US, corresponding to roughly 12,000 births, eclampsia follows from a progression of hypertension and is necessary to study because of its severe nature and life threatening outcomes. Given these characteristics and because many PQCs focus on reducing severe outcomes of hypertension it is an appropriate measure of how PQCs may affect maternal health in a meaningful way.

Birth weight, low birth weight, very low birth, and premature births are all common measures used to study infant health. In addition to the variables measuring infant health, I study early cesareans which can be preformed for medically necessary reasons or medically unnecessary reasons. The American College of Obstetricians and Gynecologists (ACOG) recommends against non-medically necessary deliveries before 39 weeks gestation because adverse outcomes are greater in infants born in the early term period (ACOG, 2019). Studying early cesareans accounts for both medically necessary and unnecessary early deliveries. PQCs can reduce early cesareans through two channels, the first of which is the improvement of health which can translate to a reduction in need for medically necessary cesareans prior to 39 weeks. Secondly, a common PQC initiative strives to reduce medically unnecessary early deliveries which will be reflected in a reduction to early cesareans.[6]

Because the US has high rates of maternal mortality, studying the effect of PQCs on maternal mortality is particularly relevant. Unfortunately, the measurement of maternal mortality available in the NCHS multiple causes of

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**TABLE 1** Adoption years.

| | (1) PQC adoption year | (2) MMRC adoption year |
|---|---|---|
| Alabama | 2018 | 2018 |
| Alaska | 2019 | 1989 |
| Arizona | 1980 | 2011 |
| Arkansas | In development | In development |
| California | 2006 | 2007 |
| Colorado | 1975 | 1993 |
| Connecticut | No date | 2018 |
| Delaware | 2011 | 2011 |
| Florida | 2010 | 1996 |
| Georgia | 2012 | 2012 |
| Hawaii | 2009 | 2016 |
| Idaho | In development | 2019 |
| Illinois | 2012 | 2000 |
| Indiana | 2013 | 2018 |
| Iowa | In development | 1970 |
| Kansas | 2018 | 2018 |
| Kentucky | In development | 2018 |
| Louisiana | 2018 | 2010 |
| Maine | 2017 | 2005 |
| Maryland | 2006 | 2000 |
| Massachusetts | 2011 | 1998 |
| Michigan | Differs by region | 1950 |
| Minnesota | 1974/2018 | 2011 |
| Mississippi | 2014 | 2016 |
| Missouri | 2018 | 2011 |
| Montana | In development | 2013 |
| Nebraska | 2015 | 2013 |
| Nevada | In development | In development |
| New Hampshire | 2003 | 2010 |
| New Jersey | No date | 1932 |
| New Mexico | 2016 | 2018 |
| New York | 2010 | 2010 |
| North Carolina | 1997 | 1945 |
| North Dakota | 2018 | In development |
| Ohio | 2007 | 2011 |
| Oklahoma | 2014 | 2009 |
| Oregon | 2012 | 2018 |
| Pennsylvania | 2019 | 2019 |

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**TABLE 1** (Continued)

| | (1) PQC adoption year | (2) MMRC adoption year |
|---|---|---|
| Rhode Island | In development | In development |
| South Carolina | 2011 | 2016 |
| South Dakota | 2018 | In development |
| Tennessee | 2007 | 2017 |
| Texas | 2013 | 2013 |
| Utah | 2013 | 1995 |
| Vermont | 2003 | 2011 |
| Virginia | 2017 | 2002 |
| Washington | 2008 | 2016 |
| West Virginia | 2006 | 2008 |
| Wisconsin | 1970/2015 | 1997 |
| Wyoming | In development | In development |

*Note*: Data: State Websites. States that have PQCs in development are states that did not have a PQC by 2019, but are currently developing one. These states are defined as "never treated" in empirical specification because the birth data ends in 2019. Connecticut, Michigan, Minnesota, New Jersey, and Wisconsin were left out of the main analysis. Michigan's PQC is broken into regions and does not have a unique start date. Wisconsin and Minnesota report having a PQC in 1970 and 1974, respectively, but appear to go inactive before restarting in 2014 and 2018. New Jersey and Connecticut do not have the date on their website and did not respond to my inquiry via email on start data.

**TABLE 2** Summary statistics.

| | (1) All births Mean/sd | (2) 1st births Mean/sd | (3) Not 1st births Mean/sd | (4) Black mothers Mean/sd | (5) White mothers Mean/sd | (6) Hispanic mothers Mean/sd |
|---|---|---|---|---|---|---|
| Hypertension | 0.0373 | 0.0642 | 0.0334 | 0.0523 | 0.0427 | 0.0377 |
| | (0.0215) | (0.0211) | (0.0186) | (0.0522) | (0.0246) | (0.0423) |
| Eclampsia | 0.0031 | 0.0052 | 0.0027 | 0.0038 | 0.0025 | 0.0032 |
| | (0.0050) | (0.0054) | (0.0049) | (0.0143) | (0.0053) | (0.0171) |
| Birth weight | 3342.2932 | 3274.7239 | 3351.9459 | 3138.4554 | 3414.3901 | 3341.1864 |
| | (101.7989) | (58.3439) | (103.0151) | (181.3866) | (103.4486) | (158.1548) |
| Low birth weight | 0.0708 | 0.0720 | 0.0706 | 0.1182 | 0.0558 | 0.0614 |
| | (0.0277) | (0.0123) | (0.0293) | (0.0853) | (0.0260) | (0.0631) |
| Very low birth weight | 0.0118 | 0.0129 | 0.0117 | 0.0228 | 0.0084 | 0.0104 |
| | (0.0077) | (0.0035) | (0.0082) | (0.0389) | (0.0088) | (0.0246) |
| Premature | 0.1236 | 0.1014 | 0.1267 | 0.1751 | 0.0998 | 0.1254 |
| | (0.0407) | (0.0157) | (0.0421) | (0.1022) | (0.0360) | (0.0906) |
| Early cesarean | 0.1001 | 0.0850 | 0.1023 | 0.1158 | 0.0963 | 0.0966 |
| | (0.0380) | (0.0254) | (0.0390) | (0.0843) | (0.0400) | (0.0764) |
| Observations | 11,160 | 1395 | 9765 | 10,731 | 11,104 | 10,831 |

*Note*: Data: NHCS restricted access birth data with state identifiers: 1989–2019. This table reports mean and standard deviation of the outcome variables. Either is an index variable for having either eclampsia or hypertension. Low birth weight is defined as one when birthweight is less than 2500 g, and Very low birth weight is defined as one when birthweight is less than 1500 g. Premature birth is defined as a birth prior to 37 weeks gestation. Early cesarean is defined as a C-section prior to 39 weeks gestation.

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death files is inaccurately reported with a 2003 change in death records (Hoyert et al., 2020). For this reason, I do not include mortality as an outcome measure.[7] While I can't directly measure mortality, I do study maternal morbidities for a subset of states. Similar to the mortality data, the Vital Statistics Birth records changed in 2003, making it so only select variables are available consistently for all states in all years from 1989 to 2019. Hypertension and eclampsia are available in every year, but maternal morbidities including, ruptured uterus, laceration, transfusion, unplanned hysterectomy, and ICU admission are limited to the subset of states which adopted the 2003 change by 2010 and were treated by 2010.

I use a newly collected data set on PQC years of establishments to estimate their effects on maternal health. To gather data on program dates, I collected data from PQC program directors and PQC websites on the year of implementation. Five states with PQCs are excluded from the analysis due to a lack of information on the timing of establishment.[8] I also collect data from MMRC websites on the year of establishment.

## 3.2 | Empirical specification

Because treatment occurs at the state level, I create a state-by-year panel of data and use a difference-in-differences identification strategy. The state-by-year-by-birth order panel is constructed by taking the average of each outcome for a given state, year, and birth order. There is variation in when states establish their PQCs. Because of this, a canonical two-way fixed effects specification may result in negative weighting (Goodman-Bacon, 2021). Negative weights result from dynamic treatment effects, which are possible if PQCs learn from each other. To avoid these concerns, I use a stacked version of a difference-in-differences estimation following Deshpande and Li (2019).[9]

I organize my data into stacks where each stack is defined by a state that adopts a PQC in a given year. For any given stack, the control group consists of states that are "not yet treated" and "never treated."[10] To ensure a clean post period within each stack, the not yet treated states are defined as those treated at least 4 years after year $y$, where $y$ is the year that a state is treated. To create a balanced panel around event time, the first state included in the treatment established a PQC in 1994, and the last established its PQC in 2015. Including states treated from 1994 to 2015 limits the number of treated states to 24. Lastly, I append the stacks together and estimate a stacked difference-in-differences weighted least squares (WLS) shown in Equation (1).

$$Y_{asy} = \beta_1 D_{sy} + \gamma_{as} + \gamma_{ay} + \epsilon_{asy} \tag{1}$$

$Y_{asy}$ measures maternal or infant health outcomes in state $s$, year $y$, and stack a. $D_{sy}$ is an indicator variable equaling one for states after a PQC is newly established. $\gamma_{as}$ and $\gamma_{ay}$ are state and year fixed effects, respectively. The fixed effects allow for only within-stack comparisons. Standard errors are clustered at the state level, and each specification is weighted by the number of births in each state and year.[11]

The identification assumption is that the precise timing of a state establishing a PQC is uncorrelated with trends in maternal and infant health. If trends in observable state characteristics correlate with the exact timing of treatment, this could threaten the parallel trends assumption. The observable state-level demographic characteristics included are percent Black mothers, percent Hispanic mothers, average mother's age, percent Black fathers, percent Hispanic fathers, average father's age, marital status, and percentage of mothers with a college education. Additional state policy and economic variables include Medicaid expansion, MMRC timing, EED initiative timing, employment, median household income, and poverty rate.[12] To test the correlation, I estimate how the baseline and time varying observables change relative to PQC establishment.

$$x_s = \beta_1 D_{sy} + \epsilon_{sy} \tag{2}$$

In addition to the main specification shown in Equation (1), I also perform an event study specification using the stacking design:

$$Y_{asy} = \delta_{as} + \delta_{ay} + \sum_{t=-5}^{-2} \mu_t \mathbf{1}\{y - y_s^* = t\} * treat_{as} + \sum_{t=0}^{3} \gamma_t \mathbf{1}\{y - y_s^* = t\} * treat_{as} + \epsilon_{asy} \tag{3}$$

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where $\mathbf{1}\{y - y_s^* = t\}$ is an indicator for state $s$ being $t$ years away from PQC establishment and $a$ is a stack. The event study provides testable implications for the parallel trends assumption.

I present estimates for all mothers and subsetted by race and parity.[13] Birth order may matter for a few reasons: the riskiest births include both women giving birth for the first time as well as higher-order births, since birth order is correlated with maternal age. Results may differ by age and number of births because there is a documented increase in prenatal care services for mothers at age 35 (Geiger et al., 2021). The inclusion of results by race is motivated by the documented racial disparities in maternal health and the growing research suggesting that the quality of prenatal care is a critical factor in these disparities (Howell, 2018).

## 4 | RESULTS

### 4.1 | Maternal health

To show the effects of PQCs on maternal outcomes, I first present graphical evidence of the implementation of PQCs on hypertension and eclampsia that corresponds to the stacked difference-in-differences identification strategy. Figures 2–4 and show results separated by Non-Hispanic Black, Non-Hispanic White, and Hispanic mothers, respectively. The effects of PQCs on hypertension and eclampsia are driven by Non-Hispanic Black mothers. Figure 2 plots the event study coefficient estimates for hypertension and eclampsia and their corresponding 95% confidence intervals from Equation (3) by birth order for Non-Hispanic Black mothers. I estimate the effects relative to $t = -1$ since my sample is limited to treated states with at least 4 years of data before treatment. Figure 2a plots the event study coefficient estimates for hypertension regardless of parity, Figure 2b plots the estimates for first births and second birth or above in Figure 2c. The corresponding estimates for eclampsia are in Figure 2d–f. Estimates to the left of the vertical line are statistically indistinguishable from zero, supporting the notion that maternal health trends were not diverging in the years before treatment.

Table 3 presents the corresponding stacked difference-in-differences coefficient estimates for the implementation of PQCs on hypertension and eclampsia by race and parity. I find statistically insignificant decreases for eclampsia and hypertension for all mothers and for Non-Hispanic White mothers in all cases.

While the results for all mothers are statistically insignificant, these may be masking important heterogeneity for Non-Hispanic Black mothers who have higher rates of maternal mortality. As such, I find evidence of an effect of PQCs on eclampsia and hypertension for Non-Hispanic Black mothers. The decrease in hypertension ranges from 0.44 to 0.61 percentage points, or $9\% - 10\%$, and the decrease in eclampsia ranges from 0.16 to 0.19 percentage points, or $29\% - 61\%$. The estimates differ by birth order; the top panel reports estimates for all parity, the middle panel reports for the subset of first births, and the bottom panel reports estimates for women not giving birth for the first time. The reduction in eclampsia is driven by second or above births—Figure 2 shows event study evidence of the decrease. The decrease in eclampsia that I find is in line with related literature. Shields et al. (2017) found a decrease in eclampsia of 42.6% when California PQC implemented standardized protocols in 23 hospitals to manage and treat hypertensive disorders.

To understand if women giving birth for the second time are driving the estimates for those not giving birth for the first time, Table 4 reports estimates further broken down by birth order subgroups. Each column represents a different subgroup of women given a specific number of births. It shows that the reduction in eclampsia for women not giving birth for the first time is driven by higher-order births, 4th and above. However, because age and birth order are correlated, Table 5 reports related estimates by the subgroup of maternal ages. The top panel reports the estimates where the outcome of interest is eclampsia. I find that mothers over the age of 30 experience the greatest reduction in eclampsia. However, only the reduction for women aged 30–34 is statistically significant at the 10% level. The bottom panel reports the estimates where the outcome of interest is hypertension. For hypertension, women ages 20–24 experience the largest reductions. For the hypertension result, only mothers aged 20–24 have a statistically significant at the 10% reduction in hypertension.

For a subset of states, I estimate the effect of PQCs on maternal morbidity. Table 6 shows estimates from Equation (1) for the subset of treated states that had adopted the 2003 birth certificate and were treated after 2012. The treated states included are Indiana, Nebraska, New Mexico, Oklahoma, Texas, and Utah.[14] Most notably I find an overall significant reduction in ICU admissions during labor of 0.082 percentage points or 46%. I also find a reduction in

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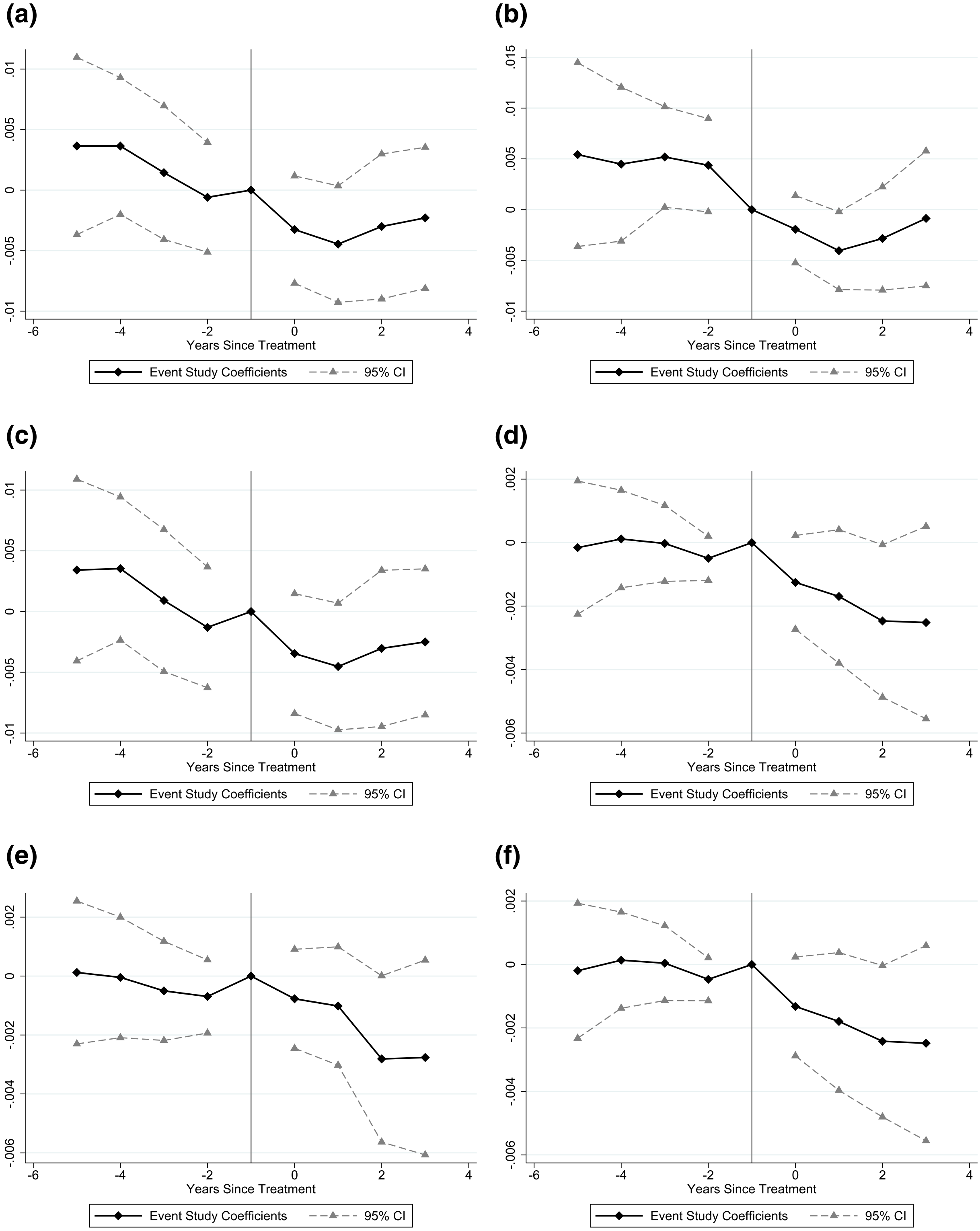


**FIGURE 2** Hypertension and eclampsia event studies Non-Hispanic Black mothers. (a) Hypertension – all births. (b) Hypertension – 1st birth. (c) Hypertension – 2nd or above birth. (d) Eclampsia – all births. (e) Eclampsia – 1st birth. (f) Eclampsia – 2nd or above birth. Each figure displays the coefficients and their respective 95% confidence intervals from WLS regressions, as specified in Equation (3) for Non-hispanic Black mothers. The vertical line represents the year prior to treatment. Estimates are based on restricted NCHS birth files from 1989 to 2019. Standard errors are clustered at the state level and estimates are weighted by the number of births in each state. Figures (a–c) report estimates for the hypertension outcome by birth order. Figures (d–f) report estimates for the eclampsia outcome by birth order.

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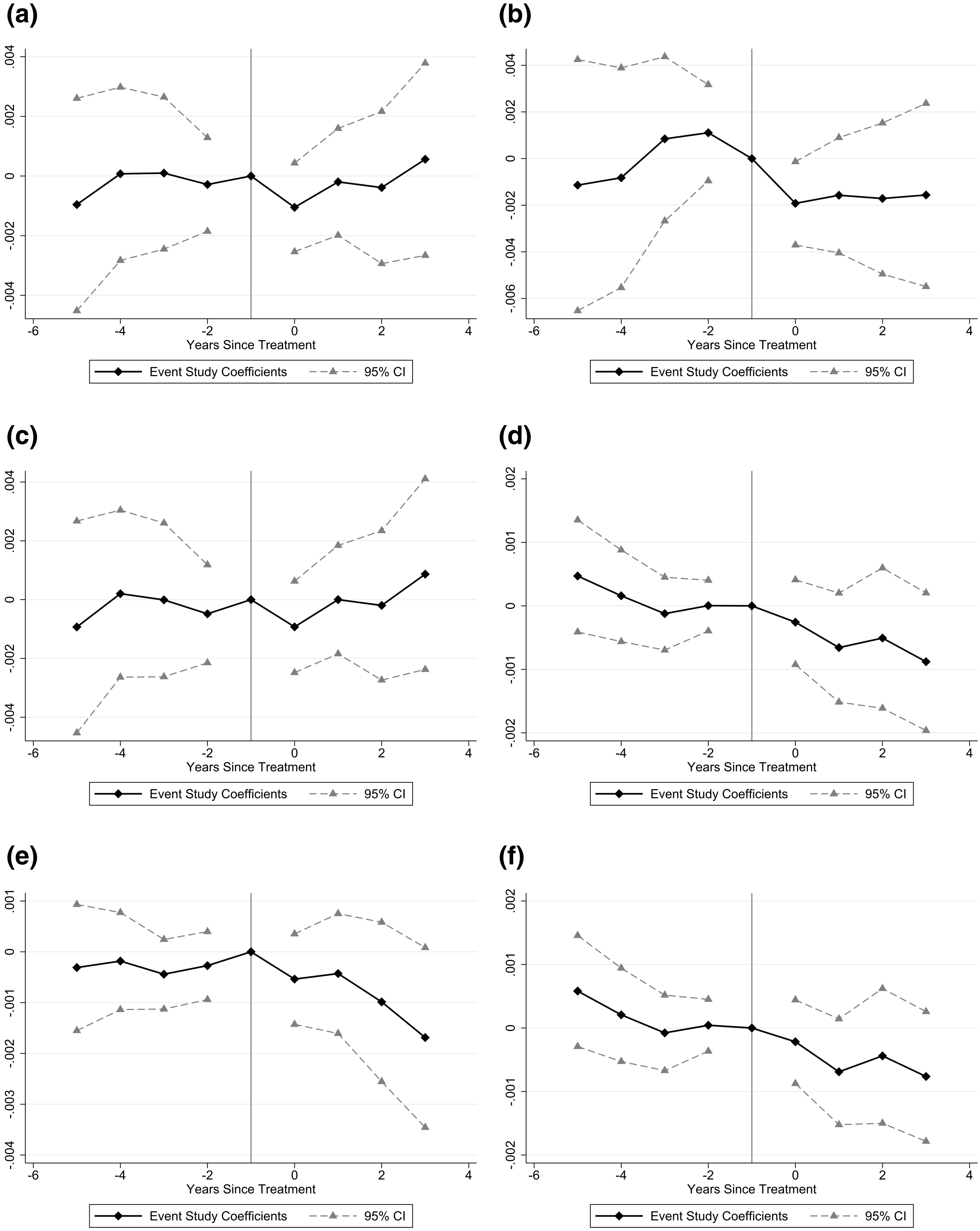


**FIGURE 3** Hypertension and eclampsia event studies Non-Hispanic White mothers. (a) Hypertension – all births. (b) Hypertension – 1st birth. (c) Hypertension – 2nd or above birth. (d) Eclampsia – 1st birth. (e) Eclampsia – 1st birth. (f) Eclampsia – 2nd or above birth. Each figure displays the coefficients and their respective 95% confidence intervals from WLS regressions, as specified in Equation (3) for White mothers. The vertical line represents the year prior to treatment. Estimates are based on restricted NCHS birth files from 1989 to 2019. Standard errors are clustered at the state level and estimates are weighted by the number of births in each state. Figures (a–c) report estimates for the hypertension outcome by birth order. Figures (d–f) report estimates for the eclampsia outcome by birth order.

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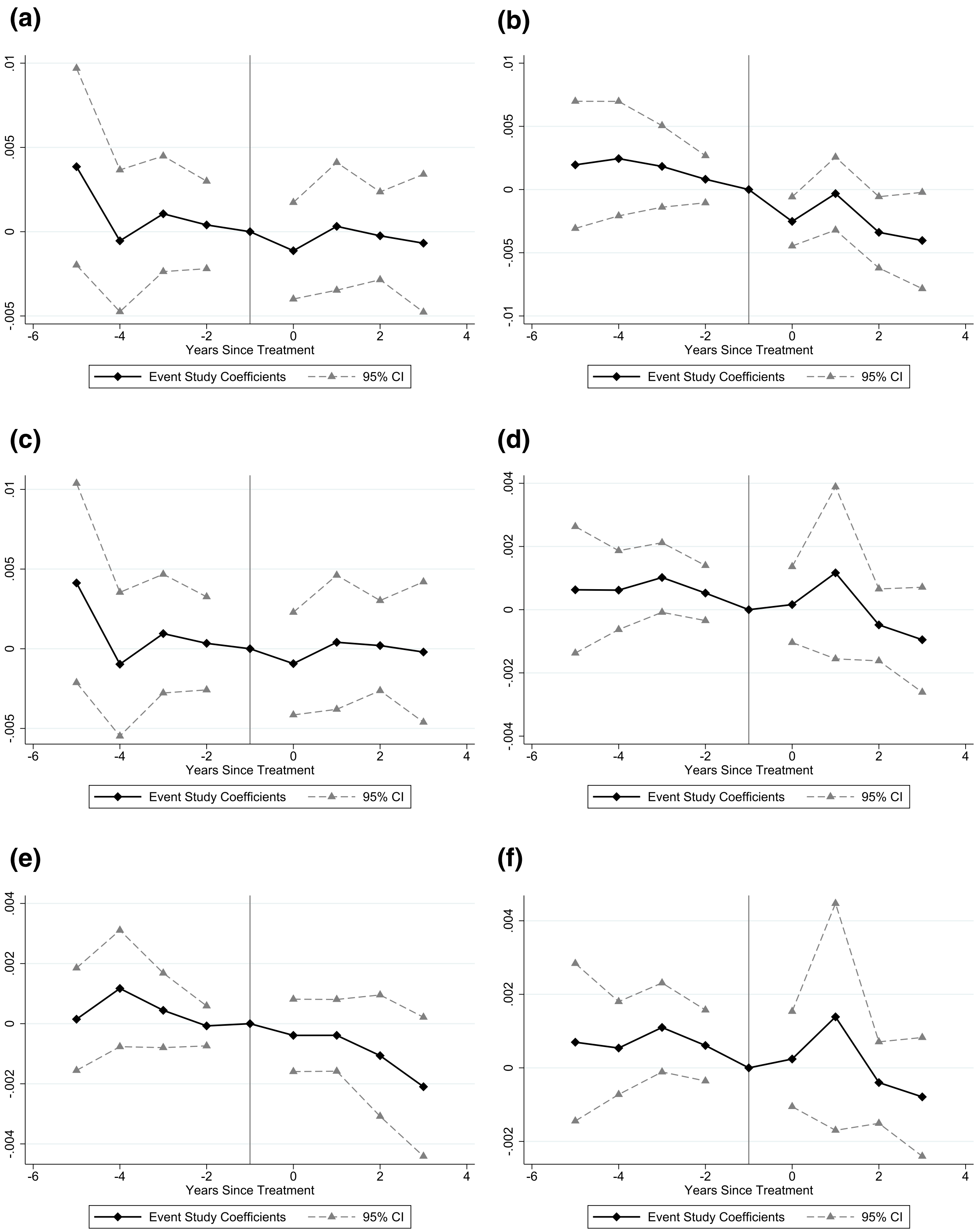


**FIGURE 4** Hypertension and eclampsia event studies Hispanic mothers. (a) Hypertension – all births. (b) Hypertension – 1st birth. (c) Hypertension – 2nd or above birth. (d) Eclampsia – 1st birth. (e) Eclampsia – 1st birth. (f) Eclampsia – 2nd or above birth. Each figure displays the coefficients and their respective 95% confidence intervals from WLS regressions, as specified in Equation (3) for White mothers. The vertical line represents the year prior to treatment. Estimates are based on restricted NCHS birth files from 1989 to 2019. Standard errors are clustered at the state level and estimates are weighted by the number of births in each state. Figures (a–c) report estimates for the hypertension outcome by birth order. Figures (d–f) report estimates for the eclampsia outcome by birth order.

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**TABLE 3** Effect of PQC on maternal health, by parity.

| | All mothers | | Non-Hispanic White mothers | | Non-Hispanic Black mothers | | Hispanic mothers | |
|---|---|---|---|---|---|---|---|---|
| | (1) Eclampsia | (2) Hypertension | (3) Eclampsia | (4) Hypertension | (5) Eclampsia | (6) Hypertension | (7) Eclampsia | (8) Hypertension |
| All births | | | | | | | | |
| PQC in effect | −0.000901 | −0.001137 | −0.000677 | −0.000107 | −0.001869 | −0.004577 | −0.000580 | −0.001229 |
| | (0.0006) | (0.0015) | (0.0005) | (0.0014) | (0.0011) | (0.0030) | (0.0008) | (0.0017) |
| | (0.0006) | (0.0015) | (0.0005) | (0.0014) | (0.0011) | (0.0030) | (0.0008) | (0.0017) |
| Mean | 0.0028 | 0.0376 | 0.0023 | 0.0371 | 0.0035 | 0.0438 | 0.0026 | 0.0319 |
| Observations | 43,992 | 43,992 | 43,984 | 35,712 | 42,694 | 34,826 | 43,341 | 35,269 |
| First births | | | | | | | | |
| PQC in effect | −0.000844 | −0.002871 | −0.000664 | −0.001847 | −0.001612 | −0.006147* | −0.001319 | −0.003848** |
| | (0.0008) | (0.0020) | (0.0007) | (0.0022) | (0.0013) | (0.0031) | (0.0011) | (0.0017) |
| Mean | 0.0045 | 0.0648 | 0.0042 | 0.0678 | 0.0055 | 0.0673 | 0.0044 | 0.0496 |
| Observations | 5499 | 5499 | 5498 | 4464 | 5498 | 4464 | 5498 | 4464 |
| Non-First births | | | | | | | | |
| PQC in effect | −0.000909 | −0.000890 | −0.000678 | 0.000142 | −0.001905* | −0.004364 | −0.000475 | −0.000856 |
| | (0.0006) | (0.0015) | (0.0004) | (0.0014) | (0.0011) | (0.0031) | (0.0007) | (0.0017) |
| Mean | 0.0025 | 0.0337 | 0.0020 | 0.0327 | 0.0031 | 0.0403 | 0.0024 | 0.0294 |
| Observations | 38,493 | 38,493 | 38,486 | 31,248 | 37,196 | 30,362 | 37,843 | 30,805 |

*Note*: Each column reports a different WLS regression from Equation (1) where dependent variable is different in each column. Columns (1)–(2) are the estimates for all mothers, (3)–(4) are the subset of Non-Hispanic White mothers and (5)–(6) are Non-Hispanic Black mothers and (7)–(8) are Hispanic mothers. Treatment is the timing of state PQC establishment. Each regression includes state and year fixed effects. Standard errors are clustered at the state level and estimates are weighted by the number of births in each state. Data is collapsed to the state by year by live birth order level. The top panel reports the estimates for all births the middle panel reports the subset of first births for women and the bottom panel reports the estimates for the subset of women not giving birth for the first time. Data: NHCS 1989–2019.

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

**TABLE 4** Effect of PQC on eclampsia, by parity.

| | First | Second | Third | Fourth | Fifth | Sixth | Seventh | Eighth |
|---|---|---|---|---|---|---|---|---|
| PQC in effect | −0.000844 | −0.000656 | −0.000718 | −0.000860 | −0.001167* | −0.001132 | −0.000856 | −0.000975 |
| | (0.0008) | (0.0005) | (0.0005) | (0.0005) | (0.0006) | (0.0007) | (0.0009) | (0.0009) |
| Mean | 0.0040 | 0.0020 | 0.0020 | 0.0020 | 0.0030 | 0.0030 | 0.0030 | 0.0030 |
| Observations | 5499 | 5499 | 5499 | 5499 | 5499 | 5499 | 5499 | 5499 |

*Note*: Each column reports a different WLS regression from Equation (1) where dependent variable is average eclampsia for each parity. Column (1) reports estimates of the effect of PQCs on eclampsia for first births. Treatment is the timing of state PQC establishment. Each regression includes state and year fixed effects. Standard errors are clustered at the state level and estimates are weighted by the number of births in each state. Data is collapsed to the state by year by live birth order level. Data: NHCS 1989–2019.

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

unplanned hysterectomies for all births of 0.0312 percentage points or a 31%. The corresponding event studies and their 95th% confidence intervals are presented in Figure 5. Overall, these estimates provide evidence that PQCs can reduce maternal morbidity which are often associated with maternal mortality.

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**TABLE 5** Effect of PQC on maternal health, by age.

| | (1) 15–19 | (2) 20–24 | (3) 25–29 | (4) 30–34 | (5) 35–39 | (6) 40–44 |
|---|---|---|---|---|---|---|
| Eclampsia | | | | | | |
| PQC in effect | 0.000428 | −0.001125 | −0.000780 | −0.001175* | −0.001088 | −0.000970 |
| | (0.0014) | (0.0008) | (0.0006) | (0.0007) | (0.0008) | (0.0009) |
| Mean | 0.0029 | 0.0029 | 0.0024 | 0.0026 | 0.0032 | 0.0042 |
| Observations | 26,857 | 41,341 | 43,855 | 43,991 | 43,992 | 43,992 |
| Hypertension | | | | | | |
| PQC in effect | 0.002359 | −0.005202* | −0.000341 | −0.001449 | −0.001977 | −0.002798 |
| | (0.0038) | (0.0028) | (0.0017) | (0.0019) | (0.0023) | (0.0022) |
| Mean | 0.0271 | 0.0311 | 0.0351 | 0.0396 | 0.0458 | 0.0576 |
| Observations | 21,612 | 33,564 | 35,603 | 35,712 | 35,712 | 35,712 |

*Note*: Each column reports a different WLS regression from Equation (1) where dependent variable is average eclampsia or hypertension for maternal age subgroups. Treatment is the timing of state PQC establishment. The top panel reports estimates for eclampsia and the bottom estimates for hypertension. Each regression includes state and year fixed effects. Standard errors are clustered at the state level and estimates are weighted by the number of births in each state. Data is collapsed to the state by year level. Data: NHCS 1989–2019.

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

**TABLE 6** The effect of PQC on maternal morbidity.

| | (1) Ruptured uterus | (2) Laceration | (3) Transfusion | (4) Unplanned hyst. | (5) ICU |
|---|---|---|---|---|---|
| All births | | | | | |
| PQC in effect | −0.000108 | −0.002639 | 0.000042 | −0.000312** | −0.000820** |
| | (0.0001) | (0.0018) | (0.0004) | (0.0001) | (0.0003) |
| Mean | 0.0007 | 0.0047 | 0.0050 | 0.0010 | 0.0018 |
| Observations | 3664 | 3664 | 3664 | 3664 | 3664 |
| First births | | | | | |
| PQC in effect | 0.000005 | −0.004634 | 0.000078 | −0.000026 | −0.000701** |
| | (0.0000) | (0.0044) | (0.0004) | (0.0000) | (0.0003) |
| Mean | 0.0001 | 0.0206 | 0.0036 | 0.0002 | 0.0013 |
| Observations | 458 | 458 | 458 | 458 | 458 |
| Non-first births | | | | | |
| PQC in effect | −0.000124 | −0.002354 | 0.000037 | −0.000353** | −0.000836** |
| | (0.0002) | (0.0015) | (0.0004) | (0.0002) | (0.0003) |
| Mean | 0.0008 | 0.0024 | 0.0052 | 0.0011 | 0.0019 |
| Observations | 3206 | 3206 | 3206 | 3206 | 3206 |

*Note*: Each column reports a different WLS regression from Equation (1) where dependent variable is a different maternal morbidity outcome. Treatment is the timing of state PQC establishment. The top panel reports estimates for all births, the middle for first births, and the bottom for non-first births. Each regression includes state and year fixed effects. Standard errors are clustered at the state level and estimates are weighted by the number of births in each state.Data is collapsed to the state by year by live birth order level. The subset of included states are those that adopted the 2003 birth certificate revision by 2010 and are treated after 2012 or never treated. Treated states that meet the criteria IN, NE, NM, OK, TX, and UT. Data: NHCS 2010–2019.

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

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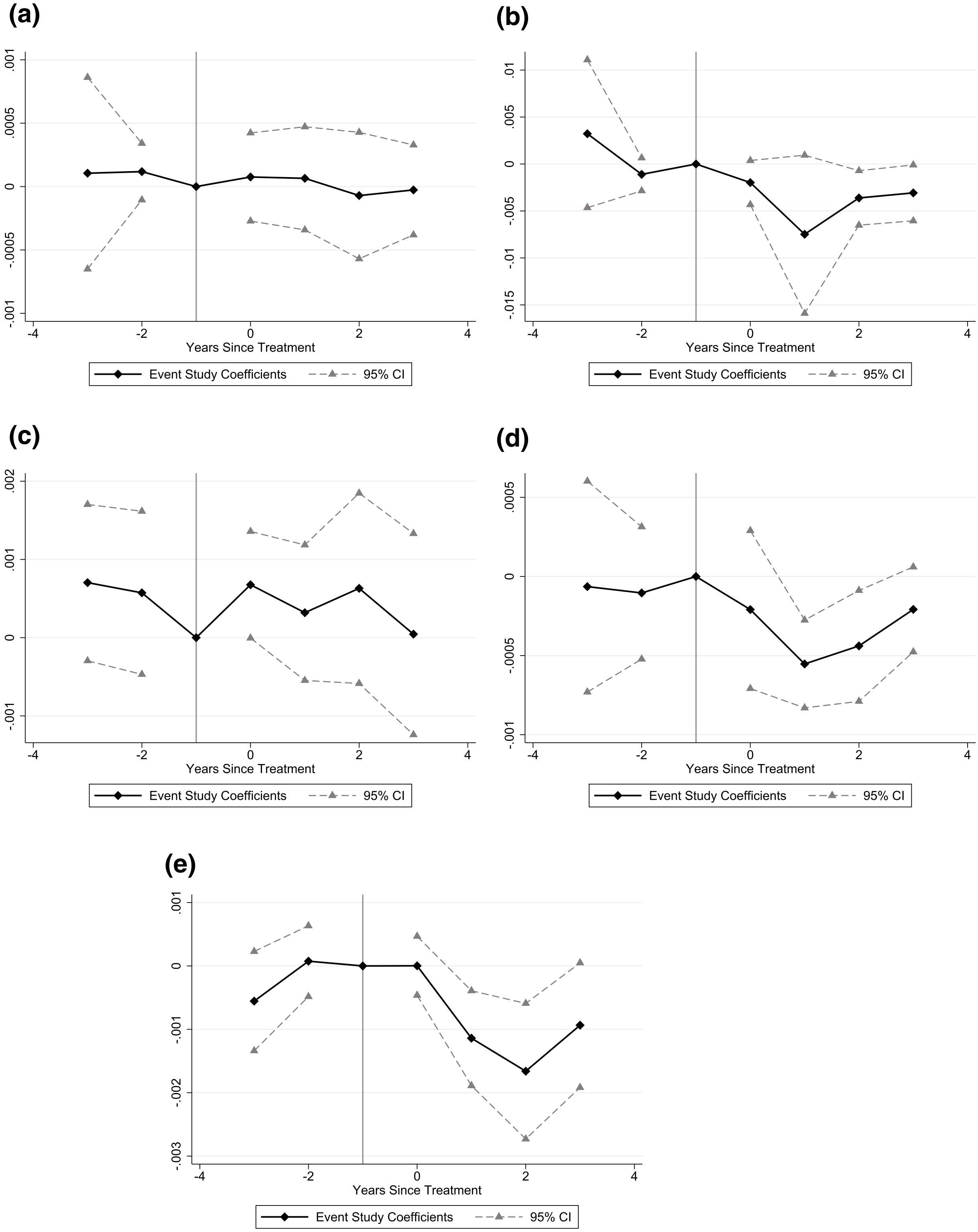


**FIGURE 5** Morbidity event studies for all births. (a) Ruptured Uterus. (b) Laceration. (c) Blood Transfusion. (d) Unplanned Hysterectomy. (e) ICU Stay. Each figure displays the coefficients and their respective 95% confidence intervals from WLS regressions, as specified in Equation (3) for all mothers. The vertical line represents the year prior to treatment. Estimates are based on restricted NCHS birth files from 2010 to 2019. Standard errors are clustered at the state level and estimates are weighted by the number of births in each state. The subset of included states are those that adopted the 2003 birth certificate revision by 2010 and are treated after 2012 or never treated. Treated states which meet the criteria IN, NE, NM, OK, TX, and UT.

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## 4.2 | Infant health

Because maternal health is an input into infant health, I also estimate the effects of PQCs on to neonatal outcomes. In Table 7, I present coefficient estimates on average birth weight, probability of low birth weight, probability of very low birth weight, premature births, and early cesareans. Table 7 shows a small statistically significant at the 5% level decrease in the probability of low birth weight and null effects for average birth weight, probability of very low birth weight, premature births, and early cesareans. The top panel shows all births and indicates that I can reject effects greater than a 5.57 g increase or less than a 2.23 g decrease in birth weight and effects greater than an 0.066 percentage point increase or a 0.051 percentage point decrease in VLBW. For gestation outcomes, I can reject effects greater than a 0.299 percentage point increase or less than a 0.245 percentage point decrease in premature births and effects greater than a 0.583 percentage point increase or less than a 0.397 percentage point decrease in early cesareans.

Table 8 shows estimates for subsets of Non-Hispanic Black mothers. Again, the results are driven by Non-Hispanic Black mothers, supporting evidence that PQCs improve health for Black mothers, which may have a downstream effect on infant health. Despite finding no significant effect in birth weight for all infants, I find a 8.4 g increase in birth weight for Non-Hispanic Black mothers. This corresponds to a 0.2% increase in birth weight.[15]

Figure 6 presents the event studies, which provide visual evidence supporting the main estimates of infant health. Because this result is not robust to changes in specifications, and pretrends are trending downward prior to treatment, as shown in Figure 6, I report this as suggestive evidence of a decrease in the probability of having low birth weight for infants.

## 4.3 | Potential mechanisms

Maternal risk and clinical practices may be a driving mechanism behind the differential effects by mothers' age and parity. Older age and high parity pregnancies, defined as those having five or more births, are linked to higher maternal and infant mortality (Ndiaye, 2018). Evidence from Geiger et al. (2021) suggests that prenatal care services including visits, ultrasounds, and surveillance are larger for mothers aged 35 or above. Healthcare practitioners' knowledge about the additional risks associated with age and high parity pregnancies may result in an increased focus on care for these mothers and stronger adherence to the toolkits provided by the PQC; however, this mechanism is not directly testable due to data limitations. Further, Maeda et al. (2021) suggest that preventative treatment may improve hypertensive outcomes for women in subsequent pregnancies who had pre-eclampsia during a previous pregnancy. Therefore, the reduction that I find for non-first births could be driven by women with hypertensive disorders during a previous pregnancy rather than mothers being diagnosed for the first time. Unfortunately, because I cannot identify a mother across multiple pregnancies, I cannot identify this heterogeneity.[16] Below, I lay out a patchwork of evidence for potential mechanisms and explain how each could contribute to the above findings.

### 4.3.1 | Prenatal visits

One possible way PQCs may affect maternal health outcomes is by encouraging women, especially high-risk women, to schedule and attend more prenatal visits. On average, doctors recommend one prenatal visit per month from weeks 4 to 28, one visit every 2 weeks from 28 to 36 weeks, and one visit every week from 36 to 40 weeks (Cleveland Clinic, 2022). This averages to around 13 prenatal visits, although many mothers attend fewer than the recommended amount. In Figure 7, I present estimates of the effect of PQCs on the number of prenatal visits. I find an increase in prenatal care visits for women attending higher than the average number of visits. There is a statistically significant increase in the number of women having 13, 16, 17, 18, and 19 visits. There is a small and statistically insignificant decrease in the number of women having zero to nine visits, which suggests that the increase in visits is driven by mothers going to more visits than they would have in the absence of the PQC rather than mothers up taking up any prenatal care. In other words, after a state adopts a PQC initiative, mothers who were already attending some prenatal visits attend even more.

It is possible that PQC initiatives aid in identifying mothers needing more care or can get mothers to schedule and attend more visits, leading to an increase in the number of prenatal visits for higher-risk pregnancies. This may occur through multiple streams. While the majority of prenatal care occurs in a doctor's office, as many as 50% of pregnant

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**TABLE 7** Effect of PQC on infant health, by parity.

| | (1) Birth weight | (2) Pr(LBW) | (3) Pr(vLBW) | (4) Premature | (5) Early cesarean |
|---|---|---|---|---|---|
| All births | | | | | |
| PQC in effect | 1.717992 | −0.001352** | 0.000075 | 0.000248 | 0.000926 |
| | (1.9638) | (0.0006) | (0.0003) | (0.0014) | (0.0025) |
| Mean | 3330.5765 | 0.0708 | 0.0118 | 0.1279 | 0.1177 |
| Observations | 43,992 | 43,992 | 43,992 | 43,992 | 43,992 |
| First births | | | | | |
| PQC in effect | 0.719768 | −0.000524 | 0.000056 | −0.001083 | −0.001749* |
| | (1.6703) | (0.0005) | (0.0002) | (0.0011) | (0.0010) |
| Mean | 3265.9210 | 0.0730 | 0.0130 | 0.1040 | 0.0960 |
| Observations | 5499 | 5499 | 5499 | 5499 | 5499 |
| Non-first births | | | | | |
| PQC in effect | 1.860595 | −0.001471** | 0.000078 | 0.000439 | 0.001308 |
| | (2.0945) | (0.0006) | (0.0003) | (0.0015) | (0.0028) |
| Mean | 3339.8130 | 0.0710 | 0.0120 | 0.1310 | 0.1210 |
| Observations | 38,493 | 38,493 | 38,493 | 38,493 | 38,493 |

*Note*: Each Column represents a different WLS regression with an infant dependent variable for Equation (1). Data is collapsed to the state by year by live birth order level. Each regression includes state and year fixed effects. Standard errors are clustered at the state level and estimates are weighted by the number of births in each state. The top panel reports the estimates regardless of parity. The middle panel reports the estimates for the subset of first births and the bottom panel reports the estimates for the subset of women not giving birth for the first time. Data: NCHS 1989–2019

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

women received care at the Emergency Department during pregnancy. The most common reasons to seek care at the Emergency Department include concern that there is an issue with the pregnancy, such as abnormal bleeding, headache, abnormal blood pressure reading at home, or decreased fetal movement. The health care provider can also refer the patient to seek care at the emergency department (Kilfoyle et al., 2017). These interactions at hospitals are unplanned prenatal care and provide opportunity for healthcare providers at hospitals that participate in the PQC to identify high risk mothers and recommend additional care. In addition, the educational component of initiatives may influence obstetricians to implement similar protocols at non-hospital prenatal visits.

### 4.3.2 | Changes in prescribing patterns

Another way to test how PQCs affect mothers' outcomes is to analyze changes in prescribing patters. For example, medications such as Labetalol, Nifedipine, and Hydralazine are common blood pressure drugs prescribed to treat hypertension and eclampsia (Brown & Garovic, 2014). It is unclear whether we expect units of these prescribed drugs to increase or decrease with the establishment of PQCs. Prescriptions of these medications could increase if there is an increase in early treatment with drugs which ultimately contributes to the decrease in hypertension and eclampsia that I find. On the other hand, if other preventative measures, such as increased prenatal care visits, early monitoring of high-risk pregnancies, and rapid response in recognizing and diagnosing hypertension in pregnancy, then fewer blood pressure medications can be used and in turn there will be less incidence of eclampsia.

To test the use of blood pressure medication, I estimate Equation (3) to find the effect of PQCs on units of Labetalol, Nifedipine, and Hydralazine prescribed to all Medicaid users. To do so, I use Medicaid Claims data which includes measures of units prescribed. These data report aggregate measures, which include populations outside of pregnant women. Because this data is aggregated and I cannot distinguish pregnant women, estimates provide only suggestive evidence. As shown in Figure 8, there is a small decrease in the log of units of blood pressure medication prescribed after the establishment of a PQC. While these estimates are not precise, it does suggest that PQCs are associated with a

**TABLE 8** Effect of PQC on infant health for Non-Hispanic Black mothers, by parity.

| | (1) Birth weight | (2) Pr(LBW) | (3) Pr(VLBW) | (4) Premature | (5) Early cesarean |
|---|---|---|---|---|---|
| All births | | | | | |
| PQC in effect | 8.397815** | −0.004474** | −0.000652 | 0.000434 | 0.000320 |
| | (3.6757) | (0.0018) | (0.0008) | (0.0028) | (0.0026) |
| Mean | 3137.9030 | 0.1150 | 0.0220 | 0.1730 | 0.1320 |
| Observations | 42,700 | 42,700 | 42,700 | 42,700 | 42,700 |
| First births | | | | | |
| PQC in effect | 2.179280 | −0.001536 | −0.000668 | −0.001211 | −0.001302 |
| | (2.9390) | (0.0010) | (0.0006) | (0.0014) | (0.0015) |
| Mean | 3090.2550 | 0.1190 | 0.0270 | 0.1400 | 0.1130 |
| Observations | 5498 | 5498 | 5498 | 5498 | 5498 |
| Non-first births | | | | | |
| PQC in effect | 9.268175** | −0.004882** | −0.000649 | 0.000678 | 0.000561 |
| | (4.0723) | (0.0020) | (0.0008) | (0.0031) | (0.0030) |
| Mean | 3144.9440 | 0.1150 | 0.0220 | 0.1780 | 0.1350 |
| Observations | 37,202 | 37,202 | 37,202 | 37,202 | 37,202 |

*Note*: Each Column represents a different WLS regression with an infant dependent variable for Equation (1) for Non-Hispanic Black mothers. Data is collapsed to the state by year by live birth order level. Each regression includes state and year fixed effects. Standard errors are clustered at the state level and estimates are weighted by the number of births in each state. The top panel reports the estimates regardless of parity. The middle panel reports the estimates for the subset of first births and the bottom panel reports the estimates for the subset of women not giving birth for the first time. Data: NCHS 1989–2019. *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

reduction in the amount of blood pressure medication prescriptions. Because of the aggregate nature of the data and because women who are not enrolled in Medicaid will not appear in this data, it should be interpreted extremely cautiously.

## 4.4 | Exploring heterogeneous effects across state PQCs

Above I present average treatment effects for states that have recently implemented a PQC. However, these average effects may mask important heterogeneity in practice. States with PQCs may choose different guidelines or protocols; for example, roughly half of the states have documented a hypertension initiative during the sample years.[17,18] These initiatives include protocols with checklists and policies for managing severe hypertension. For example, after two elevated blood pressure readings within 15 min, treatment should be initiated within 60 min. They also implement standard responses for early warning signs and educate prenatal and postpartum women on the signs and symptoms of hypertension and eclampsia. In this section, I test whether states with PQCs that have specifically bundled initiatives were more successful in improving maternal and infant health outcomes. I focus on two such initiatives: the Severe Hypertension initiative and EED initiative. In addition, I study PQCs' relationships with MMRCs, another state-level program aimed at preventing maternal deaths. The timings of states establishing MMRCs and EEDs are correlated with PQC timing, as shown in Table B8.

To understand the effect of PQCs' Severe Hypertension initiative, I estimate Equation (1), where treatment is PQC establishment timing for the states that also have a Hypertension initiative at some point during the study period. The control group remains those states that do not yet or never have a PQC.[19] Table B9 shows that the subgroup of states that have a Hypertension initiative at some point during the study period have slightly higher magnitude estimates than the entire group of treated states. The subgroup estimates confirm ex-ante expectations of higher magnitudes for the group of states that specifically focus on hypertension initiatives.

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**TABLE 9** Effect of PQC on infant health for Non-Hispanic White mothers, by parity.

| | (1) Birth weight | (2) Pr(LBW) | (3) Pr(VLBW) | (4) Premature | (5) Early cesarean |
|---|---|---|---|---|---|
| All births | | | | | |
| PQC in effect | 0.422709 | −0.000323 | 0.000748** | 0.001186 | −0.000618 |
| | (2.5656) | (0.0009) | (0.0003) | (0.0016) | (0.0023) |
| Mean | 3392.3380 | 0.0580 | 0.0090 | 0.1070 | 0.1140 |
| Observations | 43,984 | 43,984 | 43,984 | 43,984 | 43,984 |
| First births | | | | | |
| PQC in effect | 1.032685 | −0.000528 | 0.000062 | −0.000893 | −0.002578** |
| | (1.7980) | (0.0004) | (0.0001) | (0.0009) | (0.0011) |
| Mean | 3307.2500 | 0.0640 | 0.0110 | 0.0940 | 0.0960 |
| Observations | 5498 | 5498 | 5498 | 5498 | 5498 |
| Non-first births | | | | | |
| PQC in effect | 0.335569 | −0.000293 | 0.000846** | 0.001483 | −0.000338 |
| | (2.7679) | (0.0010) | (0.0003) | (0.0017) | (0.0026) |
| Mean | 3404.4930 | 0.0570 | 0.0080 | 0.1080 | 0.1170 |
| Observations | 38,486 | 38,486 | 38,486 | 38,486 | 38,486 |

*Note*: Each Column represents a different WLS regression with an infant dependent variable for Equation (1) for Non-Hispanic White mothers. Data is collapsed to the state by year by live birth order level. Each regression includes state and year fixed effects. Standard errors are clustered at the state level and estimates are weighted by the number of births in each state. The top panel reports the estimates regardless of parity. The middle panel reports the estimates for the subset of first births and the bottom panel reports the estimates for the subset of women not giving birth for the first time. Data: NCHS 1989–2019.
$^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Another PQC initiative many states adopt is one to reduce EED, commonly called Healthy Babies are Worth the Weight. Buckles and Guldi (2017) exploit state variation in EED policies and show that the reduction in EEDs can explain one-third of the overall increase in birth weights from 2010 to 2013. Table B1 shows that there is a decrease in early cesareans and premature births when controlling for EED deliveries. However, the effect of PQCs on infant birth weight outcomes remains the same as the main specification.

Unlike the Hypertension and EED initiatives, MMRCs are not an initiative of PQCs but a separate organization. For this reason, I spend more time on the analysis related to MMRCs. To understand the extent to which MMRCs interact with PQCs, I estimate the effect of PQCs separately for states that, in addition to a PQC, have an MMRC at some point during the pre or post-period within a stack.[20] The control group also consists of states with MMRCs in the same period but no PQC. Tables B10 and B11 show that the effect of PQCs on maternal and infant health is driven by the subset of states that ever have an MMRC. Figure B1 shows event studies that provide visual evidence of the heterogeneity between MMRC and non-MMRC states.[21] This suggests that MMRCs may influence PQCs through initiative setting. MMRCs influencing PQCs is possible, especially if MMRCs reports on how to improve maternal health produced after they review all maternal deaths within a state are used by PQCs when initiative selecting.

In addition to initiative setting, the effect could also result from heterogeneous treatment effects, where the states are systematically different in some way that the MMRC signals. I explore the difference in observable characteristics between MMRC subgroups. Table B14 reports descriptive statistics by the MMRC groups. It shows that states with an MMRC have a higher percentage of Black women giving birth, higher average maternal education, higher average employment, and higher average family income. These statistically significant differences establish that states that have MMRCs are different in an observable way. Possibly, these states are more productive at addressing maternal health concerns with the PQC than states that do not have an MMRC as well. From this evidence, MMRCs may interact with PQCs, signal some heterogeneity between states, or both of these mechanisms work in tandem such that states with an MMRC and a PQC are experiencing improvements in maternal health.

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**TABLE 10** Effect of PQC on infant health for Hispanic mothers, by parity.

| | (1) Birth weight | (2) Pr(LBW) | (3) Pr(VLBW) | (4) Premature | (5) Early cesarean |
|---|---|---|---|---|---|
| All births | | | | | |
| PQC in effect | −0.673036 | −0.001504 | −0.000364 | 0.000788 | 0.000959 |
| | (3.3848) | (0.0013) | (0.0007) | (0.0020) | (0.0036) |
| Mean | 3329.9470 | 0.0620 | 0.0100 | 0.1310 | 0.1130 |
| Observations | 43,327 | 43,341 | 43,341 | 43,341 | 43,341 |
| First births | | | | | |
| PQC in effect | 0.634560 | −0.000602 | −0.000120 | −0.001831 | −0.002165 |
| | (2.8349) | (0.0010) | (0.0005) | (0.0017) | (0.0017) |
| Mean | 3238.1560 | 0.0710 | 0.0130 | 0.1080 | 0.0940 |
| Observations | 5498 | 5498 | 5498 | 5498 | 5498 |
| Non-first births | | | | | |
| PQC in effect | −0.909822 | −0.001633 | −0.000398 | 0.001166 | 0.001408 |
| | (3.6210) | (0.0014) | (0.0007) | (0.0022) | (0.0041) |
| Mean | 3343.2880 | 0.0610 | 0.0100 | 0.1340 | 0.1160 |
| Observations | 37,829 | 37,843 | 37,843 | 37,843 | 37,843 |

*Note*: Each Column represents a different WLS regression with an infant dependent variable for Equation (1) for Hispanic mothers. Data is collapsed to the state by year by live birth order level. Each regression includes state and year fixed effects. Standard errors are clustered at the state level and estimates are weighted by the number of births in each state. The top panel reports the estimates regardless of parity. The middle panel reports the estimates for the subset of first births and the bottom panel reports the estimates for the subset of women not giving birth for the first time. Data: NCHS 1989–2019.

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

## 4.5 | Robustness

A threat to the identifying assumption would be baseline if observable characteristics varied with treatment timing. Table B15 presents the results for Equation (2) with baseline state covariates. Using a left-hand side balancing test proposed in (Pei et al., 2019) I find that the individual and joint left hand side balancing tests have large *p*-values resulting in a failure to reject of the null hypothesis that the covariates are individually or jointly balanced. In other words, we fail to reject the hypothesis that the variables are uncorrelated, strengthening the confidence in the assumption that baseline covariates are not cofounders. Additionally, Table B8 shows the estimates from Equation (2) where covariates are time varying state characteristics of Medicaid expansion, MMRC establishment and EED initiatives. Unsurprisingly MMRCs and Early Elective Delivery Policies are correlated with PQC establishment. As described in Section 4.4, I control for these policies in robustness tests shown in Appendix B. I also control for time varying state level covariates which are shown in Tables B5–B7. The magnitude and sign of the results remain consistent with the inclusion of time varying controls.[22] Lastly, to provide additional evidence of the identification assumption, Table B16 shows that baseline state maternal health outcomes are not correlated with the timing of PQC establishing in states.

When collecting the PQC timing data, I directly collected data from program websites and program directors. In the case of six states, treatment dates provided by PQC program directors were slightly different from those on their websites (see Appendix B for additional details). In the main specification, I used dates collected from the website; however, because of these slight inconsistencies, I estimate the preferred specification with the alternative treatment years provided by directors in Tables B17–B19. In this case, the sign and magnitude of maternal and infant health outcomes are robust to alternative years.

In Appendix C, I also show results using five alternative estimators for difference-in-differences with staggered treatment timing. Figure C1 shows estimates for eclampsia and hypertension for non-Hispanic Black mothers not giving birth for the first time using the five alternative estimators in Panel (a) and the stacking estimator in Panel (b). Overall, the reduction in eclampsia is robust to other estimators. Across all estimators, the magnitude of reduction in eclampsia hovers around 0.2 percentage points, which is similar to the effect size found in the main specification.

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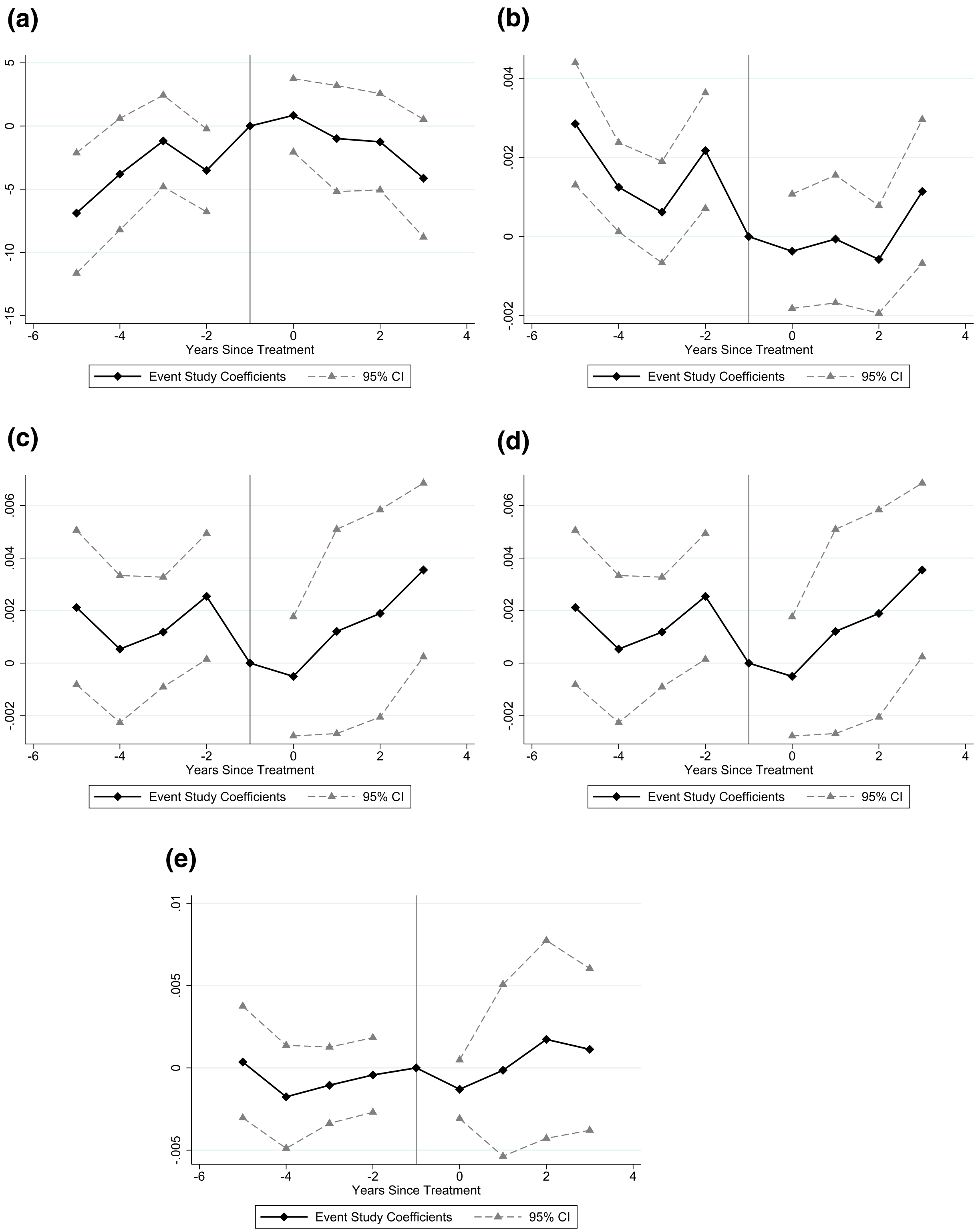


**FIGURE 6** Infant event studies for all mothers. (a) Birth weight. (b) Low birth weight. (c) Very low birth weight. (d) Premature ≤36 weeks gestation. (e) Early Cesarean ≤38 weeks gestation. Each figure displays the coefficients and their respective 95% confidence intervals from WLS regressions, as specified in Equation (3), where outcomes are birth weight, low birth weight, very low birth weight, premature, and early cesarean. The vertical line represents year prior to treatment. Estimates are based on restricted NCHS birth files from 1989 to 2019. Standard errors are clustered at the state level and estimates are weighted by the number of births in each state.

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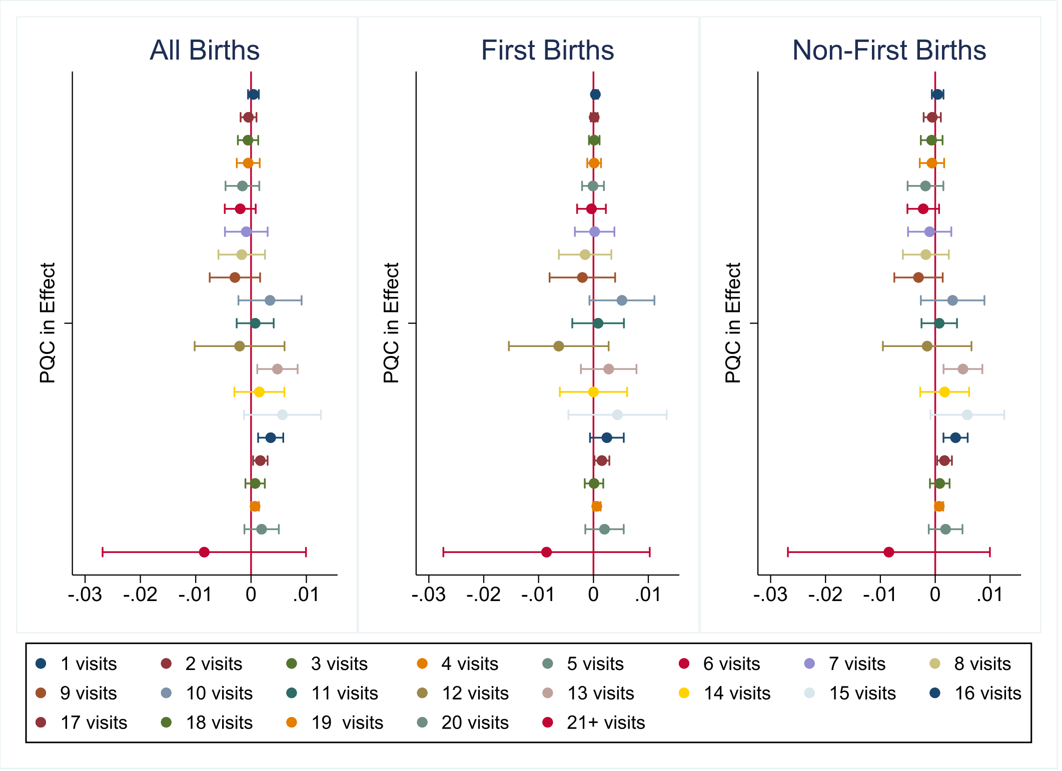


**FIGURE 7** Effect of PQC on number of prenatal visits. This figure shows point estimates and their 95% confidence intervals for different WLS regressions from Equation (1) where dependent variable is the total number of prenatal visits. Treatment is the timing of state PQC establishment. The first panel reports estimates for all births, the second reports estimates for first births, and the third reports estimates for non-first births. Each regression includes state and year fixed effects. Standard errors are clustered at the state level and estimates are weighted by the number of births in each state. Data is collapsed to the state by year level. Data: NCHS 1989–2019.

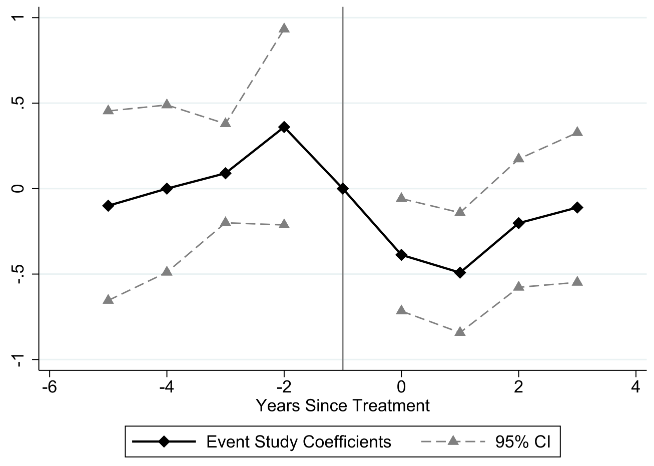


**FIGURE 8** 3 blood pressure drugs. This figure displays the coefficients and their respective 95% confidence intervals from WLS regressions, as specified in Equation (3), and include state and year fixed effects for infant outcomes. The vertical line represents the year prior to treatment. Estimates are based are from Center for Medicare and Medicaid (CMS) State Drug Utilization files with state geographic information for the US from 1991 to 2019 (CMS, 2022). Standard errors are clustered at the state level. The outcome is the log of aggregate units prescribed of three blood pressure medications Labetalol, Nifedipine, and Hydralazine.

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Unlike eclampsia, the results of the effect of PQCs on hypertension appear less robust. Figure C1 shows that for other estimators, the effects on hypertension hover around zero.

Figure C2 presents the five alternative estimators compared to the stacked estimator for non-first birth maternal morbidity measures. The estimated effects on ICU admissions remain consistent across estimators, however, the effect on unplanned hysterectomies is less robust to other estimators. From these results, I conclude that the decrease in hypertension and unplanned hysterectomies found from the stacking result is only suggestive evidence that PQCs reduce these negative maternal health outcomes.

## 5 | CONCLUSION

In this paper, I show that PQCs have significant positive maternal health effects for Black mothers and show suggestive evidence of a positive impact on infant health. When a state implements a PQC, hospitals choose to enact new prenatal care guidelines and change the quality of prenatal care, and maternal health improves. PQCs lead to a 0.19 percentage point, 61% decrease in eclampsia for Non-Hispanic Black mothers non-first births. The reduction is driven by states that also have an MMRC at some point during the analysis period. I also show that PQCs reduce ICU admissions during delivery by 46% for all non-first mothers. The improvement in maternal health corresponds with an improvement in infant health through the reduction of the likelihood an infant is born low birth weight.

Eclampsia leads to severe maternal morbidity and mortality. Hypertensive disorders, which include eclampsia, caused 6.6% of pregnancy-related deaths in the US from 2014 to 2017 (CDC, 2020). The estimates indicate that the adoption of a state PQC can lead to a reduction of racial disparity in maternal health.

While the costs of PQCs vary by state, the CDC currently funds 13 PQCs where the grant floor is $100000, and the ceiling is $350000 a year. Assuming $400000 per year is the average across states, PQCs cost roughly $5 per birth in 2019. The reduction in eclampsia and probability of low birth weight corresponds to direct hospital savings and long-run health benefits. Stevens et al. (2017) estimate that pre-eclampsia increases spending by about $6500 for each birth. However, we know that the rates of eclampsia, which is an escalation of pre-eclampsia, are low, affecting around 0.3% of all births from 1989 to 2019. Assuming around 4 million births in a given year, this corresponds to 12,000 cases of eclampsia, which would cost around 78 million. Assuming PQCs reduce the rate of eclampsia by 31%, this would lead to 3720 fewer cases or a savings of 24 million. Compared to the overall cost of PQCs for all 51 states, around 18 million, therefore PQCs are a relatively inexpensive way to improve maternal and infant well-being and reduce healthcare costs.

The data that support the main findings of this study are available from the National Center for Health Statistics. Restrictions apply to the availability of these data, which were used under a Data Use Agreement for this study.

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### DATA AVAILABILITY STATEMENT

The data that support the main findings of this study are available from the National Center for Health Statistics. Restrictions apply to the availability of these data, which were used under a Data Use Agreement for this study. The publicly available data that support the findings of this study are openly available at openICPSR at https://doi.org/10.3886/E198427V3.

### ENDNOTES

[1] Perinatal refers to care before and after birth, while prenatal care relates to care before birth.

[2] Eclampsia is marked by systolic blood pressure >160 mm Hg or diastolic >110 mm Hg with a marked increase in the level of protein in the urine and associated with seizures, comas, and overactive or over-responsive reflexes.

[3] Appendix B describes the method of collecting information about site participation. Because the information comes from email correspondence with a limited number of program directors, unfortunately, it does not contain the full set of information on the number of participating sites per state. I have information on the 2021 percentage of participating sites for 11 states. For these 11 states, participation rates range from 35% to 100% with only one state having below 50% participation.

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[4] Gestational hypertension, which is the specific outcome used in this study, is defined as systolic blood pressure >140 mm Hg or diastolic >90 mm Hg with no increase in the level of protein in the urine on at least two occasions 4 – 6 h apart after 20 weeks gestation. Hypertension can lead to eclampsia, pre-eclampsia, severe maternal morbidity and mortality, and Hemolysis Elevated Liver enzymes and Low Platelet count (HELLP) syndrome. Eclampsia is marked by systolic blood pressure >160 mm Hg or diastolic >110 mm Hg with a marked increase in the level of protein in the urine. Eclampsia is associated with seizures, comas, and overactive or over-responsive reflexes. Low birth weight is defined as when birth weight is less than 2500 g. Very low birth weight is defined as when birth weight is less than 1500 g. Premature birth is before 37 weeks gestation, and an early cesarean is a cesarean delivery before 39 weeks gestation. Note that it is not necessarily the case that all women coded as having eclampsia also have hypertension. In 2006, roughly 2000 women had both, but around 10,000 had eclampsia. In this paper, a mother who is denoted having eclampsia can either have eclampsia only or have both hypertension and eclampsia.

[5] Pre-eclampsia is not reported in NCHS birth records.

[6] These initiatives are discussed further in Section 4.4

[7] When estimating effects of maternal mortality using a subset of data from 2003 to 2017, I find no evidence of a statistically significant effect on mortality rates.

[8] The main analysis uses dates from program websites and directors' emails if the website did not contain the information. Six state program directors gave slightly different years of establishment than were listed on the respective websites, usually 1 year before or after. In these cases, the main specification uses the dates collected from the websites, but dates collected from email correspondence with program directors are used in robustness checks. See Appendix B for further details and results.

[9] See Appendix C for a discussion on why stacking was chosen as the main specification as well as description and results for alternative estimators.

[10] In this context, never treated states are classified as states that did not establish a PQC by 2019.

[11] The main specification does not include covariates, but in alternative specifications, I include time-varying state-level economic and demographic covariates and controls for Maternal Mortality Review Committees and Early Elective Deliveries. These results are shown in the Appendix, Tables B1–B7 (Flood et al., 2021).

[12] Data on state Medicaid expansion is from the Kaiser Family Foundation (KFF, 2021). Data

[13] The number of observations in each specification corresponds to the number of treatment and control groups across all stacks for a given subgroup of mothers. The number of treated groups is the number of stacks, 24, multiplied by the number of years in the pre- and post-period, which is nine for all stacks.

[14] I restrict the comparison group to never treated states and states treated at least 3 years after the current treated state to allow for more states in the comparison group.

[15] Table 9 shows small positive estimated effects on very low birth weight for White non-Hispanic mothers. However, because these estimates become insignificant when time varying state covariates are included in Tables B4 and B7, I hesitate to interpret this as causal evidence of an increase in very low birth weight infants. Table 10 shows no significant effects on infant health for Hispanic mothers.

[16] I also estimate the effect of PQCs on cigarette usage and maternal weight gain to see if pregnant women are changing their behaviors. I find no evidence of an effect on cigarette use ($\beta = 0.99$pp) or weight gain ($\beta = 0.79$pp).

[17] Many utilize aspects of the AIM Severe Hypertension Bundle which is shown in Appendix A. Not all states with a hypertension bundle use the AIM Severe Hypertension Bundle. Still, it provides a helpful reference for the content of a hypertension initiative.

[18] Other common initiatives include those related to neonatal abstinence syndrome and obstetric hemorrhage. However, due to the lack of consistent data for all states on these initiatives, I do not use them for heterogeneity analysis.

[19] See Appendix B for details describing the collection of Hypertension Initiative data. I do not have data on the exact timing of the implementation of the Hypertension initiative; therefore, I cannot exploit it as a treatment.

[20] These states could have gotten an MMRC in the pre-period, post-period, or before the pre-period. There are 23 states in this group.

[21] To test whether MMRCs alone are driving the observed effects, I estimate difference-in-difference specifications based on the timing of MMRC establishment. Tables B12 and B13 report estimates for when the treatment is defined by the year a state established its MMRC. It appears that the MMRC is not alone in driving the decrease in eclampsia and hypertension. Additionally, Tables B2 and B3 report estimates of the effect of PQCs where MMRCs are included as controls. While the magnitudes of the estimates are smaller, they remain negative. This estimation shows that after controlling for MMRCs, PQCs are still affecting maternal outcomes.

[22] Table B7 shows that the results for eclampsia are not longer significant when time varying state covariates are included. However, as Sant'Anna and Zhao (2020) discuss, strong additional assumptions are needed when including time varying covariates.

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