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The downstream effects of state tobacco control policies on maternal smoking during pregnancy and birth outcomes

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ABSTRACT

Background: Research has demonstrated that the implementation of tobacco control policies is associated with improved birth outcomes. Ascertainment of prenatal smoking on the US birth certificate has changed over the past decade to record smoking across each trimester.

Methods: Using 2005–2015 birth certificate data on 26,436,541 singletons from 47 states and DC linked to state-level cigarette taxes and smoke-free legislation, we conducted conditional mixed-process models to examine the impact of tobacco control policies on prenatal smoking and quitting, then on the associated changes in birth outcomes. We included interactions between race/ethnicity, education, and taxes and present average marginal effects.

Results: Among white and black mothers with less than a high school degree, 36.0% and 14.1%, respectively, smoked during the first trimester and their babies had the poorest birth outcomes. However, they were the most responsive to cigarette taxes. Every $1.00 increase in taxes was associated with a 3.45 percentage point decrease in prenatal smoking among white mothers and a 1.20 percentage point decrease among black mothers. These reductions translated to increases in birth weight by 4.19 g for babies born to white mothers and 0.89 g for babies born to black mothers. Among smokers, there was some evidence that taxes increased quitting and improved birth outcomes, although most associations were not statistically significant. We found limited effects of smoke-free legislation on smoking, quitting or birth outcomes.

Conclusions: Cigarette taxes continue to have important downstream effects on reducing prenatal smoking and improving birth outcomes among the most vulnerable mothers and infants.

1. Introduction

Despite the known short- and long-term health consequences of in utero exposure to tobacco smoke (Leonardi-Bee et al., 2011; US Department of Health and Human Services, 2006, 2010, 2014), 7–14% of women report smoking during pregnancy. Prenatal smoking estimates depend on the data source, with those based on state birth certificate data having lower estimates (e.g., Curtin and Matthews, 2016; Drake et al., 2018) versus those based on surveys having higher estimates (e.g., Kurti et al., 2017). Disparities continue to persist with a higher prevalence among women who are American Indian/Alaskan Native or white, younger, have less than a high school degree, or on Medicaid (Curtin and Matthews, 2016). Estimates of prenatal exposure to secondhand smoke are likely to be higher, as over 20% of nonsmoking adults have serum cotinine levels indicative of secondhand exposure, with a higher prevalence among those below the poverty level or with lower levels of education (Homa et al., 2015). In utero exposure via both mechanisms has been associated with poor birth outcomes, including a decrease in birth weight and increased risk for low birth weight and being born small-for-gestational age (Leonardi-Bee et al., 2008; US Department of Health and Human Services, 2006, 2010, 2014).

A growing body of research has shown that the implementation of smoke-free legislation (Been et al., 2014; Faber et al., 2017) and cigarette taxes (Faber et al., 2017) are associated with improved birth outcomes. Policies may directly affect levels of in utero exposure by reducing women's prenatal use of tobacco products or indirectly by reducing environmental tobacco smoke. In our previous work using

Abbreviations: cmp, conditional mixed-process; CI, confidence interval; LGA, large-for-gestational age; NCHS, National Center for Health Statistics; OR, odds ratio; SGA, small-for-gestational age

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data from the 1989 revision of the US birth certificate from 2000 to 2010, we found that white and black women without a high school degree had the highest prevalence of prenatal smoking but were the most responsive to cigarette taxes (Hawkins and Baum, 2014). Every $1.00 cigarette tax increase reduced prenatal smoking by nearly 2 percentage points (Hawkins and Baum, 2014) and birth weight increased by 5.4 g for infants born to white mothers and 4.0 g for infants born to black mothers (Hawkins et al., 2014). In contrast, we found no effects of smoke-free legislation on prenatal smoking or birth outcomes.

Over this time period there has been a transition in the adoption of the 2003 revision of the birth certificate across US states, which ascertains prenatal smoking differently and the Centers for Disease Control and Prevention report that results are not directly comparable to the 1989 revision (Centers for Disease Control and Prevention, 2015). Implementation of the revised birth certificate was a gradual process and only 12 states used the latest version in 2005. Previously, the maternal worksheet asked women to report how many cigarettes they smoked on an average day, ranging from 'none' to more than 30. Currently, mothers are asked to report the number of cigarettes or packs of cigarettes smoked daily during each trimester of pregnancy, with '0' indicating no smoking (Curtin and Matthews, 2016). Previously, cigarette tax increases have been shown to increase quitting smoking from pre-pregnancy to the third trimester of pregnancy using a state-representative survey postpartum (Adams et al., 2012). Successful quitting across pregnancy can now be assessed using the 2003 revision of the birth certificate by comparing cigarette use between the first and third trimesters.

The revised question on tobacco use provides a unique opportunity to assess the impact of tobacco control policies on a more sensitive measure of cigarette use during pregnancy, quitting smoking across pregnancy, and their subsequent effect on birth outcomes. Using data from the 2003 revision of the birth certificate, we sought to determine whether groups we previously identified as responsive to tax increases, i.e. low-educated white and black women, continue to be amenable to policy changes. Our aims were to examine the impact of state cigarette taxes and smoke-free legislation on prenatal smoking and quitting and, separately, birth outcomes across maternal racial/ethnic and educational groups.

2. Methods

2.1. Data sources

We acquired the microdata natality files for 2005 through 2015 from the National Center for Health Statistics (NCHS), which includes information on all births registered in the 50 US states and Washington, DC (National Center for Health Statistics, 2015). The 2003 revision of the birth certificate expanded from 12 states in 2005 to 47 states and DC in 2015 (Table 1). Connecticut, New Jersey, and Rhode Island were, thus, not included; however, despite using the 2003 revision Hawaii did not enquire about tobacco use until 2015. Four states (CA, FL, GA, MI) also did not consistently collect data on cigarette use in the early years of implementation and were excluded for those years only.

2.1.1. Birth certificate variables

On the maternal worksheet of the 2003 revision of the birth certificate, women self-reported the number of cigarettes or packs of cigarettes smoked daily at each trimester of pregnancy (Curtin and Matthews, 2016). We dichotomized maternal smoking in each trimester as smoking any cigarettes or packs of cigarettes versus not (yes/no). Among women who reported smoking during the first trimester, we defined quitting smoking as smoking 0 cigarettes in the third trimester (yes/no).

On the maternal worksheet, women reported their race and, separately, Hispanic origin (White, Black, Hispanic, Other), highest level of education (0–11, 12, 13–15, ≥16 years), age (≤19, 20–24, 25–29, 30–34, or ≥35 years), nativity status (US born, foreign born), and marital status at the time of delivery (married, not married). The facility worksheet records the mothers' parity (1, 2, 3+), month of prenatal care initiation (first, second, third trimester, none, unknown), gestational age based on the obstetric estimate of gestation (30–44 weeks), birth weight (grams), and infant sex (male, female). We used imputed values generated by NCHS provided in the datasets when data on maternal race, age, marital status, gestational age, and sex were missing (Centers for Disease Control and Prevention, 2015). Missing values for nativity and parity were coded to be retained in analyses.

From the facility worksheet, our dependent variables were birth weight (grams) and the following dichotomous outcomes: low birth weight (< 2500 g), preterm birth (< 37weeks), small-for-gestational age (SGA; < 10^{th} percentile for gestational age and sex) (Oken et al., 2003), and large-for-gestational age (LGA; > 90^{th} percentile for gestational age and sex) (Oken et al., 2003).

2.1.2. Tobacco control policies

We obtained state tobacco control policies for each month-year over the study period. The cigarette tax per pack of 20 cigarettes for each state was obtained from the Tax Burden on Tobacco (Orzechowski and Walker, 2017) and translated into real dollars using the national consumer price index (1982–1984 = 100) (US Bureau of Labor Statistics, 2015). For each birth, we determined the cigarette tax (coded in dollars) 9 months prior to the month of delivery, which was used to approximate the month of conception (Ringel and Evans, 2001). We obtained effective dates of 100% smoke-free legislation for workplaces and restaurants in each state from the American Nonsmokers' Rights Foundation (American Nonsmokers' Rights Foundation, 2018). Since 26 states with smoke-free workplaces also had smoke-free restaurants (32 states), we used smoke-free restaurant legislation as a proxy for state smoke-free policies. For each birth, we determined whether there was smoke-free restaurant legislation (yes/no) 9 months prior to the month of delivery (Ringel and Evans, 2001).

2.2. Analytic sample

Over the study period, there were 26,723,428 singletons born at 30 to 44 weeks of gestation to women aged 16 to 49 years from 47 states and DC with information on smoking from the revised birth certificate and birth weights consistent with gestational age (Alexander et al., 1996). We further excluded births to women with missing information on education (286,887 births [1.1%]). The final analytic sample included 26,436,541 births.

The Boston College Institutional Review Board reviewed this study and considered it exempt.

2.3. Statistical methods

We first described the study population and risk factors for smoking during the first trimester and quitting across pregnancy. The logistic regression models examining smoking and, separately, quitting included maternal socio-demographic characteristics (maternal race/ethnicity, education, nativity, age, marital status, parity, prenatal care), state- and year-fixed effects, and clustering by state.

We next conducted a series of difference-in-differences models, a causal inference technique (Dimick and Ryan, 2014), to evaluate the impact of tobacco control policies on birth outcomes. We estimated a two-stage conditional mixed-process (cmp) model (Roodman, 2011), which first examined the impact of tobacco control policies on women's smoking during the first trimester of pregnancy, then on the associated change in birth outcomes conditional on the probability of smoking. In the first equation, we estimated a probit difference-in-differences regression model to examine the effects of state cigarette taxes and smoke-free restaurant legislation on the probability of prenatal smoking, with an interaction between race/ethnicity, education, and

Table 1
Characteristics of states and tobacco control policies, 2005–2015 (N = 26 436 541).

State	N	Years	% Smoked during first trimester	% Quit smoking across pregnancy[a]	12/2015 Cigarette Tax ($)	2005-2015 Tax change (%)	100% Smoke-free restaurants
Alabama	109635	14-15	10.2	16.2	0.67	27.8	
Alaska	30481	13-15	11.9	22.1	2.00	0.6	
Arizona	161647	14-15	5.1	26.0	2.00	36.4	5/1/2007[b]
Arkansas	70945	14-15	14.0	20.4	1.15	56.9	
California	4203391	07-15	2.1	34.1	0.87	−19.5	1/1/1998
Colorado	562217	07-15	7.5	18.3	0.84	−19.5	7/1/2006
District of Columbia	55210	09-15	2.9	43.0	2.91	134.2	1/1/2007[b]
Delaware	104948	06-15	11.0	23.1	1.60	134.2	11/27/2002[b]
Florida	1008972	11-15	6.3	15.4	1.34	217.9	7/1/2003[b]
Georgia	552728	11-15	6.1	12.2	0.37	−19.5	
Hawaii	13942	15	7.1	13.9	3.20	84.0	
Idaho	239078	05-15	10.7	25.3	0.57	−19.5	7/1/2004
Illinois	878452	10-15	6.9	15.1	1.98	62.6	1/1/2008[b]
Indiana	716458	07-15	16.2	16.5	0.99	44.3	7/1/2012[b]
Iowa	329763	07-15	15.1	21.7	1.36	204.1	7/1/2008[b]
Kansas	409557	05-15	14.0	15.8	1.29	31.4	7/1/2010[b]
Kentucky	572777	05-15	22.2	11.2	0.60	1509.8	
Louisiana	292490	11-15	7.8	14.7	0.86	92.3	1/1/2007[b]
Maine	28885	13-15	15.4	12.5	2.00	61.0	1/1/2004[b]
Maryland	401843	10-15	6.8	28.9	2.00	61.0	2/1/2008[b]
Massachusetts	314670	11-15	6.2	26.5	3.51	87.1	7/5/2004[b]
Michigan	219424	14-15	12.4	23.0	2.00	−19.5	5/1/2010[b]
Minnesota	303774	11-15	10.0	20.1	3.42	474.5	10/1/2007[b]
Mississippi	106952	13-15	10.5	13.3	0.68	204.1	
Missouri	417560	10-15	16.5	22.1	0.17	−19.5	
Montana	91296	08-15	15.6	17.6	1.70	−19.5	10/1/2005[b]
Nebraska	270762	05-15	12.6	25.6	0.64	−19.5	6/1/2009[b]
Nevada	213693	09-15	5.2	22.7	1.80	81.1	12/8/2006[b]
New Hampshire	124685	05-15	14.4	21.2	1.78	175.5	9/17/2007
New Mexico	203455	08-15	6.6	29.2	1.66	46.8	6/15/2007
New York	1790941	08-15	5.8	22.5	4.35	133.4	7/24/2003[b]
North Carolina	573153	10-15	9.6	22.8	0.45	624.4	1/2/2010
North Dakota	89793	06-15	15.6	27.4	0.44	−19.5	12/6/2012[b]
Ohio	1303148	06-15	17.0	19.6	1.60	134.2	12/7/2006[b]
Oklahoma	329880	09-15	13.7	17.5	1.03	−19.5	
Oregon	344353	08-15	10.2	21.4	1.31	−10.6	1/1/2009[b]
Pennsylvania	1423430	05-15	14.6	22.1	1.60	−4.6	
South Carolina	587907	05-15	11.5	21.9	0.57	555.4	
South Dakota	112022	06-15	15.8	31.0	1.53	132.4	11/10/2010[b]
Tennessee	834388	05-15	16.4	19.5	0.62	149.5	
Texas	4070539	05-15	4.6	23.6	1.41	176.8	
Utah	333724	09-15	3.8	24.6	1.70	96.9	1/1/1995[b]
Vermont	59793	05-15	17.1	16.7	3.08	108.3	9/1/2005[b]
Virginia	269207	12-15	7.4	22.5	0.30	20.7	
Washington	887441	05-15	8.8	19.0	3.02	70.9	12/8/2005[b]
West Virginia	36208	14-15	24.1	14.7	0.55	−19.5	
Wisconsin	312623	11-15	12.7	24.2	2.52	163.4	7/5/2010[b]
Wyoming	68301	06-15	17.1	25.2	0.60	−19.5	

[a] Also had legislation for smoke-free workplaces.
[b] Among women who reported smoking during the first trimester (N = 2 285 529).

taxes. Models were adjusted for nativity, parity, marital status, prenatal care, and an interaction between maternal race/ethnicity with age, state, and year (Hawkins and Baum, 2014).

In the second equation, using birth weight as an example, we estimated a linear regression model to assess the impact of a $1.00 cigarette tax increases on the predicted change in birth weight conditional on smoking during the first trimester. For the dichotomous birth outcomes (low birth weight, preterm birth, SGA, LGA), in the second equation, we estimated a probit regression model to examine the predicted change in each outcome conditional on the probability of prenatal smoking. Models were adjusted for smoke-free restaurant legislation, infant sex, maternal education, nativity, marital status, parity, prenatal care, state and an interaction between maternal race/ethnicity with age and year (Hawkins et al., 2014). Birth outcomes were also adjusted for gestational age except for preterm birth. We estimated the probability of smoking during pregnancy, then computed the impact on each birth outcome using a chain-rule prediction (Hawkins et al., 2014).

We repeated this series of analyses among women who reported smoking during the first trimester using the same specifications. In the first equation, we estimated a regression model to examine the effects of state cigarette taxes and smoke-free restaurant legislation on the probability of quitting by the third trimester of pregnancy. In the second equation, we then examined the predicted change in each birth outcome conditional on the probability of quitting smoking.

We present average marginal effects to describe the predicted change in the probability of smoking, quitting or each birth outcome in response to the enactment of smoke-free legislation and a $1.00 cigarette tax increase. We conducted two sensitivity analyses to test the robustness of our results. First, we repeated smoking analyses among the 11 states with data from 2005 through 2015 (FL was also an early adopter but did not consistently record cigarette use until 2011). Second, we repeated original models with smoking during the third trimester (yes/no) indicating that these women smoked throughout

Table 2
Characteristics of study population and maternal risk factors for smoking in the first trimester of pregnancy (N = 26 436 541) and quitting smoking across pregnancy (among smokers in the first trimester) (N = 2 285 529).

	N (%)	% Smoked during first trimester	Adjusted OR[a] (95% CI)	% Quit smoking across pregnancy[b]	Adjusted OR[a] (95% CI)
Race/ethnicity					
White	14 175 231 (53.6)	12.9	1.00	19.1	1.00
Black	3 429 245 (13.0)	7.4	0.25 (0.22, 0.28)	23.9	1.73 (1.62, 1.84)
Hispanic	6 867 402 (26.0)	1.9	0.15 (0.11, 0.21)	33.2	2.25 (2.01, 2.52)
Other	1 964 663 (7.4)	3.5	0.51 (0.43, 0.61)	26.5	1.51 (1.34, 1.69)
Education (years)					
0-11	4 824 416 (18.3)	13.2	1.00	14.6	1.00
12	6 734 979 (25.5)	13.6	0.64 (0.59, 0.68)	19.6	1.50 (1.48, 1.53)
13-15	7 513 875 (28.4)	8.8	0.36 (0.33, 0.39)	26.0	2.82 (2.21, 2.36)
16+	7 363 271 (27.9)	1.0	0.05 (0.04, 0.06)	37.5	3.70 (3.50, 3.92)
Nativity					
US born	20 084 554 (76.0)	11.1	1.00	20.4	1.00
Foreign born	6 212 451 (23.5)	0.8	0.15 (0.13, 0.17)	32.6	1.40 (1.33, 1.47)
Unknown	139 536 (0.5)	8.2	0.61 (0.36, 1.02)	22.6	1.13 (0.90, 1.42)
Age (years)					
< 19	2 133 985 (8.1)	11.6	1.00	25.5	1.00
20-24	6 298 629 (23.8)	13.4	1.73 (1.67, 1.80)	21.5	0.79 (0.77, 0.81)
25-29	7 607 232 (28.8)	8.8	1.86 (1.77, 1.95)	19.4	0.70 (0.68, 0.73)
30-34	6 571 967 (24.9)	5.4	1.71 (1.60, 1.81)	19.0	0.65 (0.62, 0.68)
35+	3 824 728 (14.5)	4.4	1.56 (1.45, 1.69)	17.8	0.58 (0.56, 0.61)
Marital status					
Married	15 931 425 (60.3)	4.5	1.00	21.1	1.00
Not married	10 505 116 (39.7)	14.9	3.17 (2.80, 3.60)	20.4	0.85 (0.82, 0.87)
Parity					
1	10 479 051 (39.6)	7.5	1.00	29.0	1.00
2	8 357 890 (31.6)	8.2	1.28 (1.15, 1.31)	18.8	0.58 (0.57, 0.59)
3+	7 470 479 (28.3)	10.7	1.64 (1.60, 1.68)	14.0	0.43 (0.42, 0.44)
Unknown	129 121 (0.5)	7.6	0.96 (0.77, 1.20)	19.5	0.67 (0.58, 0.76)
Prenatal care initiation					
First trimester	18 920 894 (71.6)	7.4	1.00	21.8	1.00
Second Trimester	5 045 503 (19.1)	11.8	1.27 (1.21, 1.34)	19.9	0.96 (0.93, 0.99)
Third trimester	1 210 611 (4.6)	13.2	1.45 (1.33, 1.58)	17.8	0.87 (0.83, 0.92)
None	396 806 (1.5)	15.6	1.86 (1.64, 2.12)	10.3	0.48 (0.43, 0.54)
Unknown	862 727 (3.3)	8.5	1.07 (0.98, 1.16)	19.3	0.92 (0.83, 1.01)

[a] Confidence interval based on cluster robust standard errors; state- and year-fixed effects not shown.
[b] Among women who reported smoking during the first trimester.

pregnancy (Blatt et al., 2015). We conducted analyses using Stata statistical software version 15.1 (StataCorp, College Station, Texas) with cluster-robust standard errors and clustering at the state level.

3. Results

3.1. Summary statistics

Tobacco control policies varied widely across US states (Table 1). Over the study period, cigarette tax increases, in real terms, ranged from -19.5% in the 12 states that did not increase their taxes to 1509.8% in KY. from 2005 to 2015, 24 states enacted comprehensive smoke-free restaurant legislation.

Overall, 8.6% of mothers smoked during the first trimester, on average, varying from 2.9% in DC to 24.1% in WV (Table 1). Among the 11 states with data from 2005 to 2015, the prevalence of prenatal smoking declined from 11.5% to 7.9%. Mothers who were white, US born, younger, not married, had less than a high school degree, more children, and started prenatal care later had a higher prevalence of prenatal smoking than their respective counterparts (Table 2). In the adjusted model with state- and year-fixed effects, associations remained and exhibited similar gradients to those seen in the unadjusted prevalence estimates.

3.2. Model results for prenatal smoking and birth outcomes

Among white and black mothers with less than a high school degree, 36.0% and 14.1%, respectively, reported smoking early in pregnancy (Table 3). These women were also the most responsive to cigarette taxes. Every $1.00 increase in cigarette taxes was associated with a 3.45 percentage point decrease (95% CI -6.03, -0.87; p = 0.009) in prenatal smoking among white mothers and a 1.20 percentage point decrease (-2.45, 0.05; p = 0.06) among black mothers. Overall, the associations with prenatal smoking were largely null among women from other racial/ethnic and educational groups. We found no evidence for an association between the enactment of smoke-free legislation and prenatal smoking.

Babies born to low-educated white and black women also had the poorest birth outcomes, including lower birth weights and a higher prevalence of being born low birth weight, preterm, and SGA than their respective counterparts (Table 4). In contrast, these babies had a lower prevalence of being born LGA than babies born to higher-educated mothers.

Reductions in prenatal smoking in response to cigarette tax increases translated to improved birth outcomes (Table 4). Among white mothers with 0–11 years of education, every $1.00 increase in cigarette taxes increased their infants' birth weight by 4.19 g (1.40, 6.99; p = 0.003) and decreased the likelihood of having a baby born low birth weight by -0.05 percentage points (-0.09, -0.01; p = 0.01), preterm by -0.04 percentage points (-0.07, -0.01; p = 0.02), or SGA by -0.18 percentage points (-0.32, -0.05; p = 0.008). In contrast, cigarette taxes increased the likelihood of having a baby born LGA by 0.07 percentage points (0.02, 0.13; p = 0.01).

Similar patterns were evident among black mothers with 0–11 years of education, albeit with attenuated effect sizes and 95% confidence intervals include zero (Table 4). Every $1.00 increase in cigarette taxes

Table 3
Impact of cigarette tax increases and the enactment of smoke-free legislation on the probability of smoking in the first trimester (N = 26 436 541) and quitting smoking across pregnancy (across smokers in the first trimester) (N = 2 285 529) by maternal race/ethnicity and education.

	% Smoked during first trimester	Predicted change in prenatal smoking in first trimester, percent[a]	% Quit smoking across pregnancy[b]	Predicted change in quitting smoking across pregnancy, percent[a,b]
All births	8.6%		20.7%	
Smoke-free legislation (yes/no)		0.20 (-0.03, 0.43)		−0.18 (-1.47, 1.12)
$1.00 tax increase by maternal race/ethnicity and education				
White				
0-11 years	36.0	−3.45 (-6.03, -0.87)	12.3	1.14 (-0.12, 2.39)
12 years	23.7	−1.18 (-2.82, 0.46)	18.1	1.27 (0.05, 2.50)
13-15 years	12.3	0.01 (-0.38, 0.39)	24.4	0.70 (-0.92, 2.32)
16+ years	1.2	0.03 (-0.07, 0.13)	36.4	2.55 (-0.49, 5.59)
Black				
0-11 years	14.1	−1.20 (-2.45, 0.05)	18.0	1.32 (-0.94, 3.57)
12 years	8.1	−0.00 (-0.65, 0.64)	23.9	0.68 (-1.69, 3.06)
13-15 years	5.7	−0.15 (-0.64, 0.34)	31.0	−0.90 (-3.85, 2.05)
16+ years	0.9	−0.06 (-0.15, 0.02)	39.2	2.21 (-2.66, 7.07)
Hispanic				
0-11 years	1.9	0.13 (-0.05, 0.31)	27.9	−0.70 (-3.41, 2.02)
12 years	2.2	0.03 (-0.14, 0.19)	33.9	−0.72 (-3.66, 2.22)
13-15 years	2.1	−0.12 (-0.30, 0.05)	39.7	1.97 (-1.39, 5.34)
16+ years	0.4	−0.02 (-0.05, 0.01)	47.6	4.18 (-3.60, 11.95)
Other				
0-11 years	9.9	−0.21 (-1.60, 1.19)	20.1	1.95 (-1.59, 5.49)
12 years	7.2	0.64 (-0.00, 1.28)	24.8	1.15 (-3.18, 5.47)
13-15 years	4.4	0.37 (-0.10, 0.83)	32.6	4.21 (0.69, 7.72)
16+ years	0.3	0.03 (-0.04, 0.11)	50.0	0.37 (-5.82, 6.57)

[a] First equation of the conditional mixed-process model included an interaction between maternal race/ethnicity, education, and taxes; interactions between race/ethnicity with age, state, and year; and adjustment for smoke-free restaurant legislation, maternal nativity, marital status, parity, prenatal care.
[b] Among women who reported smoking during the first trimester.

increased their infants' birth weight by 0.89 g (-0.22, 2.00; p = 0.1) and decreased the likelihood of having a baby born low birth weight by -0.03 percentage points (-0.07, 0.00; p = 0.06), preterm by -0.02 percentage points (-0.03, 0.00; p = 0.1), or SGA by -0.07 percentage points (-0.15, 0.01; p = 0.07). In contrast, cigarette taxes increased the likelihood of having a baby born LGA by 0.01 percentage points (-0.00, 0.03; p = 0.1). Overall, the associations between cigarette taxes with birth outcomes were largely null among women from other racial/ethnic and educational groups. We found no evidence for associations between the enactment of smoke-free legislation and all birth outcomes except preterm birth, such that smoke-free legislation was associated with a 5.60 percentage point increase in preterm birth (3.70, 7.50; p < 0.01)

3.3. Model results for quitting smoking and birth outcomes

Among women that reported smoking during the first trimester, 20.7% quit by the third trimester, ranging from 11.2% in KY to 43.0% in DC (Table 1). Mothers who were Black, Hispanic, and other race/ethnicity, foreign born, younger, married, had a high school degree or higher, fewer children, and started prenatal care earlier had a higher prevalence of quitting smoking than their respective counterparts (Table 2). In the adjusted model with state- and year-fixed effects, associations remained and were consistent with those seen with the unadjusted prevalence estimates.

Among women who smoked during the first trimester, there was some evidence that cigarette taxes increased quitting across trimesters and reduced adverse birth outcomes, although most of the associations were not statistically significant. Among white women with 0–11, 12 and 16+ years of education, every $1.00 increase in cigarette taxes was associated with a 1.14–2.55 percentage point increase in quitting smoking at the p ≤ 0.1 level (Table 3). While there was some evidence for an increase in quitting smoking among low-educated black women, 95% confidence intervals include zero. Overall, there were trends in improved birth outcomes in response to cigarette tax increases although none of the associations reached statistical significance (Table 5).

3.4. Sensitivity analyses

In the first sensitivity analysis, we examined these findings among the 11 states with data from 2005–2015. Although the coefficients for the associations between cigarette taxes and smoke-free legislation with maternal smoking during the first trimester and birth outcomes were of similar magnitude and direction with our findings across all states, most of the associations were not statistically significant beyond p ≤ 0.1 (Supplemental Table 1). In the second sensitivity analysis, we repeated the original models with smoking during the third trimester. Overall, 7.1% of mothers smoked during the third trimester. We found consistent associations between cigarette taxes and smoke-free legislation with maternal smoking during the third trimester and birth outcomes (Supplemental Table 2).

4. Discussion

Over the past decade tobacco control policies across the US have continued to strengthen and states have altered their ascertainment of prenatal smoking. The 2003 revision of the birth certificate includes a more sensitive measure of smoking in each trimester, which has allowed us to examine smoking in the first and third trimesters as well as quitting smoking across pregnancy. We found that low-educated white and black women are the most responsive to cigarette taxes and, consistently, smoke-free legislation has no effect on prenatal smoking. Among white and black women with less than a high school degree, every $1.00 cigarette tax increase reduced smoking in the first trimester by 3.45 and 1.20 percentage points, respectively, which are relative reductions of, on average, 9.6% and 8.5%. These reductions in smoking translated to increases in birth weight by 4.19 g for babies born to white women and 0.89 g for babies born to black women. We also found these effects were consistent for women who smoked throughout pregnancy. Furthermore, there was some evidence that cigarette taxes increased quitting across trimesters and reduced adverse birth outcomes, although most of the associations were not statistically significant. This may be due to a much smaller sample of smokers across states and

Table 4
Change in probability of each birth outcome (conditional on the probability of smoking in the first trimester) in response to a $1.00 cigarette tax increase and the enactment of smoke-free legislation by maternal race/ethnicity and education (N = 26 436 541).

	Birth weight		Low birth weight		Preterm birth		Small-for-gestational age		Large-for-gestational age	
	Mean (g)	Predicted change, percent[a,b] (95% CI)	% of infants	Predicted change, percent[a,b] (95% CI)	% of infants	Predicted change, percent[a] (95% CI)	% of infants	Predicted change, percent[a,b] (95% CI)	% of infants	Predicted change, percent[a,b] (95% CI)
All births	3323		5.4		8.9		11.7		9.1	
Smoke-free legislation (yes/no)		3.16 (-1.46, 7.78)		−0.52 (-1.75, 0.71)		5.80 (3.68, 7.91)		−0.41 (-1.49, 0.67)		1.13 (-0.28, 2.54)
$1.00 tax increase by maternal race/ethnicity and education										
White										
0-11 years	3249	4.19 (1.40, 6.99)	7.5	−0.05 (-0.09, -0.01)	10.6	−0.04 (-0.07, -0.01)	15.3	−0.18 (-0.32, -0.05)	7.6	0.07 (0.02, 0.13)
12 years	3323	1.29 (-0.21, 2.79)	5.7	−0.01 (-0.04, 0.01)	9.0	−0.01 (-0.03, 0.01)	12.1	−0.05 (-0.13, 0.02)	9.3	0.03 (-0.01, 0.06)
13-15 years	3385	0.05 (-0.31, 0.42)	4.5	0.00 (-0.00, 0.00)	8.0	0.00 (-0.00, 0.00)	9.4	0.00 (-0.01, 0.01)	10.9	0.00 (-0.01, 0.01)
16+ years	3440	−0.16 (-0.31, -0.01)	3.3	0.00 (-0.00, 0.00)	6.2	0.00 (-0.00, 0.00)	7.5	0.00 (-0.00, 0.01)	11.8	−0.00 (-0.00, 0.00)
Black										
0-11 years	3090	0.89 (-0.22, 2.00)	11.3	−0.03 (-0.07, 0.00)	15.0	−0.02 (-0.03, 0.00)	21.3	−0.07 (-0.15, 0.01)	4.5	0.01 (-0.00, 0.03)
12 years	3134	−0.12 (-0.67, 0.43)	10.0	−0.00 (-0.01, 0.01)	13.2	0.00 (-0.01, 0.01)	19.2	0.00 (-0.04, 0.04)	5.2	−0.00 (-0.01, 0.01)
13-15 years	3179	0.12 (-0.29, 0.52)	8.9	−0.00 (-0.01, 0.01)	11.9	−0.00 (-0.01, 0.00)	17.0	−0.01 (-0.03, 0.02)	6.1	0.00 (-0.01, 0.01)
16+ years	3253	0.04 (-0.05, 0.14)	7.1	−0.00 (-0.00, 0.00)	9.9	−0.00 (-0.00, 0.00)	13.9	−0.00 (-0.01, 0.00)	7.5	0.00 (-0.00, 0.00)
Hispanic										
0-11 years	3308	−0.18 (-0.34, -0.03)	5.2	0.00 (-0.00, 0.00)	10.3	0.00 (-0.00, 0.00)	11.6	0.01 (-0.00, 0.01)	8.7	−0.00 (-0.01, 0.00)
12 years	3305	−0.06 (-0.18, 0.06)	5.2	0.00 (-0.00, 0.00)	9.3	0.00 (-0.00, 0.00)	11.7	0.00 (-0.01, 0.01)	8.3	−0.00 (-0.00, 0.00)
13-15 years	3318	0.09 (-0.03, 0.21)	5.1	−0.00 (-0.00, 0.00)	8.8	−0.00 (-0.00, 0.00)	11.1	−0.00 (-0.01, 0.00)	8.6	0.00 (-0.00, 0.01)
16+ years	3350	−0.00 (-0.03, 0.03)	4.3	−0.00 (-0.00, 0.00)	7.6	−0.00 (-0.00, -0.00)	9.9	−0.00 (-0.00, 0.00)	9.0	0.00 (0.00, 0.00)
Other										
0-11 years	3239	0.55 (-0.83, 1.93)	6.6	−0.00 (-0.03, 0.02)	11.4	−0.00 (-0.02, 0.01)	14.8	−0.03 (-0.11, 0.06)	7.0	0.00 (-0.02, 0.03)
12 years	3259	−0.78 (-1.46, -0.10)	6.1	0.01 (-0.00, 0.02)	9.7	0.01 (-0.00, 0.01)	14.1	0.03 (-0.00, 0.07)	7.5	−0.01 (-0.02, 0.00)
13-15 years	3265	−0.52 (-1.03, -0.01)	5.9	0.01 (-0.00, 0.01)	9.0	0.00 (-0.00, 0.01)	13.9	0.02 (-0.00, 0.04)	7.5	−0.01 (-0.02, 0.00)
16+ years	3234	−0.08 (-0.16, -0.00)	5.6	0.00 (-0.00, 0.00)	6.8	0.00 (-0.00, 0.00)	15.3	0.00 (-0.00, 0.01)	5.2	−0.00 (-0.00, 0.00)

[a] Second equation of the conditional mixed-process model included the probability of smoking from the first equation and adjustment for smoke-free restaurant legislation to infant sex, maternal education, nativity, marital status, parity, prenatal care, state; interactions between maternal race/ethnicity with age and year.
[b] Also adjusted for gestational age.

Table 5
Change in probability of each birth outcome (conditional on the probability of quitting smoking across pregnancy) in response to a $1.00 cigarette tax increase and the enactment of smoke-free legislation by maternal race/ethnicity and education (N = 2 285 529 smokers in the first trimester).

	Birth weight		Low birth weight		Preterm birth		Small-for-gestational age		Large-for-gestational age	
	Mean (g)	Predicted change, percent[a,b] (95% CI)	% of infants	Predicted change, percent[a,b] (95% CI)	% of infants	Predicted change, percent[a] (95% CI)	% of infants	Predicted change, percent[a,b] (95% CI)	% of infants	Predicted change, percent[a,b] (95% CI)
All births	3151		9.9		11.8		19.8		5.4	
Smoke-free legislation (yes/no)		2.30 (-4.96, 9.55)		−0.55 (-3.40, 2.30)		5.47 (2.36, 8.58)		−0.10 (-2.61, 2.40)		0.78 (-2.70, 4.27)
$1.00 tax increase by maternal race/ethnicity and education										
White										
0-11 years	3114	1.43 (-0.63, 3.49)	10.8	0.35 (-0.08, 0.78)	12.5	0.00 (-0.01, 0.02)	21.6	−0.08 (-0.18, 0.02)	4.5	0.02 (-0.01, 0.05)
12 years	3169	1.51 (-0.46, 3.47)	9.1	0.42 (-0.04, 0.88)	10.9	0.00 (-0.01, 0.02)	19.1	−0.08 (-0.16, 0.01)	5.5	0.02 (-0.01, 0.06)
13-15 years	3207	0.56 (-1.51, 2.63)	8.3	0.24 (-0.32, 0.80)	10.5	0.00 (-0.01, 0.01)	17.2	−0.03 (-0.13, 0.06)	6.4	0.02 (-0.02, 0.05)
16+ years	3267	2.95 (-1.74, 7.63)	7.2	0.91 (-0.28, 2.09)	9.5	0.01 (-0.02, 0.04)	14.6	−0.13 (-0.31, 0.05)	7.9	0.06 (-0.03, 0.16)
Black										
0-11 years	2962	1.57 (-1.51, 4.66)	16.7	0.31 (-0.25, 0.87)	17.6	0.01 (-0.02, 0.03)	28.3	−0.10 (-0.29, 0.09)	2.9	0.01 (-0.01, 0.04)
12 years	3000	0.89 (-2.22, 4.00)	15.1	0.18 (-0.44, 0.79)	15.9	0.00 (-0.01, 0.02)	26.5	−0.05 (-0.23, 0.14)	3.4	0.01 (-0.02, 0.04)
13-15 years	3035	−0.97 (-5.05, 3.11)	14.1	−0.25 (-1.06, 0.57)	14.8	−0.00 (-0.02, 0.02)	24.9	0.07 (-0.16, 0.29)	3.9	−0.02 (-0.06, 0.03)
16+ years	3097	2.97 (-3.78, 9.72)	12.6	0.64 (-0.81, 2.08)	14.2	0.01 (-0.03, 0.05)	21.2	−0.14 (-0.49, 0.21)	5.1	0.04 (-0.05, 0.13)
Hispanic										
0-11 years	3126	−1.57 (-4.98, 1.85)	10.9	−0.21 (-1.06, 0.63)	13.6	−0.00 (-0.01, 0.01)	20.5	0.06 (-0.11, 0.24)	5.2	−0.01 (-0.06, 0.04)
12 years	3173	−1.37 (-5.18, 2.44)	9.2	−0.23 (-1.20, 0.73)	11.7	−0.00 (-0.02, 0.01)	18.7	0.06 (-0.12, 0.25)	5.8	−0.02 (-0.08, 0.04)
13-15 years	3197	3.05 (-2.38, 8.48)	8.7	0.66 (-0.52, 1.85)	11.5	0.01 (-0.02, 0.03)	17.4	−0.11 (-0.32, 0.09)	6.5	0.04 (-0.04, 0.13)
16+ years	3261	5.06 (-5.72, 15.83)	7.2	1.43 (-1.34, 4.19)	10.6	0.01 (-0.04, 0.07)	14.5	−0.21 (-0.65, 0.23)	7.4	0.11 (-0.12, 0.33)
Other										
0-11 years	3169	2.36 (-2.16, 6.88)	9.9	0.62 (-0.56, 1.80)	14.9	0.01 (-0.03, 0.04)	18.2	−0.11 (-0.35, 0.12)	6.8	0.05 (-0.05, 0.14)
12 years	3223	1.95 (-4.18, 8.08)	8.7	0.39 (-1.10, 1.88)	12.4	0.00 (-0.02, 0.02)	16.3	−0.07 (-0.33, 0.20)	7.7	0.03 (-0.09, 0.16)
13-15 years	3244	4.75 (-1.63, 11.13)	8.4	1.47 (0.01, 2.93)	12.2	0.01 (-0.05, 0.07)	15.6	−0.21 (-0.45, 0.03)	9.0	0.12 (-0.04, 0.27)
16+ years	3245	0.07 (-7.67, 7.82)	7.1	0.14 (-2.16, 2.43)	9.4	0.00 (-0.02, 0.02)	14.3	−0.00 (-0.31, 0.31)	6.9	0.01 (-0.20, 0.22)

[a] Second equation of the conditional mixed-process model included the probability of smoking from the first equation and adjustment for smoke-free restaurant legislation to infant sex, maternal education, nativity, marital status, parity, prenatal care, state; interactions between maternal race/ethnicity with age and year.
[b] Also adjusted for gestational age.

years. Taken together, our findings suggest that cigarette taxes continue to have important downstream effects on reducing prenatal smoking and improving birth outcomes among the most vulnerable mothers and infants.

The World Health Organization endorses tobacco taxes as the most effective method for reducing demand for cigarettes and other tobacco products (World Health Organization, 2015). While pregnant women in the US have lower levels of smoking than women of reproductive age (Robbins et al., 2018), pregnancy is an active time of behavior change. Our prior work utilized the 1989 revision of the birth certificate with one measure of smoking across pregnancy and found that cigarette taxes reduced smoking among low-educated white and black women and improved birth outcomes (Hawkins and Baum, 2014; Hawkins et al., 2014). Using the 2003 revision of the birth certificate and more recent data from 2005 to 2015, we have shown that cigarette taxes reduced smoking in the first and third trimesters and may have increased quitting smoking among women with the highest prevalence of prenatal smoking and poorest birth outcomes—low-educated white and black women—compared to their college-educated counterparts. Our findings suggest that continuing to raise cigarette taxes may help address these disparities by improving outcomes among the highest risk and narrowing the gap by educational attainment.

Faber and colleagues identified two studies from the US, including our previous study (Hawkins et al., 2014), which found that higher cigarette taxes improved birth outcomes (Faber et al., 2017). The SimSmoke simulation model has examined the effect of tobacco control policies on prenatal smoking and adverse birth outcomes (Levy et al., 2016). Using corrected prenatal smoking estimates due to the underreporting of smoking (Tong et al., 2013), Levy et al. (2016) found that a $1.00 cigarette tax independently would decrease prenatal smoking by 4.5% and avert 700 low birth weight and 1100 preterm babies by 2025. Our results fall within the scope of these estimates. Consistent with this body of research, we found that conditional on smoking in the first and third trimesters, cigarette taxes increased average birth weight among infants born to low-educated white and black women and decreased their risk for being born low birth weight, preterm, and SGA. Overall effects sizes were small, with a reduction in the likelihood their baby had poor birth outcomes ranging from 0.01 to 0.18 percentage points. By shifting the overall mean distribution of birth weight by over 4 g for babies born to low-educated white mothers and nearly 1 g for babies born to black mothers, higher taxes also slightly increased the risk for LGA infants by 0.01 to 0.07 percentage points. Being born SGA or LGA increases health risks (Lei et al., 2018; Norris et al., 2015) and these trade-offs are important considerations when implementing population-based interventions.

While recent systematic reviews have concluded that the enactment of smoke-free legislation reduced the prevalence of preterm birth (Been et al., 2014; Faber et al., 2017), we found that state-level smoke-free legislation increased preterm birth, which is in contrast to our previous study using earlier data (Hawkins et al., 2014). In many of the prior studies, smoke-free legislation occurred at the country- or local-level, while state was the lowest identifiable geographic area in our US natality data. As of December 2018, in addition to the 38 states and DC with state-wide 100% smoke-free restaurant legislation, there were over 1500 municipalities with 100% smoke-free laws in workplaces, restaurants, or bars (American Nonsmokers' Rights Foundation, 2013). This patchwork of coverage across the US poses a particular challenge to testing the true effects of smoke-free legislation as it is unlikely for an entire state to move from zero coverage to 100% enforcement as local laws often precede state laws or are more comprehensive. Further research is needed to test the independent and joint (with state) effects of local smoke-free policies on prenatal smoking and birth outcomes.

4.1. Limitations

There are a number of limitations to address, particularly as prenatal smoking was self-reported. Tong and colleagues found that the prevalence of smoking reported on the birth certificate was 41% lower than the prevalence calculated from a survey administered postpartum that recalled prenatal smoking (Tong et al., 2013). These differences extended across all socio-demographic groups, such that both instruments identified social gradients in smoking similar to those reported in Table 2. This suggests that the magnitude of our effects likely underestimate the true impact of cigarette taxes on prenatal smoking and birth outcomes. We were also not able to assess quitting from pre-pregnancy to smoking in the third trimester (Adams et al., 2012) because data on smoking prior to pregnancy were missing from 22% of women in the analytic sample. Despite increases in the use of alternative tobacco products, such as e-cigarettes (Jaber et al., 2018), information on other tobacco products is not collected on the birth certificate. While cigarette taxes only increase the price of cigarettes, it is important to monitor broader patterns of prenatal tobacco use over time, particularly as women may substitute alternative tobacco products due to cost or perceived harm reduction. Women are also likely exposed to sources of secondhand smoke (Homa et al., 2015), including sources from partners, workplaces, and/or public places. However, information on secondhand smoke exposure is not collected on the birth certificate. As the birth certificate and other vital statistics are continually modified, it is necessary to incorporate changes that will improve surveillance.

4.2. Conclusions

In summary, we found that cigarette tax increases decreased smoking in the first and third trimesters of pregnancy and improved birth outcomes among the most vulnerable mothers and infants. For the 47 states and DC included in this analysis, as of December 2018, cigarette taxes ranged from $0.17 in Missouri to $4.50 in DC (Campaign for Tobacco-free Kids, 2013). According to our estimates, if Missouri increased its cigarette tax to that of DC, the birth weight of infants born to Missouri mothers with less than a high school degree would increase, on average, by 18.1 gs for white infants and 3.9 g for black infants. While clinical guidelines recommend prenatal screening for tobacco use and offer smoking cessation interventions throughout pregnancy (Committee on Underserved Women and Committee on Obstetric Practice, 2017), cigarette taxes should continue to serve as a population-level intervention to encourage smoking cessation and improve birth outcomes.

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Contributors

Dr. Hawkins conceptualized and designed the study, participated in data collection, analysis, and interpretation, drafted the initial manuscript. Dr. Baum participated in data analysis and interpretation, reviewed and revised the manuscript. Both authors approved the final manuscript as submitted.

Declaration of Competing Interest

No conflict declared.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.drugalcdep.2019.107634.

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