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Impact of state tobacco control policies on birth defects

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ABSTRACT

While research has demonstrated the effects of tobacco control policies on birth outcomes, there is little known about their impact on birth defects. Using 2005–2015 natality data on 26,334,854 singletons from 47 US states and District of Columbia linked to state-level cigarette taxes and smoke-free restaurant legislation, we examined the impact of tobacco control policies on birth defects by maternal race/ethnicity and education. We found that among white women with less than a high school degree, every $1.00 increase in cigarette taxes reduced prenatal smoking by 3.48 percentage points and reduced the risk of their infant having any birth defect by 0.0023 percentage points. Tax increases also reduced the risk of cyanotic heart defects, cleft palate, gastroschisis, and limb reduction. We found no evidence for associations between the enactment of smoke-free legislation, prenatal smoking and birth defects. Our findings suggest that state cigarette taxes are a population-level intervention that can help reduce prenatal smoking and the risk of birth defects.

1. Introduction

In the US, 3% of infants are born each year with major birth defects (Centers for Disease Control and Prevention, 2008) and birth defects are the leading cause of infant deaths (Matthews et al., 2015). In utero exposure to tobacco smoke is one of the most modifiable determinants of adverse birth outcomes, including select birth defects, and has been attributed to interfering with fetal development through fetal hypoxia, restrictions in essential nutrients, teratogenic properties, and DNA damage (US Department of Health and Human Services, 2014). There is evidence for a causal relationship between maternal smoking in early pregnancy and cleft lip and/or cleft palate, while evidence is suggestive of a relationship between prenatal smoking and limb reduction, gastroschisis, and heart defects (US Department of Health and Human Services, 2014; Hackshaw et al., 2011). Infants born to nonsmoking pregnant women who are exposed to tobacco smoke are also at higher risk for birth defects overall (Leonardi-Bee et al., 2011), and specifically, non-syndromic orofacial clefts (Sabbagh et al., 2015).

While research has demonstrated the direct and indirect effects of cigarette taxes and smoke-free legislation on birth outcomes, including low birth weight and preterm birth (Hawkins et al., 2014; Hawkins and Baum, 2014; Been et al., 2014; Faber et al., 2017), there is little known about their impact on birth defects. We have identified only two studies, in Norway and the Netherlands, that have examined the effects of smoke-free legislation on birth defects and both reported no associations (Peelen et al., 2016; Bharadwaj et al., 2012). Furthermore, neither of the studies tested whether cigarette taxes had an effect on birth defects. Previously, using 2005–2010 data from the 1989 revision of the US birth certificate, we have shown that cigarette taxes improved birth outcomes among white and black women with less than a high school degree (Hawkins et al., 2014); however, whether tobacco control policies differentially affect birth defects remains unknown. Our aim was to examine the impact of cigarette taxes and smoke-free legislation on birth defects by maternal race/ethnicity and education using more recent population-based US natality data from the 2003 revision of the US birth certificate.

2. Materials and methods

2.1. Data source

We obtained the microdata natality files with state identifiers for 2005 through 2015 from the National Center for Health Statistics, which includes information on all births registered in the 50 US states and the District of Columbia (DC) (National Center for Health Statistics, n.d.). The 2003 revision of the US Standard Certificate of Live Birth contains a maternal worksheet, which asks women about daily cigarette use during pregnancy by trimester and data cannot be compared to the

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tobacco use question on the 1989 revision (Centers for Disease Control and Prevention, n.d.). While in 2005, 12 states had implemented the 2003 revision of the birth certificate, its use expanded to 47 states and DC by 2015. Connecticut, New Jersey, and Rhode Island had not implemented the revised birth certificate and were excluded. Although Hawaii used the 2003 revision, tobacco use was not obtained consistently over the study period and was only included for 2015. An additional four states (CA, FL, GA, MI) did not consistently enquire about cigarette use in the early years of implementation and data were excluded for those years only.

We included 26,723,428 singletons born at 30 to 44 weeks of gestation to women ages 16 to 49 years with information on smoking and birth weights consistent with gestational age (Alexander et al., 1996). We further excluded those with missing information on birth defects (97,133 births [0.4%]) and education (286,887 births [1.1%]). We also excluded babies with Down's syndrome (4772 births [0.02%]) or a suspected chromosomal disorder (2958 births [0.01%]) as they are more likely to have birth defects (Rudnicka et al., 2002). The final analytic sample included 26,334,854 births.

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

2.2. Measures

On the maternal worksheet of the birth certificate, women self-reported their race and ethnicity (White, Black, Hispanic, Other), highest level of education (0–11, 12, 13–15, 16+ years), age at delivery (16–49), nativity status (US born, foreign born), and marital status (married, not married). The facility worksheet of the birth certificate records the mothers' parity (1, 2, 3+), month of prenatal care initiation (first, second, third trimester, none, unknown), gestational age (30–44 weeks), and infant sex (male, female).

On the maternal worksheet of the birth certificate, women were asked to report the "average number of cigarettes or packs of cigarettes smoked per day" in each trimester of pregnancy. Mothers were coded as smokers if they reported smoking ≥1 cigarette per day during the first trimester of pregnancy, as most defects develop during this time of organ formation (US Department of Health and Human Services, 2014). We identified infants with a birth defect if the following were indicated on the facility worksheet: cleft lip with or without cleft palate, cleft palate alone, limb reduction defect, cyanotic congenital heart disease (non-cyanotic heart defects are not assessed on the birth certificate), gastroschisis, or any of these birth defects (US Department of Health and Human Services, 2014; Hackshaw et al., 2011).

We linked the monthly state cigarette tax during the estimated month of conception, 9 months prior to birth (Ringel and Evans, 2001), translated into real dollars (1982–1984 = 100) using the national Consumer Price Index (Bureau of Labor Statistics, US Department of Labor, n.d.) and indicated whether a state had enacted 100% smoke-free restaurant legislation (American Nonsmokers' Rights Foundation, n.d.). Since 26 of the 32 states with smoke-free restaurant legislation also had smoke-free workplace legislation, we used smoke-free restaurant legislation as a proxy for state smoke-free policies.

2.3. Statistical analysis

We first described the prevalence of smoking during the first trimester of pregnancy and having an infant with a birth defect. We subsequently conducted a conditional mixed-process (cmp) model (Roodman, 2011) to estimate the impact of tobacco control policies on prenatal smoking, then on the associated change in birth defects conditional on the probability of smoking. In the first equation, we estimated a probit difference-in-differences regression model to estimate the associations of cigarette taxes and smoke-free restaurant legislation with prenatal smoking, with an interaction between race/ethnicity, education, and taxes (Hawkins and Baum, 2014). Models were adjusted for maternal nativity, marital status, parity, prenatal care, and an interaction between maternal race/ethnicity with age, state and year. In the second equation, we estimated a probit model to examine the association of a change in the predicted probability of smoking on each birth defect for a $1.00 cigarette tax increase. These two equations are estimated simultaneously by maximum likelihood. Models were adjusted for smoke-free restaurant legislation, infant sex, gestational age, maternal education, nativity, marital status, parity, prenatal care, state and an interaction between maternal race/ethnicity with age and year (Hawkins et al., 2014). We present average marginal effects to describe the change in the probability of smoking or having a birth defect in response to the enactment of smoke-free restaurant legislation and to a $1.00 tax increase.

We conducted two sensitivity analyses to test the robustness of our findings. First, we repeated analyses among the 11 states with data from 2005 through 2015. Second, we repeated the original analyses with smoking during the third trimester (yes/no) indicating that these women smoked throughout pregnancy (Blatt et al., 2015). We also included state-specific time trends in both equations of the 'any defect' model and found similar results, but models would not converge for individual birth defects (results not shown). We performed analyses using Stata statistical software version 15.1 (StataCorp, College Station, Texas) with cluster-robust standard errors and state-level clustering.

3. Results

Over the study period, 8.6% of women smoked during the first trimester and 0.17% of infants had any of the five birth defects plausibly associated with prenatal smoking. Among all women who reported smoking during the first trimester (N = 2,275,892), 0.28% of their infants had a birth defect compared to 0.16% of non-smoking mothers (N = 24,058,962; $p < 0.001$). Low-educated white women had both the highest prevalence of prenatal smoking and their infants had the highest prevalence of a birth defect (36.0% and 0.28%, respectively) (Table 1).

From 2005 to 2015, cigarettes taxes increased, in real terms, an average of 182% among the 34 states that increased their taxes and − 19.5% in the 12 states that did not increase their taxes (Supplemental Table 1). In addition, 24 states enacted 100% smoke-free restaurant legislation over the study period.

In the first equation of the cmp model (Table 1), we found that for white women with less than a high school degree every $1.00 increase in cigarette taxes reduced smoking by 3.48 percentage points (95% CI −6.11, −0.85; p = 0.01). We found no evidence for an association between the enactment of smoke-free restaurant legislation and prenatal smoking (0.20 (95% CI −0.02, 0.42); p = 0.08).

In the second equation (Table 2), conditional on the probability of smoking, a $1.00 cigarette tax increase reduced the risk of the infants born to white women with less than a high school degree having any birth defect by 0.0023 percentage points (95% CI −0.0042, −0.0003; p = 0.02). Tax increases were also found to reduce the risk of their infants born with cyanotic heart defects (−0.0006 (95% CI −0.0011, −0.0000); p = 0.04), cleft palate (−0.0004 (95% CI −0.0008, −0.0000); p = 0.04), gastroschisis (−0.0004 (95% CI −0.0008, −0.0001); p = 0.02), and limb reduction (−0.0003 (95% CI −0.0006, −0.0001); p = 0.02). We found less evidence for an effect of taxes on cleft lip (−0.0004 (95% CI −0.0010, 0.0001); p = 0.1).

Among Hispanic women with 16+ years of education, every $1.00 cigarette tax increase reduced prenatal smoking by 0.03 percentage points (95% CI −0.06, −0.01; p = 0.01) and, subsequently, reduced the risk of their infants born with any of the birth defects examined although the coefficients were effectively zero (i.e. −0.0000 (95% CI −0.0000, −0.0000); p = 0.05 for cyanotic heart defects). We found no associations among mothers from other racial/ethnic and educational groups. We also found no evidence for an association between the enactment of smoke-free legislation and any of the birth defects (all

Table 1
Impact of cigarette tax increases and the enactment of smoke-free legislation on the probability of smoking in the first trimester by maternal race/ethnicity and education (N = 26,334,854).

	N	% Smoked	Predicted change in prenatal smoking, percent[a] (95% CI)
Smoke-free restaurants (yes/no)			0.20 (−0.02, 0.42)
$1.00 tax increase, by maternal race/ethnicity and education			
White			
0–11 years	1,306,579	36.0	−3.48 (−6.11, −0.85)
12 years	3,177,137	23.7	−1.21 (−2.87, 0.46)
13–15 years	4,406,955	12.3	−0.07 (−0.45, 0.32)
16+ years	5,227,844	1.2	0.01 (−0.09, 0.11)
Black			
0–11 years	637,724	14.1	−1.19 (−2.52, 0.15)
12 years	1,123,448	8.1	0.02 (−0.66, 0.70)
13–15 years	1,158,879	5.7	−0.14 (−0.67, 0.39)
16+ years	488,855	0.9	−0.07 (−0.16, 0.01)
Hispanic			
0–11 years	2,647,408	1.9	0.14 (−0.06, 0.33)
12 years	2,057,546	2.2	0.03 (−0.15, 0.20)
13–15 years	1,496,391	2.1	−0.12 (−0.32, 0.07)
16+ years	650,631	0.4	−0.03 (−0.06, −0.01)
Other race/ethnicity			
0–11 years	212,864	9.9	−0.13 (−1.43, 1.16)
12 years	349,303	7.2	0.58 (−0.05, 1.20)
13–15 years	425,192	4.4	0.33 (−0.16, 0.81)
16+ years	968,098	0.3	0.02 (−0.05, 0.08)

[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.

$p > 0.05$).

In the first sensitivity analysis, we examined these associations among the 11 states with data from 2005 to 2015. Over this time period, the prevalence of prenatal smoking and birth defects declined from 11.5% to 7.9% and 0.19% to 0.16%, respectively. Although the coefficients for the associations between cigarette taxes and smoke-free legislation with maternal smoking during the first trimester and birth defects were largely consistent with our previous findings, none of the associations were statistically significant beyond $p \leq 0.1$ (Supplemental Table 2). 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 tobacco control policies with maternal smoking during the third trimester and birth defects (Supplemental Table 3).

4. Discussion

Although birth defects are rare, there are significant health, social, and economic consequences. Early in utero exposure to tobacco smoke is a modifiable risk factor attributed to select birth defects (US Department of Health and Human Services, 2014; Hackshaw et al., 2011). We found that white women with less than a high school degree were the most responsive to cigarette taxes. Every $1.00 increase in cigarette taxes translated to, on average, a 9.7% relative reduction in prenatal smoking and 0.8% relative reduction in the probability of their infant having a birth defect. We also found no effects of state-level smoke-free restaurant legislation on birth defects, which is consistent with two studies that examined these associations in Norway and the Netherlands (Peelen et al., 2016; Bharadwaj et al., 2012).

Increases in cigarette taxes and the enactment of smoke-free legislation across the US over the past decade (American Nonsmokers' Rights Foundation, n.d.; Campaign for Tobacco-free Kids, n.d.) created a natural experiment for us to link with individual-level natality data on over 26 million mothers from 47 states and DC and test whether policy

Table 2
Change in probability of each birth defect (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 = 26,334,854).

	% Any defect	Predicted change in any birth defect, percent[a]	Predicted change in heart defect, percent[a]	Predicted change in cleft palate, percent[a]	Predicted change in gastroschisis, percent[a]	Predicted change in limb reduction, percent[a]	Predicted change in cleft lip, percent[a]
Smoke-free restaurants (yes/no)		0.7992	1.9651	−1.9400	−1.0485	−0.1606	0.9214
$1.00 tax increase, by maternal race/ethnicity and education							
White							
0–11 years	0.28	−0.0023*	−0.0006*	−0.0004*	−0.0004*	−0.0003*	−0.0004
12 years	0.25	−0.0007	−0.0002	−0.0001	−0.0001	−0.0001	−0.0001
13–15 years	0.21	−0.0000	−0.0000	−0.0000	−0.0000	−0.0000	−0.0000
16+ years	0.15	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Black							
0–11 years	0.15	−0.0004	−0.0001	−0.0001	−0.0001	−0.0001	−0.0001
12 years	0.13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13–15 years	0.11	−0.0000	−0.0000	−0.0000	−0.0000	−0.0000	−0.0000
16+ years	0.09	−0.0000	−0.0000	−0.0000	−0.0000	−0.0000	−0.0000
Hispanic							
0–11 years	0.14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12 years	0.14	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13–15 years	0.13	−0.0000	−0.0000	−0.0000	−0.0000	−0.0000	−0.0000
16+ years	0.10	−0.0000*	−0.0000*	−0.0000*	−0.0000*	−0.0000*	−0.0000
Other race/ethnicity							
0–11 years	0.21	−0.0001	−0.0001	−0.0000	−0.0000	−0.0000	−0.0000
12 years	0.19	0.0002	0.0000	0.0001	0.0000	0.0000	0.0001
13–15 years	0.17	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
16+ years	0.10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

* $p \leq 0.05$.
[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, infant sex, gestational age, maternal education, nativity, marital status, parity, prenatal care, state; interactions between maternal race/ethnicity with age and year.

changes indirectly impacted birth defects by reducing prenatal smoking. As our analyses on birth defects are the largest to date, and our findings are robust to alternative specifications, additional population-based studies in other countries are needed to corroborate our findings. In particular, as cigarette taxes are considered the most effective measure to encourage cessation and prevent initiation of tobacco products (World Health Organization, 2015), further research is needed on the role of tax increases on smoking cessation during pregnancy, reducing the quantity of cigarettes smoked, and sustaining behavior change postpartum. Birth certificate data were only available at the state-level and we were not able to take into account smoke-free policies at the municipality-level (American Nonsmokers' Rights Foundation, n.d.). Although our findings are consistent with previous studies that did not find an effect of smoke-free legislation on birth defects (Peelen et al., 2016; Bharadwaj et al., 2012), further research is needed on the role of local- versus state-level smoke-free polices on birth outcomes.

While the 2003 revision of the birth certificate has been shown to not identify all infants born with birth defects (Salemi et al., 2017), it is the only known population-level, multi-state data source with information on both prenatal smoking and birth outcomes. It is also important to note that some defects, including cardiovascular and gastrointestinal defects, may be ascertained after the time of birth and women may under-report their smoking status on the birth certificate (Tong et al., 2013). We cannot account for terminations that may have occurred as a result of a spontaneous abortion or an ultrasound that identified a fetal defect. Taken together, our results may underestimate the true impact of cigarette tax increases on reducing smoking-related birth defects.

5. Conclusion

We found that state-level cigarette taxes reduced prenatal smoking among women with the highest prevalence and subsequently reduced the risk of their infant having a birth defect. While the effect size is small, a 0.0023 percentage point reduction, in response to a $1.00 cigarette tax increase, translates to approximately 3 fewer babies born with a birth defect to low-educated white mothers each year [in 2015, white women with 0–11 years of education had 145,010 babies and 0.26% were born with a birth defect]. Cigarette taxes are a population-level intervention that can complement individual-level interventions to reduce prenatal smoking (Committee on Underserved Women, Committee on Obstetric Practice, 2017) and the risk of birth defects.

Contributor statement

S.S. Hawkins conceptualized and designed the study, participated in data collection, analysis, and interpretation, drafted the initial manuscript. C.F. Baum participated in data analysis and interpretation, reviewed and revised the manuscript. Both authors approved the final manuscript as submitted. S.S. Hawkins had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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Appendix A. Supplementary data

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