



A national burden assessment of estimated pediatric asthma emergency department visits that may be attributed to elevated ozone levels associated with the presence of smoke

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Abstract Asthma is the most common pediatric disease in the USA. It has been consistently demonstrated that asthma symptoms are exacerbated by exposure to ozone. Ozone (O_3) is a secondary pollutant produced when volatile organic compounds (VOCs) are oxidized in the atmosphere in the presence of nitrogen oxides (NO_x). At ground level, elevated ozone is typically formed as a result of human activities. However, wildfires represent an additional source of ozone precursors. Recent evidence suggests that smoke can increase ozone concentrations. We estimated the number of excess asthma-related emergency department (ED) visits in children with asthma that may be attributed to elevated ozone associated with smoke (EOAS) in the USA. We conducted a quantitative burden assessment (BA) using a Monte Carlo approach to estimate the median number of excess pediatric asthma ED visits that may be attributed to EOAS among children with asthma in the continental USA between 2005 and 2014, as well as 95% confidence bounds (95% CB). We

estimated that a median of 2403 (95% CB 235–5382) pediatric asthma ED visits could be attributed to EOAS exposure between 2005 and 2014 in the continental USA. Furthermore, the impact of EOAS on estimated asthma ED visits was greatest in the eastern half of the continental USA. We found a significant increase in pediatric asthma ED visits that may be attributed to exposure to EOAS. EOAS may have a measurable negative impact on children with asthma in the USA.

Keywords Ozone · Wildfires · Pediatric asthma · Burden assessment · Hazard mapping system

Introduction

Asthma is one of the most common chronic pediatric conditions in the USA, affecting approximately 8% of children under the age of 18 in the USA (Akinbami et al.

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2016). In 2010, seven million children under the age of 18 in the USA had a physician diagnosis of asthma in addition to current asthma symptoms (Akinbami et al. 2012). Asthma prevalence varies by both race and socioeconomic status (SES) (Moorman et al. 2011). Asthma prevalence among black or Hispanic children is nearly twice the prevalence among non-Hispanic white children (Moorman et al. 2011). Asthma prevalence among children living in households under the federal poverty line is around 1.5 times as high as the asthma prevalence of children living in households above the federal poverty line (Moorman et al. 2011). The reasons for these disparities are multifaceted, including differential access to health care, social factors, and environmental exposures (Sacks et al. 2014). With regard to asthma-related morbidity, recent data indicate that there were approximately 571,000 asthma-related emergency department (ED) visits per year in the USA among children age 15 and younger (U.S. Department of Health and Human Services 2016). Approximately 50% of children with asthma will experience at least one asthma attack or exacerbation each year (Centers for Disease Control 2016).

Tropospheric ozone is a well-documented risk factor for asthma exacerbations (Babin et al. 2007; Bell 2004; Bell et al. 2005; Ji et al. 2011; Mar and Koenig 2009; Strickland et al. 2010; Villeneuve et al. 2007). Ozone is considered especially harmful to children because of rapid lung development during childhood, higher respiratory rate per unit body mass compared with adults, and relatively higher exposures than adults due to more time spent outside (Lin et al. 2008; Sacks et al. 2014; Silverman and Ito 2010). Ozone is a secondary pollutant that is generated when volatile organic compounds (VOCs) are oxidized in the presence of nitrogen oxide (NO_x) radicals (Crutzen 1970). VOCs are emitted from a variety of anthropogenic sources including fossil fuel production and combustion, solvent use, and fuel evaporation. The terrestrial biosphere is a major source of VOCs to the atmosphere; in terms of total carbon, this source is significantly larger than anthropogenic emissions on a global scale (Koppman 2007). NO_x is emitted from fossil fuel combustion (Zhang et al. 2003), biomass burning (Akagi et al. 2011), lightning (Kaynak et al. 2008), and soils (Zhang et al. 2003). Elevated ground-level ozone near and downwind of urban regions is primarily a summer phenomenon; the positive relationship between ozone and temperature is driven by multiple factors (Logan 1985).

The relation between ozone and acute medical care for asthma has been well established (Silverman and Ito

2010; U.S. Environmental Protection Agency 2013). Elevated ozone in many regions can be attributed to emissions from anthropogenic sources. However, fires can also be a source of ozone (Jaffe and Wigder 2012). Though the photochemistry within wildfire plumes is an ongoing area of inquiry, Brey and Fischer recently demonstrated that the presence of smoke is associated with enhanced ozone in many urban and rural regions of the USA (Brey and Fischer 2016). To our knowledge, no effort has been made to quantify the impact of ozone enhancements associated with the presence of smoke on the health burden of children with asthma. The objective of this analysis was to conduct a burden assessment to estimate the number of pediatric asthma ED visits that may be attributable to elevated ozone associated with the presence of smoke (EOAS) in the USA from 2005 to 2014.

Methods

Burden assessment

We quantified the number of pediatric ED visits due to EOAS between 2005 and 2014 using the US Environmental Protection Agency (EPA) guidelines for burden assessment (U.S. Environmental Protection Agency 2014). The EPA burden assessment (BA) is an analytic tool used to estimate the health burden for a population that may be due to exposure to an environmental contaminant. This method can be used to quantify the burden on a variety of health outcomes (e.g., heart attacks, hospitalizations, deaths, etc.) that may occur due to environmental exposures (e.g., lead, $\text{PM}_{2.5}$, ozone, etc.) (Hubbell et al. 2009). For our study, we investigated the association of EOAS on asthma-related ED visits for children aged 18 and younger with asthma. Emergency department visits were the focus of this analysis as this outcome is largely considered to be avoidable (National Asthma Education and Prevention Program 2007) and are frequently used as a measure of asthma-related morbidity, specifically for children (Akinbami et al. 2014). Further, ED visits are an important indicator for impacts among vulnerable or sensitive populations; children ages 0–4 with asthma, children with persistent asthma, and children who miss primary care visits are more likely to seek care in an ED (McGovern et al. 2017; Sills et al. 2010; Zahran et al. 2018) With regard to conducting a burden assessment,

the parameters necessary to run the model were all available for the ED visit outcome: data are reported on a national scale that allows for stratification by state, age, sex, and race/ethnicity. The BA uses a formula consisting of four parameters to estimate the number of health events that may be due to an environmental exposure. We adapted the original burden assessment equation used in other studies (Fann et al. 2012) to estimate ED visits over the entire study period (Eq. 1) and ED visits as a proportion of population at risk over the study period (Eq. 2).

Study period estimated Δy

$$\Delta y = \left[\frac{y_0}{365} \times (1 - e^{-\beta \Delta \text{pollutant}}) \times \text{population at risk} \right] \times \text{number of smoky days} \quad (1)$$

Study period estimated Δy per 100,000 children at risk

$$\frac{\Delta y}{100,000 \text{ population at risk}} = \left[\frac{y_0}{365} \times (1 - e^{-\beta \Delta \text{pollutant}}) \times \text{number of smoky days} \right] \times 100,000 \quad (2)$$

The common terms of these equations are as follows: the count of excess ED visits due to EOAS exposure (Δy) is computed from the baseline ED visit rate among children with asthma (y_0), the concentration-response function for ED visits associated with ozone exposure (β) (Hubbell et al. 2009), the change in pollutant concentration ($\Delta \text{pollutant}$), and the population at risk (the number of children with asthma). Here, $\Delta \text{pollutant}$ represents an ozone enhancement associated with the presence of smoke (EOAS). To estimate this parameter, we implemented Brey and Fischer's estimates of the average daily 8-h average ozone mixing ratio (MDA8) ozone increase associated with the presence of smoke for individual monitoring stations across the USA using 10 years of observations (2005–2014) (Brey and Fischer 2016).

To estimate Δy accurately, we modified the formula to fit differing timeframes and units for each of the terms. Our general framework was to (1) estimate Δy on a given smoke-affected day (Eq. 1), (2) multiple Eq. 1 estimate across the observed number of smoke-

affected days in the study period and estimate a Δy per 100,000 children with asthma at risk of an ED visit (Eq. 2), which is analogous to the epidemiologic measure of incidence proportion to compare state-specific estimates. Each equation was applied to each state within the continental USA where data were available. The state estimates were then summed to produce a continental US estimate.

Baseline pediatric asthma ED visit rate

We used Centers for (CDC) Vital and Health Statistic data (Centers for Disease Control 2012) to estimate the ED visit rate among children with asthma (y_0). These data are available as a national average for the USA and are stratified by race, age, and sex at the national level. Our BA is constrained by the timeframe of our ozone exposure estimates (May–September 2005–2014). However, annual data on asthma ED visits for “all children” (aged 0–17) were available only from 2001 to 2009. Therefore, to estimate y_0 for 2005–2014, we used a meta-analysis to pool the annual ED visit rates and the variance around these rates, giving us a weighted aggregate of ED visits rates over this time, as well as a standard error. Furthermore, as ED visit rates were annual, we divided by 365 days in each variation of our equation to estimate daily ED visit rates.

Ozone exposure due to wildfire smoke

To estimate EOAS, Brey and Fischer (2016) used in situ measurements from summer months (May–September) from 2005 to 2014 to determine how mean ozone abundances changed on “smoke-impacted days” compared with “smoke-free days.” A smoke-impacted day is defined as a day where (1) a location with co-located ozone and $\text{PM}_{2.5}$ measurements observed an enhancement in $\text{PM}_{2.5}$ greater than one standard deviation above the station mean and (2) smoke was present in the atmospheric column as determined by an analysis of satellite data (Brey and Fischer 2016). A smoke-free day was defined as days during summer months without smoke present in the atmospheric column (Brey and Fischer 2016). They found that in many regions, mean ozone abundance was higher on smoke-impacted days than smoke-free days even after accounting for the relationship between temperature and ozone (Brey and Fischer 2016). To produce state-specific EOAS for monitors within a state, we performed a fixed-effects

meta-analysis on the mean difference in ozone abundance on smoke-impacted days compared with non-smoke-impacted days from 2005 to 2014. This represents Δ ozone due to the presence of smoke (EOAS), on average, for a given smoke-affected day. EOAS data were missing for Arizona, Nebraska, West Virginia, and Delaware (Supplemental Table 1). These states were excluded from the initial analysis if there were not enough co-located PM_{2.5} and ozone measurement days or if there were not enough smoke-impacted days at these monitoring locations to compare smoke-impacted and smoke-free ozone.

Number of smoke-affected days

To address Brey and Fischer's finding of multiple days of smoke contributing to elevated ozone over the study period (Brey and Fischer 2016), we added a term to the BA formula: the number of smoke-affected days in each state across the study period.

Population at risk

To estimate the number of children with asthma (population at risk) in the USA from 2005 to 2014, we used the Behavioral Risk Factor Surveillance System (BRFSS) database (Centers for Disease Control 2005). BRFSS is an extensive phone survey that collects data for a range of health outcomes. Pediatric asthma prevalence data is available for most states and Washington, DC in every study year for our strata of interest: age, race, and sex.

Asthma prevalence can be defined in two ways: "current" or "lifetime" asthma. Lifetime asthma indicates a person who has ever been told by a nurse or physician that they have asthma; current asthma indicates a person who has a medical diagnosis of asthma and is currently experiencing asthma symptoms (Centers for Disease Control 2005). Both of these definitions are used in the literature (Moorman et al. 2011; Subramanian et al. 2009). For this analysis, we chose to investigate current asthma as it was likely to be the more specific definition of asthma prevalence. Asthma prevalence estimates were not available from BRFSS for Florida, South Carolina, Colorado, or Arkansas (Supplemental Table 1). For these states, we used the 2008–2010 national annual average percentage of current asthma among children (0–17) from the National

Health Interview Survey, estimated to be 9.5% (Centers for Disease Control 2012).

Beta estimate

We used the concentration-response function for ozone-related ED visits from Mar and Koenig (2009) as our β estimate. This study was included in the US Environmental Protection Agency's Integrated Science Assessment (ISA) for Ozone (U.S. Environmental Protection Agency 2013) and the most recent Regulatory Impact Analysis (RIA) for the National Ambient Air Quality Standard for ozone (U.S. Environmental Protection Agency 2015). The RIA includes a BA for proposed ozone standards and relied on a robust set of criteria when identifying appropriate concentration-response functions, including study size, location, and characteristics of the study population. Of the three studies with stratum-specific estimates for pediatric populations (Mar and Koenig 2009; Strickland et al. 2010; Villeneuve et al. 2007), only Mar and Koenig provided an estimate for the entire pediatric population age range (e.g., 0–18) on the same day as ozone exposure, where Strickland et al. estimated the association with ozone exposure as 3-day weighted averages (Strickland et al. 2010), and Villeneuve et al. had age ranges of 2–4, 5–14, and 15–44 (Villeneuve et al. 2007). Mar and Koenig investigated the age-stratified association between asthma ED visits and air pollutants (PM_{2.5} and ozone) between 1998 and 2002 (Mar and Koenig 2009). This study found a relative risk of 1.10 [95% confidence interval (CI) 1.01–1.19] per 10-ppb increase in ozone for ED visits in children under 18 in the Seattle area for the warm season (May–October) (Mar and Koenig 2009), which closely matches the EOAS seasonal timeframe. We natural-log transformed this relative risk estimate to calculate β to be 0.0095. Using the formula, relative risk 95% CI = $\exp(\beta \pm 1.96 \text{ (SE)})$, where we assumed a critical Z value of 1.96 given the study sample size, we back-calculated the standard error to be 0.0040.

Monte Carlo simulation

We implemented a Monte Carlo (MC) simulation for each state using only states 44 out of 48 states and in the continental USA (including Washington, DC) with complete data for all BA estimate terms. Term input values for our MC simulations can be found in

Supplemental Table 1. A MC simulation allowed us to incorporate the uncertainty from each of our BA formula estimate terms in the form of 95% confidence bounds (95% CB), which is analogous to the mean and 95% CI. Using the sources for our BA formula, we assumed that each point estimate represented the population mean and that the standard errors represented the population standard deviation. Under the principles of the central limit theorem, we simulated normal distributions with a sample size of $n = 10,000$ for y_o , population at risk, EOAS, and β terms using the reported means and standard errors. We simulated the distribution of number of smoke-affected days using a Poisson distribution, where the mean number of smoke-affected days was all that was needed to simulate this distribution. We checked the median value of our simulated normal distributions against the original point estimate, and the 2.5% and 97.5% values of our distribution against the reported point estimates and 95% CIs to ensure our simulated distributions reflected the original estimates.

We then randomly sampled with replacement one estimate from each simulated distribution and calculated the estimated Δy based on those sampled term estimates. We iterated this process 10,000 times to produce a normally distributed range of Δy values. We report the median value and 2.5% and 97.5% values as 95% CBs for this simulated distribution of Δy as our primary outcome of interest. A 95% CB that did not overlap with zero was considered statistically meaningful. National estimates of the median and 95% CB of Δy were obtained by summing the lower bound, median, and upper bound of each state that had a Δy estimate. This summation method underestimates Δy due to missing EOAS values for Arizona, West Virginia, Delaware, and Nebraska, but allowed us to capture the heterogeneity of EOAS across states.

Stratified analyses and figure generation

In addition to our main MC simulation, which we refer to as the overall estimate, we investigated sex and race strata. For each analysis, the ED visit rate and population at risk were sex- and race-specific (i.e., ED visit rate among Hispanic children with asthma). The β estimate, asthma ED visit rate, and EOAS terms were held constant across all race and sex strata as there were no available stratum-specific estimates for these parameters. We investigated male and female sex strata and three racial strata: non-Hispanic black, non-Hispanic

white, and Hispanic. The MC input terms for each strata and state can be found in Supplemental Table 1.

Sensitivity analyses

To test the robustness of our analytic choices, we first compared results from the fixed-effects meta-analysis for estimation of baseline ED visit rates for children with asthma (y_o) to a random-effects meta-analysis. As a second sensitivity analysis, we compared the effect of selection of the population at risk on the results. We initially considered the baseline ED visit rate (y_o) and the population at risk to be specifically for children with asthma. However, given that the concentration-response function ostensibly represents a total population estimate, we also estimated y_o for all children under 18 and defined the population at risk as all children in the state. To estimate the asthma ED visit rate among all children (y_o), we used CDC Vital and Health Statistic data (Centers for Disease Control 2012). These data were available as a national average for the USA; stratum-specific asthma ED visits rates were not available. To estimate the number of children aged 0–17 (population at risk) in the USA from 2005 to 2014, we used 2010 Census estimates that provided strata-specific counts of total (marginal), male, female, white, black, and Hispanic children aged 0–17 in each state for the continental USA (U.S. Census Bureau 2010). The 2010 Census count estimates serve as mid-point for the study period and were readily available. We compared results for using the estimates for children with asthma and for all children to estimate sensitivity of the terms selected for the burden assessment.

All data management and analyses were performed using R software (R Development Core Team 2008). Web scraping of CDC asthma prevalence used the rvest package (R Development Core Team 2008). Meta-analysis was performed using the rmeta package (Lumley 2012). MC simulations were performed using base R functions, and maps and figures were created using the ggplot2 package (Wickham 2009). All study-related R code and datasets are available upon request.

Results

A map of our pooled EOAS (Δ ozone) of state-specific monitors are presented in Fig. 1. The median EOAS for the study period was 3.7 ppb [interquartile range (IQR)

1.7–6.7 ppb]. In general, the highest concentrations of EOAS on an average smoke day were observed in the southeastern USA, where Florida monitors had the highest pooled EOAS (Fig. 1). Values for pooled EOAS and standard errors for state-specific monitors used the BA formula can be found in Supplemental Table 1.

The average number of smoke-affected days for monitors within a state are presented in Fig. 2. We observed median number of smoke-affected days of 27.0 (IQR 21.0–34.5) between 2005 and 2014 (Fig. 2).

State-specific estimates

A map of overall and stratum-specific state estimates of median ED visits (Δy) in children with asthma that may be attributed to EOAS for the study period (2005–2014) are shown in Fig. 3. The overall median estimated ED visit for the study period was 29 (IQR 3–63). The female strata median estimated ED visit for the study period was 10 (IQR 1–20). Comparatively, the male strata median estimated ED visit for the study period was 18 (IQR 2–40). The white strata median estimated ED visit for the study period was 15 (IQR 1–17). The black strata median estimated ED visit for the study period was 5 (IQR 1–17), and the Hispanic strata median estimated ED visit for the study period was 3 (IQR 1–5). Similar to the daily ED visits, Texas was observed to have the highest overall ED visits over the study period (Fig. 3); this observation was consistent across all strata (Fig. 3). Median and 95% CBs of ED visits (Δy) in children that may be attributed to EOAS over the study period between 2005 and 2014 for each state in the continental USA by strata are presented in Supplemental Fig. 1.

A map of overall and stratum-specific state estimates of median ED visits per 100,000 children with asthma that may be attributed to EOAS are shown in Fig. 4. The overall median ED visits per 100,000 children for all strata over the study period was 25 (IQR 8–40). The female strata median ED visits per 100,000 children with asthma for the study period was 22 (IQR 7–34), compared with 27 (IQR 9–44) for the male strata. The white median ED visits per 100,000 children with asthma for the study period was 22 (IQR 7–35). Comparatively, the black strata median ED visits per 100,000 children with asthma for the study period was nearly double (median = 36, IQR 11–57). The Hispanic strata median ED visits per 100,000 children with asthma for the study period was also higher compared with whites

(median = 36, IQR 11–57). When considering population at risk, the southeastern USA had a higher overall burden of asthma-related morbidity as measured by pediatric ED visits compared with other regions of the country (Fig. 4).

Continental US estimates of ED visits in children with asthma between 2005 and 2014

Summed state MC estimates for continental USA for each stratum are presented in Table 1. For the overall strata, we estimated that a median of 2403 (95% CB 235–5383) ED visits in children with asthma may be due to exposure to EOAS. Trends by sex and race are also shown in Table 1. Nationally, males had a higher burden of ED visits compared with females (Table 1), and whites had the highest burden of any racial or ethnic strata in absolute counts (Table 1).

Sensitivity analyses

Repeating the analysis with a random-effects meta-analysis to estimate baseline asthma ED visit rate (y_0) results did not differ from the initial fixed-effects model. Our second sensitivity analysis repeated the entire process using 2010 Census estimates of children < 18 as population at risk and baseline asthma ED visit rates for the children < 18 (y_0) rather than limiting these terms to children with asthma. For an overall estimate of asthma ED visits in children due to exposure to EOAS, we estimated a median of 2476 (95% CB 187–5507). These results were similar to our estimates from the population of children with asthma.

Discussion

Ozone exposure continues to be an environmental health problem in the USA. Current estimates indicate that over 168 US counties comprised of over 107 million people are currently in non-attainment with the 8-h ozone standard (U.S. Environmental Protection Agency 2018). Recent studies have indicated that wildfires can also serve as sources of ozone precursors (Jaffe and Wigder 2012). However, research on cardiopulmonary health effects associated with wildfire and other sources of ambient smoke has primarily focused on PM_{2.5} as the primary pollutant (Apte et al. 2015; Kim et al. 2015; Kioumourtoglou et al. 2015). Future climate change is

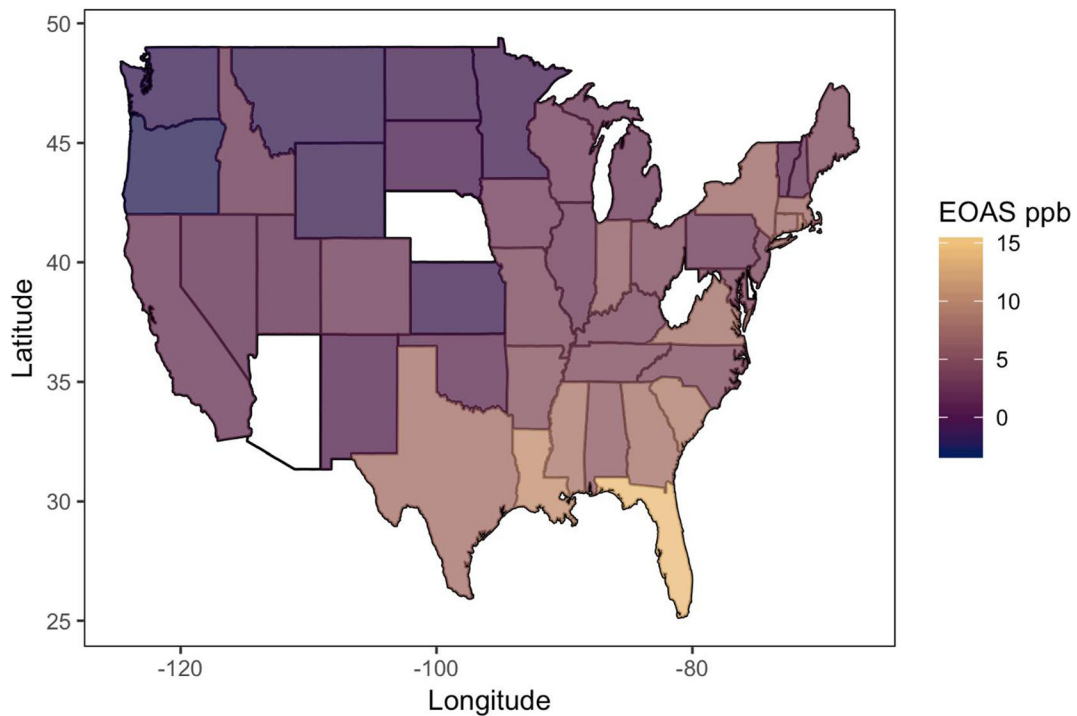


Fig. 1 Pooled estimates of elevated ozone associated with smoke (EOAS) of monitors within a state on an average smoke day. States without EOAS are indicated in white

expected to increase both forest-fire frequency (Abatzoglou and Kolden 2011; Barbero et al. 2015a, b; Dennison et al. 2014; Fried et al. 2004; Marlon et al. 2009; Westerling and Bryant 2008) and severity

(Abatzoglou and Kolden 2011; Barbero et al. 2015a, b; Dennison et al. 2014; Fried et al. 2004; Marlon et al. 2009; Westerling and Bryant 2008), thereby increasing wildfire smoke emissions (Liu et al. 2016). Despite

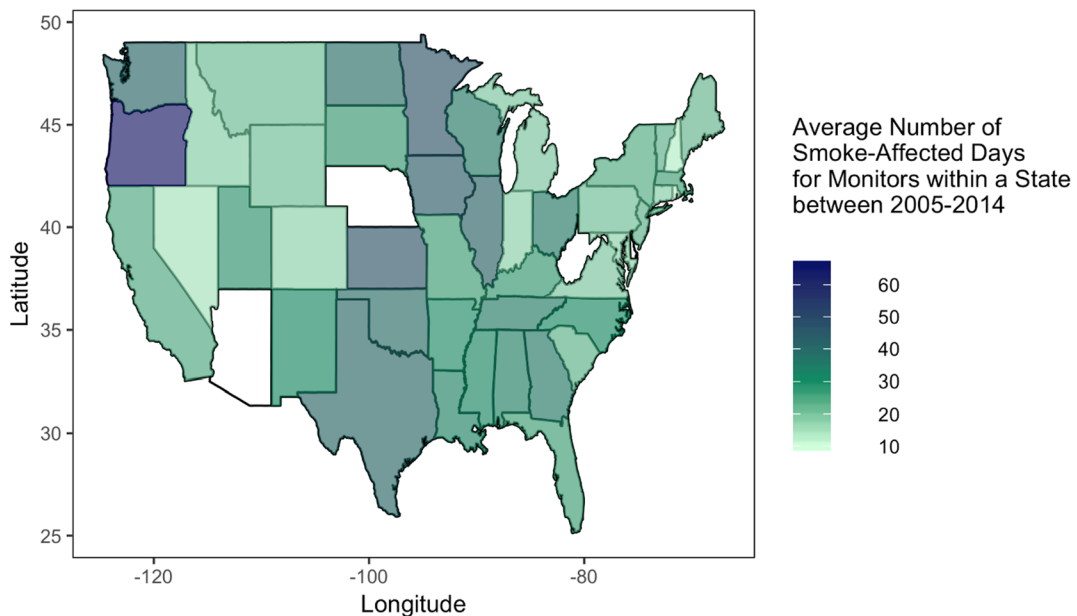


Fig. 2 Average number of smoke-affected days for monitors within a state over the study period of 2005–2014



Fig. 3 Map of state-specific median asthma emergency department visits in children with asthma that may be due to enhanced ozone associated with the presence of smoke (EOAS) over the

study period (2004–2015). States indicated in white could not be estimated due to missing EOAS data. Washington DC data was collapsed with Maryland estimates for visualization purposes

declining anthropogenic emissions of ozone precursors across much of the USA (e.g., Kim et al. 2006), this projected increase in wildfire smoke could increase ozone exposure, which in turn could affect respiratory health in sensitive populations, particularly in children.

To our knowledge, this is the first study that has attempted to quantify source-specific estimates of a novel secondary pollutant, EOAS, and its effect on the burden of childhood asthma. We used the novel estimation of EOAS, which quantified the concentration of ozone that were likely due to wildfire smoke. Our estimate of EOAS represents a measure of a secondary pollutant that was produced from wildfire-related ozone precursors and not traffic or industrial. We estimated statistically meaningful burden of asthma in the continental USA for all overall estimates and all strata evaluated. From 2005 to 2014, we found a statistically meaningful increase in pediatric asthma ED visits associated with EOAS. In addition, we found that although most large smoke-producing fires occur in Western USA (Westerling 2006), the health impacts associated

with ozone enhancements due to these fires could have a greater impact in populations further downwind from the largest fires, in the southeastern USA. This increased health burden in the southeastern USA is likely due to a combination of factors such as population density, asthma prevalence, concentrations of EOAS, and changes in ED visit rates based on strata, which can all impact our estimates. Little variation in this geographic trend was seen in sex or race strata. Recent data from the National Ambulatory Medical Care Survey estimated that children under 15 accounted for over 23 million asthma-related ED visits per year (National Center for Health Statistics 2016). While our estimates for ED visits related to EOAS represent a small fraction of this total, our results suggest a potential health risk to children with asthma through ozone generation associated with wildfire smoke.

We observed racial differences in asthma burden. Estimated Δy count was greatest among white children, given that they comprise a larger proportion of the population at risk. However, the difference in Δy could

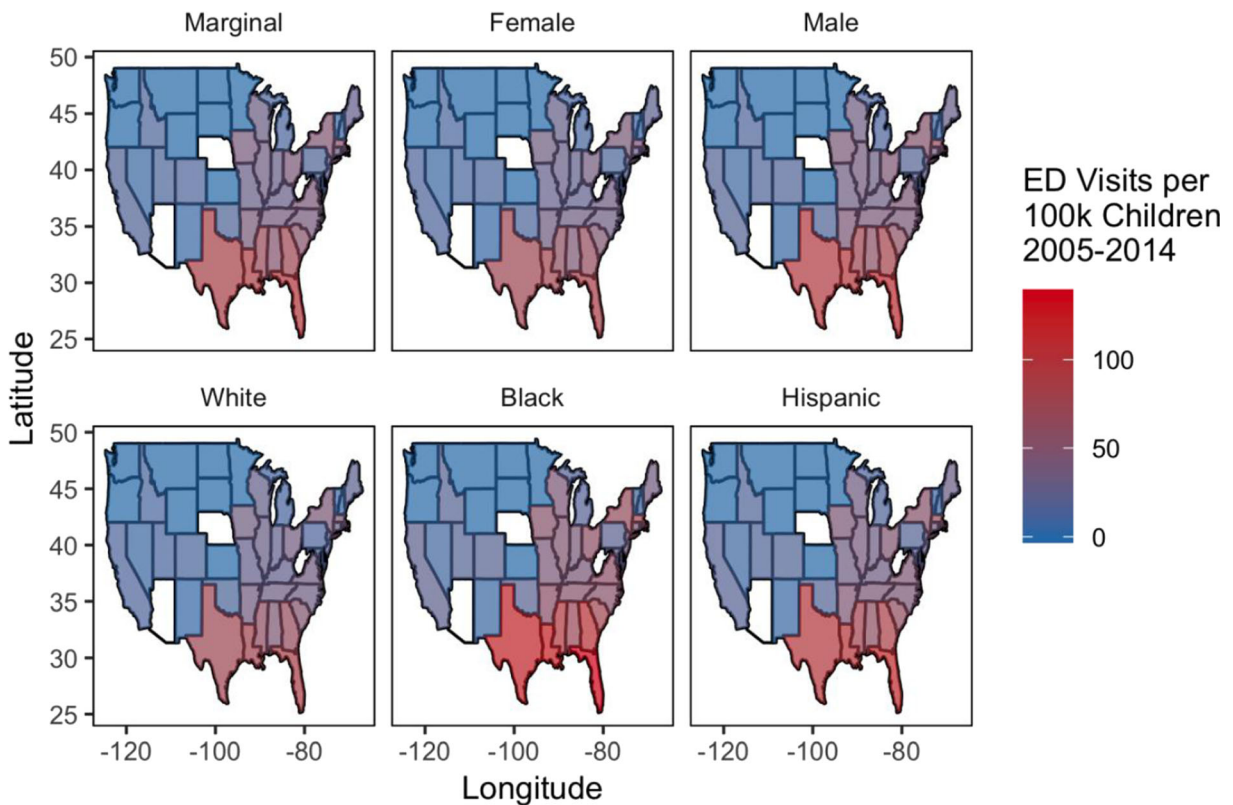


Fig. 4 Map of state-specific median asthma emergency department per 100,000 children with asthma that may be due to enhanced ozone associated with the presence of smoke (EOAS) over

the study period (2004–2015). States indicated in white could not be estimated due to missing EOAS data. Washington DC data was collapsed with Maryland estimates for visualization purposes

also be driven by variation in severity of asthma symptoms, likelihood of ED visit, and exposure to environmental pollutants related to race (Akinbami et al. 2014), which we were unable to account for in this burden assessment. However, the results of this analysis do provide evidence of a potential public health impact from EOAS and suggest that further research on the

relationship between EOAS and asthma impacts is warranted. To adequately address if EOAS has an impact on health, epidemiology studies should be designed and performed to specifically assess this relationship. Future epidemiologic studies should use population data with time and spatial scales on the same scale that EOAS is estimated. Improvements on estimates of EOAS are needed as well, as disentangling the factors contributing to ozone levels depends on many variables, including temperature, time of day, and weather conditions (Santurtún et al. 2015).

Our choice of using a burden assessment offered a straightforward, timely, and reproducible approach using publicly available data to estimate the health impact of EOAS that can help inform future epidemiologic studies. However, BAs require compromises to be made for both exposure estimates and health outcome estimates, where each term is sensitive to decisions made by researchers. For example, we selected a concentration-response function and estimates of EOAS that were statistically significant that may have led to finding

Table 1 Summed state-specific estimates of emergency department visits in children with asthma that may be due to ozone enhancements associated with the presence of smoke in the continental USA between 2005 and 2014 (period Δy)

Strata	2005–2014 Period Δy median (95% CB)
Overall	2403 (235–5383)
Female	854 (82–1990)
Male	1515 (147–3502)
White	1004 (64–2369)
Black	948 (143–2203)
Hispanic	531 (65–1273)

statistically meaningful impacts in the BA. Specific to our BA, the major consideration and goal that governed our estimate choices was to both temporally and spatially align EOAS estimates with the remaining BA estimate terms. We took a conservative approach for each estimate term to accomplish this goal, which ultimately produced a conservative estimate of the burden of EOAS on childhood asthma. Further, we considered our primary population at risk and baseline ED visit rate for children with asthma, in contrast to the traditional BA approach which selects the baseline rate and population at risk for the total population. However, our sensitivity analyses did not demonstrate large differences between these two approaches.

Our derived ED visit burden is likely to be a conservative estimate of the true number of ED visits that may be attributed to Δ EOAS. Our BA assessment was unable to estimate ED visits in Nebraska, Delaware, Arizona, and West Virginia as we did not have EOAS estimates for these states. We were unable to determine if there may be racial or sex differences in the burden of ED visits due to EOAS as we applied a standard ED visit rate to all strata. Likewise, we found a significantly meaningful burden of asthma ED visits that may be attributed to EOAS in black and Hispanic children. This burden is likely underestimated as well, as many states did not collect or report population at risk data for these race strata and were interpolated for this analysis. This highlights a major limitation of BA in that the terms are sensitive to the quality and availability of data to calculate stratum-specific estimates for populations at risk.

In addition, the estimate of the number of smoke-impacted days is likely to be a lower bound. The satellite product underlying this analysis is a conservative estimate of when smoke is in the atmospheric column. Second, there is uncertainty associated with the magnitude of the expected ozone enhancement on smoke-impacted days. In some regions, this could represent a conservative estimate, while in other regions, this could represent an overestimate. For example, in the city of Houston, smoke is transported to this region largely from fires located somewhere to the northwest. Smoke is very unlikely to be associated with atmospheric transport from the Gulf of Mexico. There could be an underlying difference in the background ozone associated with atmospheric transport from these two directions that is independent of whether there is smoke also in the air on a given day. This could impact the expected ozone enhancements associated with smoke if the

smoke-free and smoke-impacted subsets of data are associated with notably different common transport pathways.

We applied the BA formula as recommended by the EPA, where Δy was estimated with the mean difference in $\beta \times \Delta$ EOAS alone and did not account for state-specific background ozone. For example, the effect of the β term in the BA formula would have a diminished effect in a location with a higher average ambient ozone concentration (i.e., 80 ppb vs 60 ppb) due to the log scale of the relative risk estimates. Another important consideration was the study period of 2005–2014. We decided on this period of 2005–2014 as our EOAS terms were estimated over this timeframe. As our research question centered around these estimates, we constrained our other estimate terms to this time frame as well. Data on asthma ED visit rates were only available at the state spatial level for our strata of interests for the years 2001–2009, and data on population at risk were only available from 2005 to 2014, highlighting the difference in time periods for each term estimate. To produce the best possible estimates for the terms over the varying time periods, we conducted a meta-analysis of the available years to produce pooled estimates for the 2005–2014 study period, which allowed us to leverage all available data over varying time periods to produce a stable weighted estimate. Furthermore, our use of meta-analysis had another benefit as it provided pooled variance estimates that were necessary to simulate appropriate distributions for our MC simulations.

Another limitation with regard to timescale was our decision to divide the annual ED visit rate by 365 to estimate daily ED visit rates. This was done as β estimates the concentration-response between ozone and ED visits on a same-day scale. As our estimate of EOAS was a mean difference on a smoke-affected day vs non-smoke-affected day, we modified the BA formula to calculate daily Δy . We then multiplied (summed) by the number of smoke-affected days observed over the study period, thereby giving us an estimate of Δy over the study period. This decision could have resulted in a bias estimate of Δy as it does not account for seasonal variability in the ED visit rates (Strickland et al. 2010), which were only available annually. Also, our estimate of EOAS was only during summer seasons, which may also result in a biased estimate of Δy . However, our choice of concentration-response function was specific

to the warm season, which is when ozone levels are highest and wildfire smoke is likely to be present in the atmospheric column.

Another important consideration for selecting our BA terms was spatial resolution. There were spatial discrepancies between EOAS, which was station-specific; ED visit rate, which was national; and population at risk, which was state-specific. Like our decision to constrain the period of our estimate terms to align with EOAS, a similar decision was made to constrain the spatial resolution to state level. Population at risk data were available at the state level, and we could aggregate the station-specific EOAS and number of smoke-affected days terms by state. This imposes an assumption on our estimated Δy that EOAS exposure in children with asthma was constant throughout the state, which is likely not the case. However, this was an appropriate tradeoff as our population at risk term was only available at the state level.

Only national-level data were available for the baseline ED visit rate (y_0), which we applied uniformly to all our MC simulations. We believe this was appropriate as our ED visit rate was a validated CDC estimate specifically for asthma ED visits in children and was estimated for most years in the study period. Further, it is highly unlikely that the biologic response to ozone is children with asthma would differ state to state. The one term that was not state or time-specific was β (i.e., concentration-response function). Therefore, our β came from an existing study included in the most recent EPA ISA for ozone (Mar and Koenig 2009). However, like ED visit rate, this β term is appropriate as it was a US city (Seattle), specific to ED visits in children with asthma due to ozone, and on the same daily timescale as the other formula terms. More importantly, the concentration-response between ozone and ED visits in children with asthma is likely biologically similar in all children, irrespective of time or space. Further, to our knowledge, there are no national-level estimates for the ozone-ED visit concentration-response functions for pediatric populations currently published.

Conclusion

We have investigated how EOAS may impact the health of children with asthma. Our results indicate that the greatest health burden due to EOAS was in the southeastern USA. We provide the first national

BA estimating the number of pediatric asthma ED visits due to EOAS. Though these health effect estimates represent only a fraction of the overall burden of respiratory disease associated with wildfires, particularly hospitalizations and ED visits associated with direct smoke exposure (e.g., PM), the impact of EOAS on susceptible populations has not been previously identified. Policies aimed at reducing health effects of wildfires or air quality warning systems should take into considerations the long-range transport of ozone precursors.

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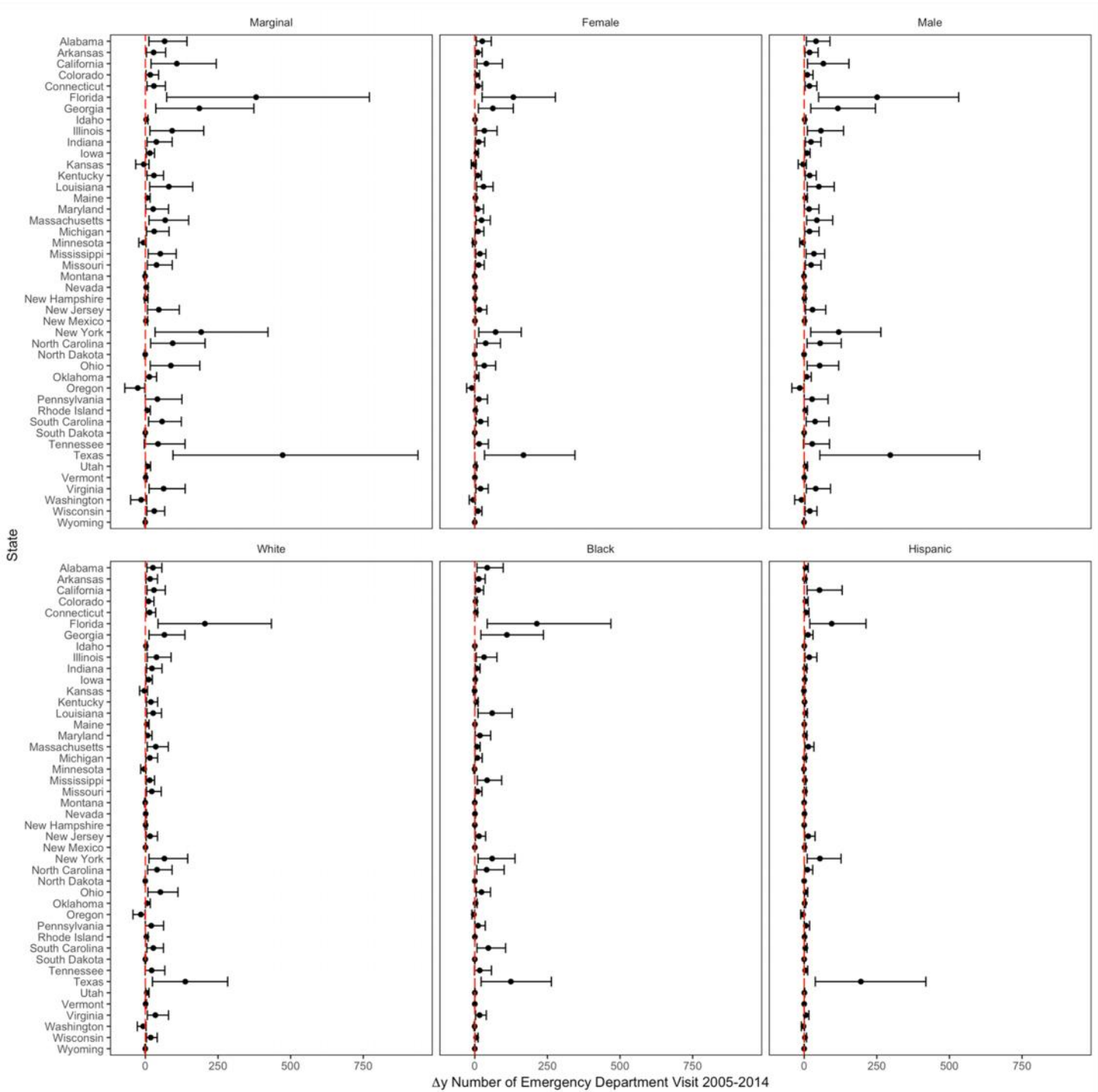
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Supplemental Tables and Figures



Supplemental Figure 1: Median and 95% confidence bound estimates of asthma ED visits (Δy) in children that may be attributed to elevated ozone associated with the presence of smoke over the study period between 2005-2014 for each state in the continental US by strata.

Supplemental Table 1: Term estimates and standard errors used in the burden assessment formula for each state and strata.

State	Strata	Population at Risk	Population at Risk SE	EOAS	EOAS SE	Average Smoke Days	Baseline ED Visit Rate	Baseline ED Visit Rate SE	Beta	Beta SE
Alabama	Black	59219.84	4401.89	6.17	0.86	32.43	0.152	0.021	0.0095	0.004
Arizona	Black	14250.73	5898.16	NA	NA	NA	0.152	0.021	0.0095	0.004
Arkansas	Black	23834.24	2043.79	5.51	1.71	29.50	0.152	0.021	0.0095	0.004
California	Black	54488.71	6712.68	2.49	0.44	24.79	0.152	0.021	0.0095	0.004
Colorado	Black	14272.16	1223.84	3.10	1.01	17.67	0.152	0.021	0.0095	0.004
Connecticut	Black	7665.34	761.08	7.53	1.59	18.40	0.152	0.021	0.0095	0.004
Delaware	Black	7299.00	1423.47	NA	NA	NA	0.152	0.021	0.0095	0.004
Florida	Black	157965.76	13545.56	14.60	0.49	26.50	0.152	0.021	0.0095	0.004
Georgia	Black	105115.46	6019.52	8.39	0.64	34.36	0.152	0.021	0.0095	0.004
Illinois	Black	67828.18	7213.56	3.08	0.63	42.11	0.152	0.021	0.0095	0.004
Indiana	Black	17444.19	1642.02	6.40	1.46	17.80	0.152	0.021	0.0095	0.004
Iowa	Black	3017.74	716.06	3.28	0.42	44.07	0.152	0.021	0.0095	0.004
Kansas	Black	5598.91	464.84	-0.93	1.24	46.00	0.152	0.021	0.0095	0.004
Kentucky	Black	12012.79	1580.12	4.04	0.54	27.82	0.152	0.021	0.0095	0.004
Louisiana	Black	48602.18	3636.98	10.90	0.89	31.70	0.152	0.021	0.0095	0.004
Washington DC	Black	11638.26	636.51	4.32	1.83	17.67	0.152	0.021	0.0095	0.004
Maryland	Black	56913.60	2703.10	4.32	1.83	17.67	0.152	0.021	0.0095	0.004
Massachusetts	Black	10709.41	2114.25	7.44	1.03	26.38	0.152	0.021	0.0095	0.004
Michigan	Black	48515.09	3034.76	2.71	0.94	19.56	0.152	0.021	0.0095	0.004
Minnesota	Black	7587.00	2928.57	-0.70	0.48	45.80	0.152	0.021	0.0095	0.004
Mississippi	Black	44055.86	1864.34	8.81	0.82	30.50	0.152	0.021	0.0095	0.004
Missouri	Black	23152.87	2331.71	4.38	1.04	26.67	0.152	0.021	0.0095	0.004
Nebraska	Black	2979.72	409.22	NA	NA	NA	0.152	0.021	0.0095	0.004
Nevada	Black	6640.60	1879.39	1.87	0.89	14.83	0.152	0.021	0.0095	0.004
New Jersey	Black	40756.05	2072.79	4.30	1.24	23.40	0.152	0.021	0.0095	0.004
New York	Black	92368.16	9036.98	7.41	0.99	24.56	0.152	0.021	0.0095	0.004
North Carolina	Black	79504.00	16045.92	4.84	0.57	30.07	0.152	0.021	0.0095	0.004
Ohio	Black	40907.20	3324.32	4.49	0.67	34.70	0.152	0.021	0.0095	0.004
Oklahoma	Black	12708.27	1112.49	1.60	0.68	38.50	0.152	0.021	0.0095	0.004
Pennsylvania	Black	53220.46	3429.45	3.04	1.42	21.00	0.152	0.021	0.0095	0.004
Rhode Island	Black	1016.99	150.42	9.44	3.13	11.00	0.152	0.021	0.0095	0.004
South Carolina	Black	61117.28	5240.81	9.33	1.24	23.00	0.152	0.021	0.0095	0.004

State	Strata	Population at Risk	Population at Risk SE	EOAS	EOAS SE	Average Smoke Days	Baseline ED Visit Rate	Baseline ED Visit Rate SE	Beta	Beta SE
South Dakota	Black	1122.72	96.27	-0.30	1.02	27.33	0.152	0.021	0.0095	0.004
Tennessee	Black	32662.92	4486.48	4.68	2.43	34.00	0.152	0.021	0.0095	0.004
Texas	Black	104037.43	8351.18	8.28	0.44	39.77	0.152	0.021	0.0095	0.004
Utah	Black	1736.40	455.83	1.75	0.47	28.36	0.152	0.021	0.0095	0.004
Vermont	Black	529.00	436.73	1.55	1.68	23.50	0.152	0.021	0.0095	0.004
Virginia	Black	29576.13	2963.58	8.12	0.91	19.57	0.152	0.021	0.0095	0.004
Washington	Black	3226.99	768.73	-1.45	0.93	40.80	0.152	0.021	0.0095	0.004
Wisconsin	Black	11394.28	1197.82	3.24	0.56	35.50	0.152	0.021	0.0095	0.004
Alabama	Female	57568.80	4324.37	6.17	0.86	32.43	0.093	0.011	0.0095	0.004
Arizona	Female	52002.49	4345.09	NA	NA	NA	0.093	0.011	0.0095	0.004
Arkansas	Female	28054.34	2114.87	5.51	1.71	29.50	0.093	0.011	0.0095	0.004
California	Female	289409.56	14239.27	2.49	0.44	24.79	0.093	0.011	0.0095	0.004
Colorado	Female	49340.23	3719.49	3.10	1.01	17.67	0.093	0.011	0.0095	0.004
Connecticut	Female	35680.46	1700.92	7.53	1.59	18.40	0.093	0.011	0.0095	0.004
Delaware	Female	11298.00	1685.20	NA	NA	NA	0.093	0.011	0.0095	0.004
Florida	Female	158816.74	11972.34	14.60	0.49	26.50	0.093	0.011	0.0095	0.004
Georgia	Female	96577.27	5326.13	8.39	0.64	34.36	0.093	0.011	0.0095	0.004
Idaho	Female	8792.93	800.53	2.82	1.31	18.50	0.093	0.011	0.0095	0.004
Illinois	Female	112855.94	8163.59	3.08	0.63	42.11	0.093	0.011	0.0095	0.004
Indiana	Female	55377.31	2663.85	6.40	1.46	17.80	0.093	0.011	0.0095	0.004
Iowa	Female	17063.53	1233.94	3.28	0.42	44.07	0.093	0.011	0.0095	0.004
Kansas	Female	24936.13	871.78	-0.93	1.24	46.00	0.093	0.011	0.0095	0.004
Kentucky	Female	40550.82	2541.59	4.04	0.54	27.82	0.093	0.011	0.0095	0.004
Louisiana	Female	39313.29	3157.27	10.90	0.89	31.70	0.093	0.011	0.0095	0.004
Maine	Female	9840.20	621.70	4.69	1.44	22.33	0.093	0.011	0.0095	0.004
Washington DC	Female	6651.07	493.66	4.32	1.83	17.67	0.093	0.011	0.0095	0.004
Maryland	Female	54409.33	2416.87	4.32	1.83	17.67	0.093	0.011	0.0095	0.004
Massachusetts	Female	54411.24	4949.53	7.44	1.03	26.38	0.093	0.011	0.0095	0.004
Michigan	Female	99354.59	3852.06	2.71	0.94	19.56	0.093	0.011	0.0095	0.004
Minnesota	Female	30402.48	4200.34	-0.70	0.48	45.80	0.093	0.011	0.0095	0.004
Mississippi	Female	29620.01	1489.97	8.81	0.82	30.50	0.093	0.011	0.0095	0.004
Missouri	Female	52130.35	3525.16	4.38	1.04	26.67	0.093	0.011	0.0095	0.004
Montana	Female	6253.46	349.09	-1.30	1.04	21.50	0.093	0.011	0.0095	0.004
Nebraska	Female	12037.91	626.88	NA	NA	NA	0.093	0.011	0.0095	0.004
Nevada	Female	20498.79	1910.09	1.87	0.89	14.83	0.093	0.011	0.0095	0.004
New Hampshire	Female	10430.41	621.39	2.24	2.54	13.00	0.093	0.011	0.0095	0.004
New Jersey	Female	73517.07	2648.51	4.30	1.24	23.40	0.093	0.011	0.0095	0.004

State	Strata	Population at Risk	Population at Risk SE	EOAS	EOAS SE	Average Smoke Days	Baseline ED Visit Rate	Baseline ED Visit Rate SE	Beta	Beta SE
New Mexico	Female	15864.32	823.25	0.67	0.54	30.00	0.093	0.011	0.0095	0.004
New York	Female	178160.70	10881.30	7.41	0.99	24.56	0.093	0.011	0.0095	0.004
North Carolina	Female	114612.00	18825.00	4.84	0.57	30.07	0.093	0.011	0.0095	0.004
North Dakota	Female	3019.24	354.63	-0.72	0.77	38.00	0.093	0.011	0.0095	0.004
Ohio	Female	91815.77	4617.02	4.49	0.67	34.70	0.093	0.011	0.0095	0.004
Oklahoma	Female	37403.43	1722.83	1.60	0.68	38.50	0.093	0.011	0.0095	0.004
Oregon	Female	29809.96	1704.95	-2.31	0.88	66.00	0.093	0.011	0.0095	0.004
Pennsylvania	Female	105191.15	4367.02	3.04	1.42	21.00	0.093	0.011	0.0095	0.004
Rhode Island	Female	10433.90	589.42	9.44	3.13	11.00	0.093	0.011	0.0095	0.004
South Carolina	Female	42842.83	3229.69	9.33	1.24	23.00	0.093	0.011	0.0095	0.004
South Dakota	Female	5041.00	918.88	-0.30	1.02	27.33	0.093	0.011	0.0095	0.004
Tennessee	Female	44803.06	5013.79	4.68	2.43	34.00	0.093	0.011	0.0095	0.004
Texas	Female	226602.37	11121.25	8.28	0.44	39.77	0.093	0.011	0.0095	0.004
Utah	Female	23360.06	961.08	1.75	0.47	28.36	0.093	0.011	0.0095	0.004
Vermont	Female	4954.39	237.77	1.55	1.68	23.50	0.093	0.011	0.0095	0.004
Virginia	Female	58205.85	4438.47	8.12	0.91	19.57	0.093	0.011	0.0095	0.004
Washington	Female	43175.00	2173.94	-1.45	0.93	40.80	0.093	0.011	0.0095	0.004
West Virginia	Female	14138.04	777.18	NA	NA	NA	0.093	0.011	0.0095	0.004
Wisconsin	Female	41459.90	2852.28	3.24	0.56	35.50	0.093	0.011	0.0095	0.004
Wyoming	Female	3273.88	302.89	-1.22	1.39	21.00	0.093	0.011	0.0095	0.004
Alabama	Hispanic	8388.00	2966.33	6.17	0.86	32.43	0.125	0.021	0.0095	0.004
Arizona	Hispanic	52606.01	4720.57	NA	NA	NA	0.125	0.021	0.0095	0.004
Arkansas	Hispanic	5826.83	609.10	5.51	1.71	29.50	0.125	0.021	0.0095	0.004
California	Hispanic	286237.41	14724.79	2.49	0.44	24.79	0.125	0.021	0.0095	0.004
Colorado	Hispanic	29552.55	3089.23	3.10	1.01	17.67	0.125	0.021	0.0095	0.004
Connecticut	Hispanic	16169.22	1176.89	7.53	1.59	18.40	0.125	0.021	0.0095	0.004
Delaware	Hispanic	2225.00	973.98	NA	NA	NA	0.125	0.021	0.0095	0.004
Florida	Hispanic	85423.58	8929.61	14.60	0.49	26.50	0.125	0.021	0.0095	0.004
Georgia	Hispanic	15506.51	2464.89	8.39	0.64	34.36	0.125	0.021	0.0095	0.004
Idaho	Hispanic	3301.26	549.71	2.82	1.31	18.50	0.125	0.021	0.0095	0.004
Illinois	Hispanic	45614.61	6442.60	3.08	0.63	42.11	0.125	0.021	0.0095	0.004
Indiana	Hispanic	10326.61	1573.75	6.40	1.46	17.80	0.125	0.021	0.0095	0.004
Iowa	Hispanic	4108.70	899.65	3.28	0.42	44.07	0.125	0.021	0.0095	0.004
Kansas	Hispanic	7334.83	543.27	-0.93	1.24	46.00	0.125	0.021	0.0095	0.004
Kentucky	Hispanic	3734.69	919.40	4.04	0.54	27.82	0.125	0.021	0.0095	0.004
Louisiana	Hispanic	4115.99	1307.55	10.90	0.89	31.70	0.125	0.021	0.0095	0.004
Maine	Hispanic	1622.00	794.39	4.69	1.44	22.33	0.125	0.021	0.0095	0.004

State	Strata	Population at Risk	Population at Risk SE	EOAS	EOAS SE	Average Smoke Days	Baseline ED Visit Rate	Baseline ED Visit Rate SE	Beta	Beta SE
Washington DC	Hispanic	1641.95	418.19	4.32	1.83	17.67	0.125	0.021	0.0095	0.004
Maryland	Hispanic	12212.68	1319.53	4.32	1.83	17.67	0.125	0.021	0.0095	0.004
Massachusetts	Hispanic	24821.35	3091.99	7.44	1.03	26.38	0.125	0.021	0.0095	0.004
Michigan	Hispanic	16480.20	1957.18	2.71	0.94	19.56	0.125	0.021	0.0095	0.004
Mississippi	Hispanic	2943.61	604.41	8.81	0.82	30.50	0.125	0.021	0.0095	0.004
Missouri	Hispanic	7849.38	1936.71	4.38	1.04	26.67	0.125	0.021	0.0095	0.004
Montana	Hispanic	1029.17	183.91	-1.30	1.04	21.50	0.125	0.021	0.0095	0.004
Nebraska	Hispanic	1880.86	232.34	NA	NA	NA	0.125	0.021	0.0095	0.004
Nevada	Hispanic	12766.31	1573.73	1.87	0.89	14.83	0.125	0.021	0.0095	0.004
New Hampshire	Hispanic	1768.83	424.64	2.24	2.54	13.00	0.125	0.021	0.0095	0.004
New Jersey	Hispanic	48074.76	2368.63	4.30	1.24	23.40	0.125	0.021	0.0095	0.004
New Mexico	Hispanic	23817.25	1038.51	0.67	0.54	30.00	0.125	0.021	0.0095	0.004
New York	Hispanic	102363.44	9329.13	7.41	0.99	24.56	0.125	0.021	0.0095	0.004
North Carolina	Hispanic	26322.00	7018.37	4.84	0.57	30.07	0.125	0.021	0.0095	0.004
Ohio	Hispanic	10512.71	1751.11	4.49	0.67	34.70	0.125	0.021	0.0095	0.004
Oklahoma	Hispanic	8471.39	826.17	1.60	0.68	38.50	0.125	0.021	0.0095	0.004
Oregon	Hispanic	9011.07	1110.01	-2.31	0.88	66.00	0.125	0.021	0.0095	0.004
Pennsylvania	Hispanic	32786.91	3251.22	3.04	1.42	21.00	0.125	0.021	0.0095	0.004
Rhode Island	Hispanic	4203.23	385.81	9.44	3.13	11.00	0.125	0.021	0.0095	0.004
South Carolina	Hispanic	6402.22	669.25	9.33	1.24	23.00	0.125	0.021	0.0095	0.004
South Dakota	Hispanic	760.35	79.48	-0.30	1.02	27.33	0.125	0.021	0.0095	0.004
Texas	Hispanic	198772.05	9719.95	8.28	0.44	39.77	0.125	0.021	0.0095	0.004
Utah	Hispanic	4908.72	461.66	1.75	0.47	28.36	0.125	0.021	0.0095	0.004
Vermont	Hispanic	512.83	115.25	1.55	1.68	23.50	0.125	0.021	0.0095	0.004
Virginia	Hispanic	12592.34	4559.18	8.12	0.91	19.57	0.125	0.021	0.0095	0.004
Washington	Hispanic	16025.49	1498.31	-1.45	0.93	40.80	0.125	0.021	0.0095	0.004
Wisconsin	Hispanic	8249.58	3023.20	3.24	0.56	35.50	0.125	0.021	0.0095	0.004
Wyoming	Hispanic	630.27	136.47	-1.22	1.39	21.00	0.125	0.021	0.0095	0.004
Alabama	Male	71246.78	4682.60	6.17	0.86	32.43	0.118	0.013	0.0095	0.004
Arizona	Male	78656.77	5250.30	NA	NA	NA	0.118	0.013	0.0095	0.004
Arkansas	Male	41757.87	2212.04	5.51	1.71	29.50	0.118	0.013	0.0095	0.004
California	Male	375535.56	15411.31	2.49	0.44	24.79	0.118	0.013	0.0095	0.004
Colorado	Male	73568.36	3897.13	3.10	1.01	17.67	0.118	0.013	0.0095	0.004
Connecticut	Male	47594.21	1964.14	7.53	1.59	18.40	0.118	0.013	0.0095	0.004
Delaware	Male	16529.00	2224.49	NA	NA	NA	0.118	0.013	0.0095	0.004
Florida	Male	236345.09	12519.90	14.60	0.49	26.50	0.118	0.013	0.0095	0.004
Georgia	Male	142879.18	6405.62	8.39	0.64	34.36	0.118	0.013	0.0095	0.004

State	Strata	Population at Risk	Population at Risk SE	EOAS	EOAS SE	Average Smoke Days	Baseline ED Visit Rate	Baseline ED Visit Rate SE	Beta	Beta SE
Idaho	Male	13696.79	1023.80	2.82	1.31	18.50	0.118	0.013	0.0095	0.004
Illinois	Male	158391.88	9750.61	3.08	0.63	42.11	0.118	0.013	0.0095	0.004
Indiana	Male	74486.96	3396.88	6.40	1.46	17.80	0.118	0.013	0.0095	0.004
Iowa	Male	22209.18	1444.69	3.28	0.42	44.07	0.118	0.013	0.0095	0.004
Kansas	Male	33697.67	1092.03	-0.93	1.24	46.00	0.118	0.013	0.0095	0.004
Kentucky	Male	57991.22	3205.52	4.04	0.54	27.82	0.118	0.013	0.0095	0.004
Louisiana	Male	52141.96	3428.15	10.90	0.89	31.70	0.118	0.013	0.0095	0.004
Maine	Male	14109.12	745.25	4.69	1.44	22.33	0.118	0.013	0.0095	0.004
Washington DC	Male	8933.09	552.06	4.32	1.83	17.67	0.118	0.013	0.0095	0.004
Maryland	Male	74649.10	2722.12	4.32	1.83	17.67	0.118	0.013	0.0095	0.004
Massachusetts	Male	79923.09	5809.68	7.44	1.03	26.38	0.118	0.013	0.0095	0.004
Michigan	Male	128530.50	4527.28	2.71	0.94	19.56	0.118	0.013	0.0095	0.004
Minnesota	Male	47944.16	5720.87	-0.70	0.48	45.80	0.118	0.013	0.0095	0.004
Mississippi	Male	43771.98	1768.58	8.81	0.82	30.50	0.118	0.013	0.0095	0.004
Missouri	Male	73263.53	4191.68	4.38	1.04	26.67	0.118	0.013	0.0095	0.004
Montana	Male	8166.21	402.30	-1.30	1.04	21.50	0.118	0.013	0.0095	0.004
Nebraska	Male	16213.59	750.45	NA	NA	NA	0.118	0.013	0.0095	0.004
Nevada	Male	23651.56	1735.38	1.87	0.89	14.83	0.118	0.013	0.0095	0.004
New Hampshire	Male	15277.71	781.19	2.24	2.54	13.00	0.118	0.013	0.0095	0.004
New Jersey	Male	105142.63	3223.38	4.30	1.24	23.40	0.118	0.013	0.0095	0.004
New Mexico	Male	24819.02	1005.53	0.67	0.54	30.00	0.118	0.013	0.0095	0.004
New York	Male	231170.90	12209.79	7.41	0.99	24.56	0.118	0.013	0.0095	0.004
North Carolina	Male	135337.00	20929.59	4.84	0.57	30.07	0.118	0.013	0.0095	0.004
North Dakota	Male	4569.30	456.06	-0.72	0.77	38.00	0.118	0.013	0.0095	0.004
Ohio	Male	120862.57	5410.86	4.49	0.67	34.70	0.118	0.013	0.0095	0.004
Oklahoma	Male	50720.79	2022.54	1.60	0.68	38.50	0.118	0.013	0.0095	0.004
Oregon	Male	35228.73	1807.05	-2.31	0.88	66.00	0.118	0.013	0.0095	0.004
Pennsylvania	Male	161730.66	5663.49	3.04	1.42	21.00	0.118	0.013	0.0095	0.004
Rhode Island	Male	14290.11	667.61	9.44	3.13	11.00	0.118	0.013	0.0095	0.004
South Carolina	Male	63275.44	3351.89	9.33	1.24	23.00	0.118	0.013	0.0095	0.004
South Dakota	Male	5678.00	820.92	-0.30	1.02	27.33	0.118	0.013	0.0095	0.004
Tennessee	Male	67314.41	6879.89	4.68	2.43	34.00	0.118	0.013	0.0095	0.004
Texas	Male	315795.89	12816.85	8.28	0.44	39.77	0.118	0.013	0.0095	0.004
Utah	Male	32826.84	1099.40	1.75	0.47	28.36	0.118	0.013	0.0095	0.004
Vermont	Male	6293.56	271.71	1.55	1.68	23.50	0.118	0.013	0.0095	0.004
Virginia	Male	91618.91	5983.62	8.12	0.91	19.57	0.118	0.013	0.0095	0.004
Washington	Male	57713.46	2575.86	-1.45	0.93	40.80	0.118	0.013	0.0095	0.004

State	Strata	Population at Risk	Population at Risk SE	EOAS	EOAS SE	Average Smoke Days	Baseline ED Visit Rate	Baseline ED Visit Rate SE	Beta	Beta SE
West Virginia	Male	17454.25	833.41	NA	NA	NA	0.118	0.013	0.0095	0.004
Wisconsin	Male	58802.21	3288.50	3.24	0.56	35.50	0.118	0.013	0.0095	0.004
Wyoming	Male	5168.44	360.27	-1.22	1.39	21.00	0.118	0.013	0.0095	0.004
Alabama	Marginal	129218.77	6234.30	6.17	0.86	32.43	0.1067	0.0047	0.0095	0.004
Arizona	Marginal	137289.83	7037.93	NA	NA	NA	0.1067	0.0047	0.0095	0.004
Arkansas	Marginal	69907.46	2884.60	5.51	1.71	29.50	0.1067	0.0047	0.0095	0.004
California	Marginal	671986.42	20890.44	2.49	0.44	24.79	0.1067	0.0047	0.0095	0.004
Colorado	Marginal	123057.78	5077.75	3.10	1.01	17.67	0.1067	0.0047	0.0095	0.004
Connecticut	Marginal	84677.37	2590.33	7.53	1.59	18.40	0.1067	0.0047	0.0095	0.004
Delaware	Marginal	27920.00	2722.96	NA	NA	NA	0.1067	0.0047	0.0095	0.004
Florida	Marginal	395707.97	16328.16	14.60	0.49	26.50	0.1067	0.0047	0.0095	0.004
Georgia	Marginal	248135.15	8370.77	8.39	0.64	34.36	0.1067	0.0047	0.0095	0.004
Idaho	Marginal	23080.28	1312.91	2.82	1.31	18.50	0.1067	0.0047	0.0095	0.004
Illinois	Marginal	273229.31	12559.98	3.08	0.63	42.11	0.1067	0.0047	0.0095	0.004
Indiana	Marginal	132569.09	4345.64	6.40	1.46	17.80	0.1067	0.0047	0.0095	0.004
Iowa	Marginal	39871.75	1891.63	3.28	0.42	44.07	0.1067	0.0047	0.0095	0.004
Kansas	Marginal	59398.97	1388.33	-0.93	1.24	46.00	0.1067	0.0047	0.0095	0.004
Kentucky	Marginal	99244.19	4045.51	4.04	0.54	27.82	0.1067	0.0047	0.0095	0.004
Louisiana	Marginal	92047.27	4601.62	10.90	0.89	31.70	0.1067	0.0047	0.0095	0.004
Maine	Marginal	24458.06	964.96	4.69	1.44	22.33	0.1067	0.0047	0.0095	0.004
Washington DC	Marginal	15798.01	730.19	4.32	1.83	17.67	0.1067	0.0047	0.0095	0.004
Maryland	Marginal	131237.97	3644.76	4.32	1.83	17.67	0.1067	0.0047	0.0095	0.004
Massachusetts	Marginal	136353.91	7529.04	7.44	1.03	26.38	0.1067	0.0047	0.0095	0.004
Michigan	Marginal	229160.95	5876.51	2.71	0.94	19.56	0.1067	0.0047	0.0095	0.004
Minnesota	Marginal	80342.46	7120.39	-0.70	0.48	45.80	0.1067	0.0047	0.0095	0.004
Mississippi	Marginal	74074.29	2279.50	8.81	0.82	30.50	0.1067	0.0047	0.0095	0.004
Missouri	Marginal	131334.26	5643.99	4.38	1.04	26.67	0.1067	0.0047	0.0095	0.004
Montana	Marginal	14629.65	532.83	-1.30	1.04	21.50	0.1067	0.0047	0.0095	0.004
Nebraska	Marginal	28713.94	977.39	NA	NA	NA	0.1067	0.0047	0.0095	0.004
Nevada	Marginal	44870.49	2601.17	1.87	0.89	14.83	0.1067	0.0047	0.0095	0.004
New Hampshire	Marginal	26518.27	1007.12	2.24	2.54	13.00	0.1067	0.0047	0.0095	0.004
New Jersey	Marginal	182991.58	4178.90	4.30	1.24	23.40	0.1067	0.0047	0.0095	0.004
New Mexico	Marginal	41115.38	1291.93	0.67	0.54	30.00	0.1067	0.0047	0.0095	0.004
New York	Marginal	419034.73	16394.57	7.41	0.99	24.56	0.1067	0.0047	0.0095	0.004
North Carolina	Marginal	250591.00	27750.00	4.84	0.57	30.07	0.1067	0.0047	0.0095	0.004
North Dakota	Marginal	8211.15	622.21	-0.72	0.77	38.00	0.1067	0.0047	0.0095	0.004
Ohio	Marginal	215438.53	7051.13	4.49	0.67	34.70	0.1067	0.0047	0.0095	0.004

State	Strata	Population at Risk	Population at Risk SE	EOAS	EOAS SE	Average Smoke Days	Baseline ED Visit Rate	Baseline ED Visit Rate SE	Beta	Beta SE
Oklahoma	Marginal	88802.09	2615.66	1.60	0.68	38.50	0.1067	0.0047	0.0095	0.004
Oregon	Marginal	66502.69	2489.94	-2.31	0.88	66.00	0.1067	0.0047	0.0095	0.004
Pennsylvania	Marginal	271045.89	7128.72	3.04	1.42	21.00	0.1067	0.0047	0.0095	0.004
Rhode Island	Marginal	25116.39	882.84	9.44	3.13	11.00	0.1067	0.0047	0.0095	0.004
South Carolina	Marginal	106335.02	4387.72	9.33	1.24	23.00	0.1067	0.0047	0.0095	0.004
South Dakota	Marginal	10719.00	1217.35	-0.30	1.02	27.33	0.1067	0.0047	0.0095	0.004
Tennessee	Marginal	116053.65	8798.85	4.68	2.43	34.00	0.1067	0.0047	0.0095	0.004
Texas	Marginal	548901.14	16874.22	8.28	0.44	39.77	0.1067	0.0047	0.0095	0.004
Utah	Marginal	56836.42	1453.90	1.75	0.47	28.36	0.1067	0.0047	0.0095	0.004
Vermont	Marginal	11422.31	359.02	1.55	1.68	23.50	0.1067	0.0047	0.0095	0.004
Virginia	Marginal	153984.97	7455.58	8.12	0.91	19.57	0.1067	0.0047	0.0095	0.004
Washington	Marginal	102209.78	3356.59	-1.45	0.93	40.80	0.1067	0.0047	0.0095	0.004
West Virginia	Marginal	31891.93	1128.96	NA	NA	NA	0.1067	0.0047	0.0095	0.004
Wisconsin	Marginal	101754.19	4353.98	3.24	0.56	35.50	0.1067	0.0047	0.0095	0.004
Wyoming	Marginal	8494.71	465.11	-1.22	1.39	21.00	0.1067	0.0047	0.0095	0.004
Alabama	White	57454.96	4084.63	6.17	0.86	32.43	0.094	0.01	0.0095	0.004
Arizona	White	60993.78	4383.92	NA	NA	NA	0.094	0.01	0.0095	0.004
Arkansas	White	45443.09	3258.60	5.51	1.71	29.50	0.094	0.01	0.0095	0.004
California	White	211383.60	9484.80	2.49	0.44	24.79	0.094	0.01	0.0095	0.004
Colorado	White	90056.25	6457.69	3.10	1.01	17.67	0.094	0.01	0.0095	0.004
Connecticut	White	47864.86	1895.57	7.53	1.59	18.40	0.094	0.01	0.0095	0.004
Delaware	White	15750.00	2048.98	NA	NA	NA	0.094	0.01	0.0095	0.004
Florida	White	243132.05	17434.35	14.60	0.49	26.50	0.094	0.01	0.0095	0.004
Georgia	White	99366.36	4382.48	8.39	0.64	34.36	0.094	0.01	0.0095	0.004
Idaho	White	17680.05	1137.99	2.82	1.31	18.50	0.094	0.01	0.0095	0.004
Illinois	White	130169.13	6998.24	3.08	0.63	42.11	0.094	0.01	0.0095	0.004
Indiana	White	91113.41	3380.29	6.40	1.46	17.80	0.094	0.01	0.0095	0.004
Iowa	White	33006.78	1726.88	3.28	0.42	44.07	0.094	0.01	0.0095	0.004
Kansas	White	40829.74	1096.95	-0.93	1.24	46.00	0.094	0.01	0.0095	0.004
Kentucky	White	74284.45	3241.94	4.04	0.54	27.82	0.094	0.01	0.0095	0.004
Louisiana	White	34753.30	2505.77	10.90	0.89	31.70	0.094	0.01	0.0095	0.004
Maine	White	21088.06	876.91	4.69	1.44	22.33	0.094	0.01	0.0095	0.004
Washington DC	White	1004.94	109.98	4.32	1.83	17.67	0.094	0.01	0.0095	0.004
Maryland	White	46007.03	1722.18	4.32	1.83	17.67	0.094	0.01	0.0095	0.004
Massachusetts	White	80985.87	5471.74	7.44	1.03	26.38	0.094	0.01	0.0095	0.004
Michigan	White	133535.10	3929.85	2.71	0.94	19.56	0.094	0.01	0.0095	0.004
Minnesota	White	65393.47	6452.27	-0.70	0.48	45.80	0.094	0.01	0.0095	0.004

State	Strata	Population at Risk	Population at Risk SE	EOAS	EOAS SE	Average Smoke Days	Baseline ED Visit Rate	Baseline ED Visit Rate SE	Beta	Beta SE
Mississippi	White	24483.55	1196.11	8.81	0.82	30.50	0.094	0.01	0.0095	0.004
Missouri	White	85216.38	4520.19	4.38	1.04	26.67	0.094	0.01	0.0095	0.004
Montana	White	11068.90	457.64	-1.30	1.04	21.50	0.094	0.01	0.0095	0.004
Nebraska	White	19697.33	724.99	NA	NA	NA	0.094	0.01	0.0095	0.004
Nevada	White	17518.02	1246.75	1.87	0.89	14.83	0.094	0.01	0.0095	0.004
New Hampshire	White	15653.67	729.26	2.24	2.54	13.00	0.094	0.01	0.0095	0.004
New Jersey	White	73545.33	2376.43	4.30	1.24	23.40	0.094	0.01	0.0095	0.004
New Mexico	White	11157.73	621.09	0.67	0.54	30.00	0.094	0.01	0.0095	0.004
New York	White	160273.50	7578.12	7.41	0.99	24.56	0.094	0.01	0.0095	0.004
North Carolina	White	123463.00	21018.37	4.84	0.57	30.07	0.094	0.01	0.0095	0.004
North Dakota	White	6752.54	545.97	-0.72	0.77	38.00	0.094	0.01	0.0095	0.004
Ohio	White	145759.74	5580.36	4.49	0.67	34.70	0.094	0.01	0.0095	0.004
Oklahoma	White	44073.85	1737.54	1.60	0.68	38.50	0.094	0.01	0.0095	0.004
Oregon	White	45555.33	1974.88	-2.31	0.88	66.00	0.094	0.01	0.0095	0.004
Pennsylvania	White	148095.08	4426.79	3.04	1.42	21.00	0.094	0.01	0.0095	0.004
Rhode Island	White	15821.21	669.03	9.44	3.13	11.00	0.094	0.01	0.0095	0.004
South Carolina	White	57321.69	4110.38	9.33	1.24	23.00	0.094	0.01	0.0095	0.004
South Dakota	White	8490.00	1121.43	-0.30	1.02	27.33	0.094	0.01	0.0095	0.004
Tennessee	White	64850.12	5768.19	4.68	2.43	34.00	0.094	0.01	0.0095	0.004
Texas	White	186071.80	8719.43	8.28	0.44	39.77	0.094	0.01	0.0095	0.004
Utah	White	43709.00	1206.00	1.75	0.47	28.36	0.094	0.01	0.0095	0.004
Vermont	White	10302.46	337.63	1.55	1.68	23.50	0.094	0.01	0.0095	0.004
Virginia	White	99251.67	6244.04	8.12	0.91	19.57	0.094	0.01	0.0095	0.004
Washington	White	61284.56	2363.57	-1.45	0.93	40.80	0.094	0.01	0.0095	0.004
West Virginia	White	28219.23	1050.98	NA	NA	NA	0.094	0.01	0.0095	0.004
Wisconsin	White	69837.35	3489.79	3.24	0.56	35.50	0.094	0.01	0.0095	0.004
Wyoming	White	6858.58	416.95	-1.22	1.39	21.00	0.094	0.01	0.0095	0.004