



Full length article

## Opioid prescription rates and risk for substantiated child abuse and neglect: A Bayesian spatiotemporal analysis

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### ABSTRACT

**Objectives:** To determine the association between opioid prescribing rates and substantiated abuse and neglect across Tennessee counties during an 11-year period.

**Methods:** We adopted a Bayesian spatiotemporal approach to determine the association between opioid prescribing and rates of substantiated child abuse and neglect over and above environmental and population-level covariates. Annual county-level data for Tennessee (2006–2016) included rates of substantiated child abuse and neglect, rates of drug and non-drug crime incidents, racial and Hispanic composition, per capita income, child poverty and teen birth rates, and vacant housing.

**Results:** Higher opioid prescribing rates were associated with greater risk for substantiated child abuse and neglect across Tennessee counties. Risk for substantiated child abuse and neglect was positively associated with vacant housing, child poverty, teen birth rates, and rates of both drug and non-drug criminal incidents - including stimulant arrests. Risk for substantiated child abuse and neglect was negatively associated with percentages of African Americans.

**Conclusions:** Results underscore the importance of opioid prescribing and crime rates as independent determinants of spatial and temporal variation in risk for substantiated child abuse and neglect. Policies that regulate and reduce opioid prescribing have the potential to reduce risk for child abuse and neglect.

### 1. Introduction

According to the United States Department of Health and Human Services, more than 130 people die each day from opioid-related drug overdoses (<https://www.hhs.gov/opioids/>). These deaths, along with increases in opioid-related morbidity, have led some researchers to describe the state of opioid-related problems as an epidemic (Kolodny et al., 2015). In 2017, Tennessee providers wrote 94.4 opioid prescriptions per 100 residents - the third highest opioid prescribing rate in the nation – and prescription opioids were implicated in 644 overdose deaths (<https://www.drugabuse.gov/opioid-summaries-by-state/>). Nationwide, prescription opioids accounted for 40% of all opioid-related overdose deaths in 2016 (Seth et al., 2018). Despite a recent decrease in opioid prescribing rates (Guy et al., 2019), the amount of opioids

prescribed in the United States in 2015 remained three times greater than in 1999 (Guy et al., 2017). Increasing opioid prescribing rates are associated with increased risk for illicit opioid abuse, opioid use disorder, and overdose deaths (Schuchat et al., 2017), and contribute to an estimated \$78.5 billion annually in health care, criminal justice, and lost productivity costs (Florence et al., 2016).

One important yet understudied consequence of prescription opioids is their impact on children. Opioid prescribing rates are likely to influence risk for child abuse and neglect through multiple pathways highlighted in alcohol and drug environmental models (Gruenewald et al., 2013). For example, higher rates of opioid prescribing and use could increase risk for neglectful parenting behaviors through impaired decision-making and inadequate supervision in a similar manner to patterns observed for other substances (Sedlak et al., 2010; Slesnick

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et al., 2014). These neglectful parenting behaviors may be exacerbated – and could include physical abuse – if substance use leads to the development of substance use disorder and mental health comorbidities (Fischer et al., 2012; Ghertner et al., 2018). Prescription opioid overdoses have been linked to higher rates of hospital discharges for child maltreatment and unintentional injury (Wolf et al., 2016). Higher opioid prescribing could also lead to greater use within parents' social companionship support networks and higher risk for physical abuse (Freisthler et al., 2014) – including more opportunities for children to be exposed to unsafe and intoxicated adults. Finally, higher opioid prescribing rates could increase illicit opioid availability (via diversion) and thereby reduce neighborhood-level factors that protect against child maltreatment such as social cohesion and social control (Freisthler et al., 2017; Maguire-Jack and Showalter, 2015). Emerging evidence reveals that opioid prescribing rates were positively associated with child removal rates for parental neglect in Florida counties (Quast et al., 2018) and with overall removal rates in California counties (Quast et al., 2019). Together, these studies suggest that children living in counties with higher opioid prescribing rates are more likely to experience severe maltreatment that requires entry into the foster care system.

Efforts to elucidate the pathways linking opioid prescribing and child maltreatment must consider the range of family services outcomes available at different stages of Child Protective Services (CPS) triage, including allegations, substantiated cases, and foster care entries. Child welfare agencies across the United States received 4.1 million referrals in 2017 detailing allegations of abuse or neglect involving 7.5 million children (U.S. Department of Health and Human Services, 2019). These referrals underwent an initial screening process in which CPS determined whether available information warranted an investigation. Of the 4.1 million referrals received in 2017, 58% were designated by CPS for further investigation. Of the 3.5 million children involved in CPS investigations in 2017, 19% were classified as substantiated cases of child abuse or neglect and 4% received foster care services (U.S. Department of Health and Human Services, 2019). These statistics have two important implications. First, child removals represent a small portion of child maltreatment reports made to CPS. Second, the majority of children with substantiated abuse or neglect remain in their homes. Therefore, it remains unclear whether higher opioid prescribing rates are associated with a broader spectrum of child maltreatment severity, including children deemed to be at low-to-moderate risk for revictimization who remain in their homes (Shusterman et al., 2005). The present study will address this question by examining the relation of opioid prescribing rates to substantiated cases of child abuse and neglect.

Rates of substantiated child abuse and neglect vary significantly between states (Smith et al., 2017) and within zip codes (Morris et al., 2019a) and counties over time (Morris et al., 2019b). Variation in risk for (and responses to) substantiated child abuse and neglect can be explained by person-centered and place-centered factors (Freisthler et al., 2006), as well as policies and practices of child welfare agencies (Maguire-Jack, 2014). Social-ecological models have delineated pathways linking neighborhood structural characteristics (e.g., poverty, crime, drug markets, alcohol availability, demographics, housing stability, rural versus urban) to risk for child maltreatment via neighborhood processes (e.g., social cohesion, social control, service availability) and family characteristics (e.g., family stress, parental substance use, parenting behaviors, teenage parents) (Coulton et al., 2007; Gruenewald et al., 2013; Morris et al., 2019b). Support for these models comes from studies conducted at different levels of the social ecology. For example, crime rates are associated with higher risk for parent-report maltreatment behaviors across neighborhood clusters (Molnar et al., 2003) and higher rates of substantiated child abuse and neglect across zip codes (Morris et al., 2019a) and counties (Morris et al., 2019b). Drug market activity, in particular, has been linked to rates of substantiated child maltreatment across Census tracts

(Freisthler et al., 2012) and counties (Morris et al., 2019b). In addition, both African American (Morris et al., 2019b) and Hispanic (Smith et al., 2017) county composition are associated with lower risk for substantiated child abuse and neglect and reports of child maltreatment, respectively. Overall, the literature on social-ecological correlates of child maltreatment provides consistent support for aggregate measures of neighborhood disadvantage (e.g., income level, poverty), social disorganization (e.g., crime, drug market activity), housing stress (e.g., vacant housing), alcohol/drug availability (e.g., alcohol outlet density), and rural versus urban effects (Albert and Barth, 1996; Coulton et al., 2007; Freisthler et al., 2006).

Opioid prescribing rates also differ between states (Schieber et al., 2019), change within counties over time (Guy et al., 2017), and could help to explain variation in risk for substantiated child abuse and neglect. To address this critical gap in our understanding of how opioid prescriptions affect children and families, the present study used a Bayesian spatiotemporal modeling approach to account for spatial and temporal dependencies in the child maltreatment and opioid prescribing data. Bayesian spatiotemporal models have previously demonstrated associations between referrals to child protective services and both alcohol outlet density and drug-related crime incidents (Freisthler and Weiss, 2008). Although the importance of accounting for both spatial and temporal effects in the analysis of social problems has long been recognized, incorporating temporal influences appropriately has presented a challenge for social-ecological research. Prior studies have commonly used linear time trend modeling (Freisthler and Weiss, 2008); however, temporal structures such as autoregressive models can be more appropriate for studies including more time periods (Martínez-Beneito et al., 2008). The autoregressive model is a particularly useful tool to examine the influence of aggregate person- and place-centered characteristics on risk for substantiated child abuse and neglect because it can describe any form of time trend.

In the present study we propose an autoregressive model to determine the relation of opioid prescription rates to risk for substantiated child maltreatment. We hypothesized that higher opioid prescribing rates would be associated with higher rates of substantiated child abuse and neglect in Tennessee counties from 2006 to 2016, over and above place-centered and person-centered correlates of maltreatment. Place-centered characteristics will include vacant housing, urban versus rural effects, liquor store density, implementation of prescription drug monitoring programs (PDMPs), and child welfare service delivery regions. Person-centered characteristics will include ethnic and racial composition, mean per capita income, child poverty rate, teen birth rate, non-drug crime incidents, overall drug-related crime incidents, and drug crime incidents related specifically to stimulants and narcotics. Opioid prescribing rates represent a potentially malleable risk factor for substantiated child abuse and neglect that could inform targeted prevention programs, policies, and legislation.

## 2. Methods

### 2.1. Data sources

This study was conducted on data spanning an 11-year period (2006–2016) using annual summary statistics for Tennessee counties ( $n = 95$ ). Study procedures were approved by the [BLINDED] institutional review board.

#### 2.1.1. Child abuse and neglect

Substantiated child abuse and neglect rates and demographic and socioeconomic data were obtained from the KIDS COUNT Data Center and provided by the Tennessee Commission on Children and Youth ([www.datacenter.kidscount.org](http://www.datacenter.kidscount.org)). We examined rates of substantiated child abuse and neglect (per 1000 youth), which were based on data provided by the Tennessee Department of Children's Services on unduplicated counts of child abuse and neglect cases supported by

sufficient evidence.

### 2.1.2. Opioid prescribing

Annual opioid prescribing rates from 2006 to 2016 were obtained from the IQVIA Xponent database, which includes data on approximately 90% of retail prescriptions obtained from a nationwide sample of over 50,000 retail pharmacies in the United States (county resident populations were obtained from the U.S. Census Bureau). Opioid prescriptions were identified using the National Drug Code and included initial or refill prescriptions of buprenorphine, codeine, fentanyl, hydrocodone, hydromorphone, methadone, morphine, oxycodone, oxycodone, propoxyphene, tapentadol, and tramadol. The IQVIA Xponent database excluded the following: cough and cold medications containing opioids; buprenorphine products to treat opioid use disorder; methadone dispensed through methadone maintenance treatment programs; all mail order pharmacy data. Opioid prescribing rates for the present study were computed as the total number of retail prescriptions dispensed annually per 100 persons within Tennessee counties (obtained from the U.S. Census Bureau).

### 2.1.3. Place-centered characteristics

Percentages of vacant housing units were based on 5-year estimates provided by the 2006–2011 and 2012–2016 U.S. Census American Community Surveys. Urban versus rural effects were examined using the 2013 Rural-Urban Continuum Codes (RUCC) provided by the U.S. Department of Agriculture Economic Research Service. The RUCC classification system is based on population size, degree of urbanization, and adjacency to metropolitan areas determined by the 2010 Census; the 9 RUCC codes range from 1 (counties in metro areas of 1 million population or more) to 9 (completely rural or less than 2500 urban population, not adjacent to a metro area). Liquor store density was based on 2010 data provided by the U.S. Census Bureau's County Business Patterns on the number of liquor stores per 10,000 residents. A state-level variable was used to reflect the introduction of the PDMP comprehensive use mandate in 2013 (PDMP = 0 from 2006 to 2012; PDMP = 1 from 2013 to 2016). The Tennessee comprehensive use mandate requires prescribers to check the PDMP, an electronic database tracking controlled substance prescriptions within the state, prior to initial opioid prescriptions with regular checks (at least annually) for continuous course treatments. Regional variations in child protective services delivery across Tennessee during the study were captured by assigning each county to one of the 12 Department of Children's Services regions ([https://files.dcs.tn.gov/dcsAssets/DCS\\_Regional\\_Map.pdf](https://files.dcs.tn.gov/dcsAssets/DCS_Regional_Map.pdf)).

### 2.1.4. Person-centered characteristics

Percentages of the population under 18-years-old identifying as African American and percentages of the population under 18-years-old identifying as Hispanic were based on annual data from 2006 to 2015 provided by the U.S. Department of Justice, Office of Juvenile Justice and Delinquency Prevention, on total numbers of African-American and Hispanic youth who reside in Tennessee. Mean per capita income was based on annual data from 2006 to 2015 provided by the Regional Economic Information System, Bureau of Economic Analysis website, on Census Bureau midyear population estimates. Percentages of children in poverty were based on annual data from 2007 to 2016 provided by the U.S. Census Bureau, Small Area Income and Poverty Program, on children under the age of 18 who were living in families whose total income was below the official poverty threshold. Teen birth rate was based on annual data from 2006 to 2016 provided by the Tennessee Department of Health on the number of live births per 1000 females ages 15 to 17.

Crime report data for victims ages 18 and over were obtained from the Tennessee Bureau of Investigation's Incident Based Reporting System ([www.crimeinsight.tbi.tn.gov](http://www.crimeinsight.tbi.tn.gov)). These variables, all reported per 100,000 population, included non-drug and drug-related arrests. Non-

drug arrests included assaults, sexual incidents, stalking incidents, thefts, and property damage incidents. Drug-related arrests included drug/narcotic violations and drug/narcotic equipment violations; these arrests were further broken down into arrests for stimulants (i.e., amphetamines, methamphetamines, other stimulants) and narcotics (i.e., crack cocaine, cocaine, heroin, morphine, opium, other narcotics). Data on arrests for fentanyl and Carfentanil were not available for specific counties during the study period.

## 2.2. Data analytic strategy

Rates of substantiated child abuse and neglect as well as correlates of child maltreatment tend to cluster together spatially and to correlate over time. Bayesian spatiotemporal models can address both spatial autocorrelation and temporal dependence, making them well-suited for the analysis of this type of longitudinal spatial data. In the present study, substantiated child abuse and neglect cases in the state of Tennessee were modeled using a conditionally independent Poisson distribution:

$$y_{it} | \eta_{it} \sim Po(E_{it} \exp(\eta_{it})), \quad i = 1, \dots, 95, \quad t = 1, \dots, 11$$

where  $y_{it}$  is the number of children with substantiated child maltreatment reports,  $\eta_{it}$  defines the log relative risk for every county and year, and  $E_{it}$  is the expected number of cases of substantiated abuse and neglect in proportion to the population under 18-years-old in each county and year.

The relation of opioid prescribing rate to risk for substantiated child abuse and neglect over time was tested using a Bayesian spatiotemporal model that controlled for place-centered characteristics (i.e., vacant housing, urban versus rural effects, liquor store density, PDMPs, child welfare delivery regions) and person-centered characteristics (i.e., percentage Hispanic, percentage African American, mean per capita income, child poverty, teen birth rate, rates of drug and non-drug crime incidents). An autoregressive model (Martínez-Beneito et al., 2008) was used to determine the relative risk for substantiated child abuse and neglect in each county based on prior risk estimates for that county, risk estimates for neighboring counties in that year, and risk estimates for neighboring counties in previous years. In this approach, relative risks are both spatially and temporally dependent at the same time (Martínez-Beneito et al., 2008). Specifically, the log relative risk was defined as follows:

$$\eta_{i1} = \beta_0 + X_{i1}\beta + \alpha_1 + (1 - \rho^2)^{-1/2}(\phi_{i1} + \theta_{i1})$$

$$\eta_{it} = \beta_0 + X_{it}\beta + \alpha_t + \rho(\eta_{i(t-1)} - \beta_0 - \alpha_{t-1}) + \phi_{it} + \theta_{it}$$

The autoregressive model includes the log relative risk for 2006 ( $\eta_{i1}$ ) and subsequent years ( $\eta_{it}$ ); the latter are defined as a function of the estimations for previous periods. In this model,  $\beta_0$  is the overall risk level,  $X_{it}$  is the vector of covariates (which multiply the vector of regression coefficients  $\beta$ ), and  $\alpha_t$  is the mean deviation of risk for year  $t$ . This model incorporates two spatial random effects: a structured spatial random effect ( $\phi_{it}$ ) and an unstructured spatial random effect ( $\theta_{it}$ ) (Besag, York and Mollié, 1991). The autoregressive model also includes a temporal correlation structure  $\rho$ , a spatially-invariant parameter to estimate changes in rates of substantiated child abuse and neglect over time. Defining time in this manner (as compared to models with linear or quadratic trends) allows for increased flexibility and precision describing temporal trends in studies with greater numbers of repeated measurements (Martínez-Beneito et al., 2008).

Prior distributions were assigned for the parameters as follows: vague Gaussian distributions for  $\beta$  parameters; improper uniform distribution for  $\beta_0$ ; normal distribution  $N(0, \sigma^2)$  for the unstructured effects ( $\theta$  and  $\alpha$ ); conditional spatial autoregressive (CAR) model for the structured effect ( $\phi$ ) (Besag et al., 1991). Mean per capita income and non-drug incidents were each divided by 1000 to solve computational problems with the prior distributions assigned to fixed effects due to the

magnitudes of these variables. Markov Chain Monte Carlo (MCMC) techniques generated 200,000 iterations but discarded the first 20,000 as burn in period.

Three different methods were used to assess convergence and goodness of fit for the autoregressive model. First, the Deviance Information Criterion (DIC; Spiegelhalter et al., 2002) of the autoregressive model was compared to other spatial (Besag et al., 1991), and spatiotemporal (Lawson et al., 2003) models. Findings revealed that the autoregressive model had a substantially better fit than the spatial and spatiotemporal models, as indicated by smaller DIC values and between-model differences greater than 10. Second, a convergence diagnosis  $\hat{R}$  (Gelman et al., 2013) close to 1.0 and an effective sample size greater than 100 for all parameters (except for the intercept) revealed good model convergence. Finally, visual inspection of plots for the spatial and temporal structures revealed good convergence. R software and the WinBUGS package were used to conduct Bayesian spatiotemporal modeling.

### 3. Results

Descriptive statistics for study variables for every year are presented in Table 1. An average of 136.6 opioid prescriptions were dispensed per 100 persons in Tennessee counties from 2006 to 2016. Opioid prescription rates in Tennessee were at 126.8 per 100 persons in 2006, reached a peak of 152.3 per 100 persons in 2010, and then decreased to 121.9 per 100 persons in 2016.

Results of the Bayesian spatiotemporal model are presented in Table 2. Variables whose 95% HDR (high density regions) did not contain zero were considered relevant. Higher risk for substantiated child abuse and neglect was independently associated with higher rates of opioid prescribing after controlling for place- and person-centered characteristics. Of the place-centered characteristics, only higher percentages of vacant housing were associated with higher risk for substantiated child abuse and neglect. Neither RUCs, liquor store density, PDMP comprehensive use mandate, nor child welfare delivery regions were independently associated with risk for substantiated child maltreatment.

Of the person-centered characteristics, higher percentages of African American residents were associated with lower risk for substantiated child abuse and neglect. In contrast, higher child poverty rates, teen birth rates, non-drug crime incidents, drug-related crime incidents, and stimulants arrests incidents were all independently associated with higher risk for substantiated child abuse and neglect. Neither Hispanic composition, per capita income, nor narcotics arrest incidents were independently associated with risk for substantiated child maltreatment.

These results can be interpreted in terms of odds ratios to assess the relative contribution of each predictor in the model to overall risk. Our results suggest that each additional 50 retail opioid prescriptions per 100 residents were associated with a 5% increase in rates of substantiated child abuse and neglect. For place-centered characteristics, an increase of 10% in vacant housing units is associated with a 16% increase in rates of substantiated child abuse and neglect. For person-centered characteristics, an increase of 10% in African American residents is associated with a 9% decrease in rates of substantiated child abuse and neglect. An increase of 10% in the child poverty rate and teen birth rates would result in 18% and 4% increases in rates of substantiated child abuse and neglect, respectively. In addition, an increase of 500 in rates of non-drug and drug-related crime incidents would result in 1.7% and 5% increases in rates of substantiated child abuse and neglect, respectively. Finally, an increase of 1 per 1000 persons in rates of stimulants arrest incidents would result in an 8% increase in rates of substantiated child abuse and neglect.

The posterior distributions of fixed effects that were found to be relevant in the autoregressive model are presented in Fig. 1. These plots indicate the probability of a negative or positive association between

each predictor and the outcome. The density plot for opioid prescription rates indicates that rates of substantiated child abuse and neglect are higher in areas with higher rates of opioid prescriptions, with a 99.5% probability of having a positive association. Annual growth in risk for substantiated child abuse and neglect, controlling for all covariates, is presented in Fig. 2. This plot reveals a pattern of decreasing risk for substantiated child abuse and neglect from 2006 to 2008, followed by increasing risk that reaches a peak in 2013.

### 4. Discussion

Opioid prescribing rates were positively associated with risk for substantiated child abuse and neglect across Tennessee counties from 2006 to 2016, such that an increase of 50 retail prescriptions dispensed per 100 residents (approximately equivalent to a one-standard-deviation increase) was linked to a 5% increase in the number of substantiated maltreatment cases per 1000 youth. Importantly, the association of opioid prescribing rates and substantiated child maltreatment remained significant over and above the influence of empirically supported environmental and population-level correlates of maltreatment. Recent work has demonstrated a link between both all-dose (Quast et al., 2018) and high-dose (Quast et al., 2019) opioid prescribing rates and foster care entries across counties. Child removals represent a small fraction of substantiated maltreatment cases (U.S. Department of Health and Human Services, 2019) and require that a child is deemed at moderate-to-high risk for subsequent maltreatment (i.e., they have already been seriously harmed or are at risk of serious harm or have their safety threatened). The present study extends research on foster care entries (Quast et al., 2018, 2019) by showing that higher opioid prescribing rates are associated with higher rates of substantiated child abuse and neglect, which reflect a broader spectrum of maltreatment severity and include maltreated children who remained in their homes. Importantly, however, rates of substantiated child maltreatment cases cannot account for incidents of abuse or neglect that were either unreported or reported but could not be substantiated by the child welfare system. The true scope of child abuse and neglect is likely to be underestimated because many survivors never report their abuse (MacMillan et al., 2003).

This study strengthens support for the link between crime and child maltreatment by showing that drug-related and non-drug crime incidents were each independently associated with higher risk for substantiated child abuse and neglect across Tennessee counties. Prior research has shown that drug-related arrests are positively associated with referrals to child protective services across counties (Freisthler and Weiss, 2008). Higher crime rates (including drug crimes) are also associated with greater risk for maltreatment using address-level data (Daley et al., 2016). The present findings add to this literature by showing that stimulants arrests – but not narcotics arrests – were associated with greater risk for substantiated child abuse and neglect. Methamphetamine use may increase risk for child maltreatment through multiple pathways, including child exposure to chemicals involved in home manufacture and negative impacts on parenting behaviors resulting in neglect (e.g., lack of supervision, abandonment, leaving children in unsafe environments), abuse (e.g., inappropriate or dangerous child care providers, punitive parenting), and children witnessing domestic violence (Brown and Hohman, 2006).

Person-centered characteristics including higher child poverty and teen birth rates were independently associated with risk for substantiated child abuse and neglect within counties over time, which extends mostly cross-sectional evidence for links between child maltreatment and both child poverty (Coulton et al., 2007; Freisthler et al., 2006) and teen birth rates (Zuravin and Diblasio, 1992). The present study also replicated prior work on racial composition (Smith et al., 2017) by demonstrating that counties with higher percentages of African Americans were at lower risk for substantiated child abuse and neglect. The mechanisms that account for this reduced risk have not

**Table 1**  
Tennessee County Characteristics and Descriptive Statistics.

Variables	Annual Summary										
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Substantiated Child Abuse and Neglect	13.46 (5.90)	11.73 (7.82)	7.59 (5.41)	6.92 (4.25)	6.63 (3.14)	6.22 (2.52)	6.30 (2.31)	6.84 (2.75)	6.69 (2.40)	7.54 (2.64)	5.86 (2.56)
Place-Centered Characteristics						14.44 (5.24)					15.38 (6.26)
Vacant housing								4.45 (2.66)			
Urban versus rural effects											
Liquor store density	0	0	0	0	0.68 (0.81)	0	0	1	1	1	1
Prescription drug monitoring programs <sup>a</sup>	8.25 (2.70)	8.25 (2.70)	8.25 (2.70)	8.25 (2.70)	8.25 (2.70)	8.25 (2.70)	8.25 (2.70)	8.25 (2.70)	8.25 (2.70)	8.25 (2.70)	8.25 (2.70)
Child welfare delivery regions											
Person-Centered Characteristics											
% Hispanic	2.49 (1.88)	2.63 (2.00)	2.76 (2.09)	2.89 (2.17)	2.97 (2.23)	3.08 (2.24)	3.19 (2.27)	3.26 (2.31)	3.35 (2.31)	3.45 (2.35)	
% African American	8.47 (11.79)	9.03 (11.98)	8.97 (11.59)	9.33 (11.41)	9.06 (12.36)	9.16 (12.24)	9.24 (12.10)	9.43 (12.01)	9.58 (11.96)	9.73 (11.92)	
Mean per capita income	19,768 (4,404)	20,583 (4,659)	21,214 (4,925)	22,552 (5,765)	22,607 (5,218)	23,791 (4,670)	24,686 (5,619)	25,457 (5,443)	26,863 (6,347)	20,844 (6,415)	
Child poverty	25.39 (9.74)	24.61 (9.81)	24.62 (6.19)	27.04 (6.25)	29.51 (6.81)	29.59 (6.27)	29.05 (6.12)	29.06 (6.34)	27.85 (5.99)	27.47 (6.55)	25.81 (6.57)
Teen birth rate	6.505 (2.870)	6.697 (2.786)	6.366 (2.797)	6.168 (2.621)	6.040 (2.450)	5.973 (2.240)	5.640 (2.119)	5.220 (2.025)	5.052 (1.989)	4.989 (2.008)	5.019 (2.010)
Non-drug crime incidents	777.8 (411.8)	837.8 (430.5)	737.8 (374.5)	776.2 (434.1)	799.2 (380.8)	863.8 (386.1)	922.9 (414.8)	891.8 (358.8)	898.7 (372.8)	936.5 (485.0)	1143.5 (586.5)
Drug-related crime incidents	0.42 (0.48)	0.37 (0.39)	0.34 (0.36)	0.50 (0.57)	0.62 (0.65)	0.65 (0.59)	0.66 (0.58)	0.69 (0.57)	0.75 (0.65)	1.05 (0.84)	1.63 (1.10)
Stimulants arrest incidents	1.39 (1.03)	1.53 (1.20)	1.39 (1.07)	1.41 (1.22)	1.42 (0.98)	1.75 (1.31)	1.84 (1.62)	1.74 (1.34)	1.59 (1.02)	1.58 (1.06)	1.77 (1.25)
Narcotics arrest incidents	126.8 (52.49)	134.3 (55.34)	138.2 (60.13)	146.4 (59.59)	152.3 (57.34)	150.7 (59.15)	150.1 (55.38)	145.5 (47.53)	137.0 (46.97)	129.5 (43.37)	121.8 (38.41)
Opioid prescribing rate											

<sup>a</sup> This variable was computed for the county level: zero for years from 2006 to 2012, and one for years from 2013 to 2016.

**Table 2**  
Tennessee County Characteristics Associated with Substantiated Child Abuse and Neglect from 2006 to 2016.

	Bayesian Spatiotemporal Model				ESS	Relative Risk
	Mean	SD	95% HDR			
Intercept	-1.1208	0.2031	-1.5019, -0.7235		79	
<b>Place-Centered Characteristics</b>						
Vacant housing	0.0156*	0.0052	0.0053, 0.0261		1000	1.016 (1.005, 1.026)
Urban versus rural effects	-0.0108	0.0126	-0.0359, 0.0143		840	
Liquor store density	-0.0571	0.0302	-0.1165, 0.0036		1000	
Prescription drug monitoring programs	0.0793	0.1203	-0.1608, 0.3196		600	
Child welfare delivery regions	-0.0006	0.0149	-0.0299, 0.0280		130	
<b>Person-Centered Characteristics</b>						
% Hispanic	-0.0102	0.0137	-0.0367, 0.0153		660	
% African American	-0.0095*	0.0033	-0.0160, -0.0030		1000	0.991 (0.984, 0.997)
Mean per capita income <sup>a</sup>	0.0033	0.0029	-0.0019, 0.0091		600	
Child poverty	0.0178*	0.0038	0.0106, 0.0256		410	1.018 (1.010, 1.026)
Teen birth rate	0.0043*	0.0015	0.0012, 0.0072		600	1.004 (1.001, 1.007)
Non-drug crime incidents <sup>a</sup>	0.0335*	0.0108	0.0117, 0.0546		130	1.034 (1.0125, 1.0568)
Drug-related crime incidents	0.0001*	0.0001	0.00001, 0.0002		1000	1.0001 (1.0001, 1.0002)
Stimulants arrest incidents	0.0760*	0.0278	0.0220, 0.1302		1000	1.079 (1.023, 1.140)
Narcotics arrest incidents	-0.0088	0.0165	-0.0418, 0.0273		530	
Opioid prescribing rate	0.0011*	0.0004	0.0003, 0.0019		1000	1.001 (1.0003, 1.002)
$\sigma_U$	0.2312	0.0139	0.2031, 0.2574		1000	
$\sigma_S$	0.2431	0.0378	0.1665, 0.3164		1000	
$\sigma_T$	0.1042	0.0356	0.0549, 0.1895		1000	
$\rho$	0.6817	0.0283	0.6643, 0.7329		1000	

Note: ESS = effective sample size.

\* 95% high density regions (HDR) does not include zero.

<sup>a</sup> This variable was divided by 1000 to solve computational problems with the prior distributions assigned to fixed effects due to its magnitude.

been elucidated but may involve cultural differences in parenting practices, extended family support, social cohesion, and/or childcare assistance. Notably, opioid prescribing rates are higher in counties with larger percentages of non-Hispanic white residents (Guy et al., 2017) and recent evidence highlights a stronger association between opioid prescribing rates and child removals in counties with higher percentages of White residents (Quast et al., 2018). Future studies are needed

to identify socio-contextual factors contributing to elevated risk for both opioid prescriptions and child maltreatment among non-Hispanic white residents.

Prescription opioid abuse and child maltreatment represent overlapping public health crises in the United States that together incur estimated annual costs exceeding \$500 billion (Florence et al., 2016; Peterson et al., 2018). Rates of opioid prescriptions and substantiated

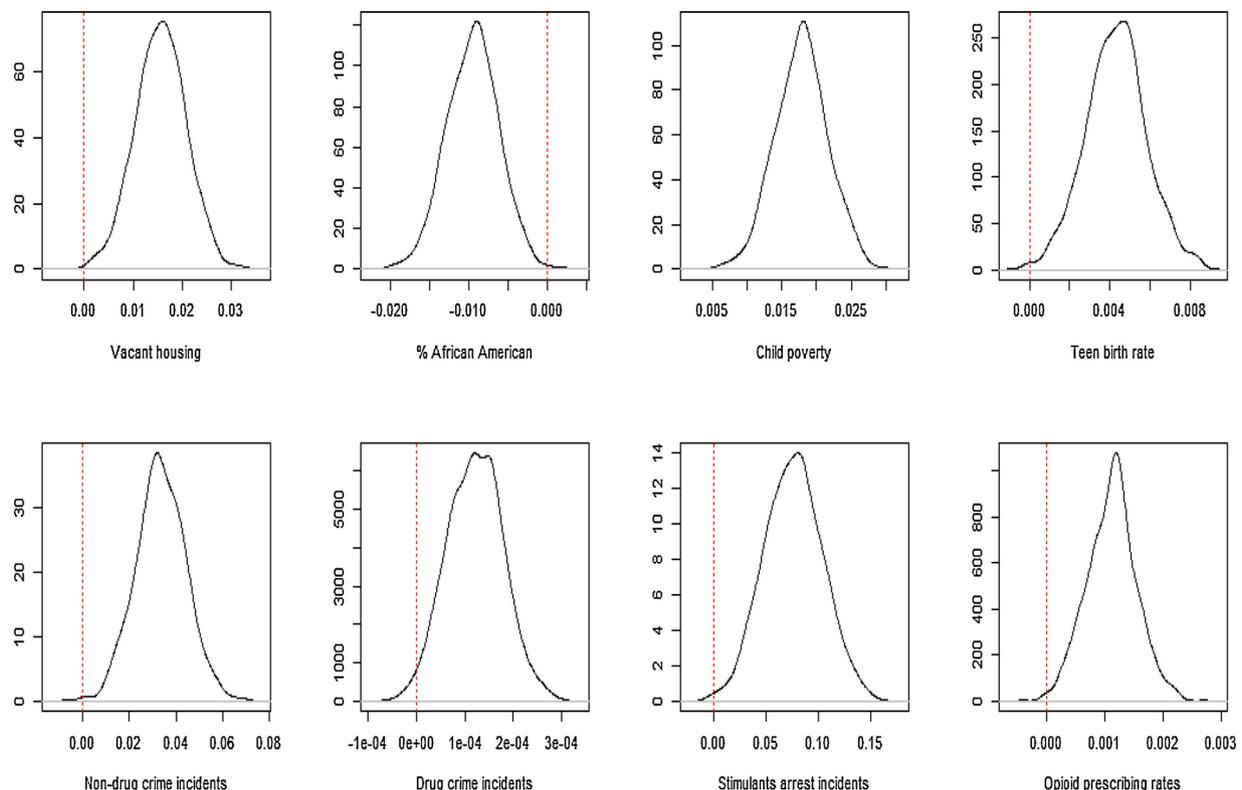


Fig. 1. Posterior density plots for fixed effects that did not include zero in the 95% HDR.

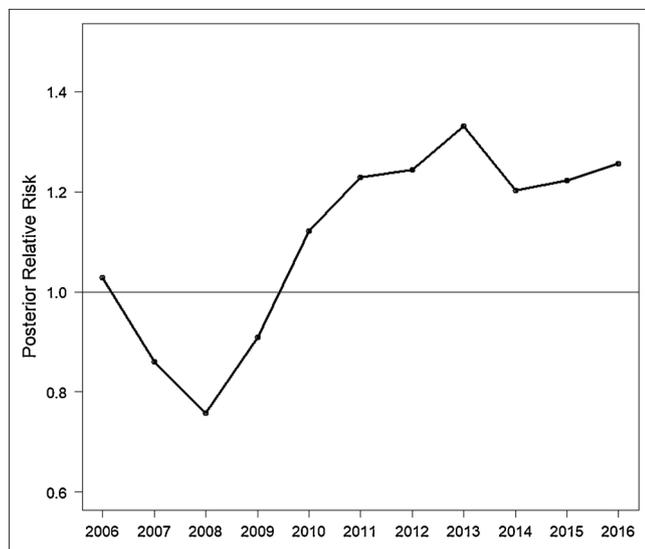


Fig. 2. Posterior estimated growth of relative risk of substantiated child abuse and neglect.

child abuse and neglect vary substantially across Tennessee counties and are associated with increased risk for a variety of negative physical and mental health outcomes across the lifespan (Kolodny et al., 2015; Wegman and Stetler, 2009). The present findings have important implications for public health efforts to prevent child maltreatment: they suggest that curbing opioid prescribing could lower rates of substantiated child maltreatment. For example, a one-standard-deviation decrease in rates of opioid prescribing in Tennessee could result in a 5% decrease in rates of substantiated child abuse and neglect. Whether recent efforts to regulate opioid prescribing are connected with decreases in substantiated child maltreatment cases represents an important avenue for future research. Although the present study found that the adoption of mandatory PDMPs in Tennessee was not significantly associated with changes in risk for substantiated child abuse and neglect, this Bayesian spatiotemporal model is not well-suited to interrogating the plausibly causal effects of this program. Quasi-experimental research shows that introduction of mandatory PDMPs, which mandate prescribers/dispensers to perform PDMP queries, resulted in a 10% decrease in child removals (Gihleb et al., 2018). The Kentucky Sobriety Treatment and Recovery Teams (START) program emphasizes early identification and screening of families with substance-exposed children, provides parents with rapid access to substance use disorder treatment, and has been shown to reduce child removal rates (Huebner et al., 2012). The broader impact of PDMPs and promising programs such as START on rates of substantiated cases of child abuse and neglect, and their capacity to reduce the staggering annual costs associated with maltreatment in the United States, have yet to be determined.

One notable methodological strength of this study stems from the specification of an autoregressive model to simultaneously assess spatial and temporal structures across an 11-year matrix of data. Whereas other spatiotemporal models incorporate linear time trends that are unlikely to adequately capture changes in risk with larger numbers of repeated measurements (see Fig. 2), the autoregressive model allows the temporal structure to take any shape, including non-linear effects. Capturing patterns of increases or decreases in relative risk for a particular year makes the autoregressive model particularly useful for local (in this case county-level) prediction of risk for substantiated child maltreatment. The present findings add to a growing literature demonstrating the utility of autoregressive models for improving our understanding of social problems with spatiotemporal properties (Gracia et al., 2017; Marco et al., 2017, 2018; Morris et al., 2019a,

2019b).

Limitations of the present study provide directions for future research. First, opioid prescribing rates were based on retail prescription data in the United States and do not capture average dosages of prescriptions, high-dose prescriptions that could be especially relevant for opioid misuse (Quast et al., 2019), nor can they account for rates of illicit opioid use or illegal diversion of prescription opioids. Nevertheless, opioid prescribing rates track closely with illicit opioid use (Schuchat et al., 2017) and can be targeted through community-based programs and policy initiatives. Second, county-level data on substantiated child abuse and neglect could not distinguish subtypes of child maltreatment (e.g., physical abuse, sexual abuse, neglect) that may be more or less strongly associated with opioid prescribing rates. Third, examining substantiated cases of child abuse and neglect as our outcome variable had a number of benefits, including verification of reports by child protective services. Nevertheless, rates of substantiations are susceptible to a variety of social-ecological factors that influence whether and where maltreatment will be detected by child protective services. Finally, the present study relied on county-level aggregate data that can be useful for the development and refinement of community programs and initiatives implemented at higher levels of the social ecology but cannot directly inform inferences regarding individual- and family-level behaviors. Replication of models using different spatial units (e.g., zip codes, census tracts, neighborhoods) and adaptation of models for the longitudinal study of family units are needed to address the modifiable area unit problem and aggregation bias, respectively.

#### 4.1. Conclusions

Although rates of child abuse and neglect have declined over the last two decades (Finkelhor et al., 2013), elevated opioid prescribing rates have the potential to alter this trajectory. The present study contributes to a growing literature on the determinants of child maltreatment by demonstrating an association between higher opioid prescribing rates and increased risk for substantiated child abuse and neglect. A Bayesian spatiotemporal approach was used to examine environmental and population-level factors for child maltreatment across Tennessee counties over an 11-year period. Monitoring spatiotemporal patterns in annual opioid prescribing rates could help to identify counties with high and/or increasing relative risk for substantiated child maltreatment that are in need of prevention services. Future studies are needed to probe the potential causal relationship between opioid prescribing rates and substantiated child abuse and neglect, and to investigate potential mediators such as the development of opioid use disorder and co-occurring psychiatric conditions as well as alterations in parenting behaviors (Fischer et al., 2012; Ghertner et al., 2018; Slesnick et al., 2014).

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#### Contributors

M.C. Morris, M. Marco, and W. Im designed the study. M.C. Morris and W. Im were involved in the data acquisition. M. Marco was involved in the data preparation and analysis. All authors were involved in the preparation and editing of the manuscript and take responsibility for the integrity of the data and accuracy of the data analysis.

## Declaration of Competing Interest

The authors have no conflicts of interest to declare.

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