



County-level associations between tobacco retailer density and smoking prevalence in the USA, 2012

Shelley D. Golden^{a,b,*}, Tzy-Mey Kuo^b, Amanda Y. Kong^a, Christopher D. Baggett^{b,c},
Lisa Henriksen^d, Kurt M. Ribisl^{a,b}

^a Department of Health Behavior, Gillings School of Global Public Health, University of North Carolina, 135 Dauer Drive, Chapel Hill, NC 27599-7440, USA

^b Lineberger Comprehensive Cancer Center, University of North Carolina, 101 Manning Drive, Chapel Hill, NC 27599-7295, USA

^c Department of Epidemiology, Gillings School of Global Public Health, University of North Carolina, 135 Dauer Drive, Chapel Hill, NC 27599-7435, USA

^d Stanford Prevention Research Center, 3300 Hillview Ave Suite 120, Palo Alto, CA 94304, USA

ARTICLE INFO

Keywords:

Tobacco retailer density
Smoking prevalence
Geographic disparities

ABSTRACT

We examine whether county-level tobacco retailer density and adult smoking prevalence are positively associated in the United States and determine whether associations differ in metropolitan vs. nonmetropolitan counties. We merged a list of likely tobacco retailers from the 2012 National Establishment Time-Series with smoking prevalence data from the Behavioral Risk Factor Surveillance System for 2828 US counties, as well as state tobacco policy information and county-level demographic data for the same year. We modeled adult smoking prevalence as a function of tobacco retailer density, accounting for clustering of counties within states. Average density in US counties was 1.25 retailers per 1000 people (range = 0.3–4.5). Smoking prevalence was 0.86 percentage points higher in the most retailer-dense counties, compared to the least. This association, however, was only significant for metropolitan counties. Metropolitan counties in the highest tobacco retailer density quartile had smoking prevalence levels that were 1.9 percentage points higher than metropolitan counties in the lowest density quartile. Research should examine whether policies limiting the quantity, type and location of tobacco retailers could reduce smoking prevalence.

1. Introduction

Tobacco use remains the leading preventable cause of death in the United States (US) (U.S. Department of Health and Human Services, 2014). The field of tobacco control increasingly recognizes the influence of the retail environment on tobacco use (State and Community Tobacco Control Research, 2017). There are nearly 375,000 tobacco retailers in the US (State and Community Tobacco Control Research, 2016), and in one study smokers in a US city passed an average of 2.7 tobacco retailers during their daily travel (Kirchner et al., 2013). Tobacco retailer density measures the concentration of tobacco retailers in a given administrative unit (e.g., census tract or county) (Lee et al., 2017; Loomis et al., 2013), specific area around a residence or school (Schleicher et al., 2016), or activity space (Kirchner et al., 2013). A better understanding of the extent to which tobacco retailer density is associated with smoking behavior could guide the development of initiatives and policies to promote a healthier retail environment (Henriksen et al., 2017).

Living in areas with a higher concentration/density of tobacco retailers is associated with higher rates of smoking (Clemens et al., 2018), and reduced likelihood of smoking cessation (Kirchner et al., 2017; Chaiton et al., 2018). However, existing evidence characterizes specific populations (e.g., non-daily smokers (Kirchner et al., 2017), young adults (Cantrell et al., 2016), pregnant women (Clemens et al., 2018)), and national studies are rare. A recent study of census tracts in the 500 largest cities in the US documented a positive association between tract-level tobacco retailer density and adult smoking prevalence, controlling for median household income and percent non-White residents (Leas et al., 2019). In New Zealand, higher odds of smoking were associated with shorter travel distances to supermarkets and convenience stores where tobacco was sold, but this effect was not significant once measures of neighborhood deprivation were included (Pearce et al., 2009). In Scotland, higher retailer density was significantly associated with a 3–7% increased chance of being a current smoker, after controlling for individual demographics, and area urbanicity (Pearce et al., 2016).

Tobacco retailer density is commonly measured by calculating the

* Corresponding author at: Department of Health Behavior, Gillings School of Global Public Health, University of North Carolina, 135 Dauer Drive, Chapel Hill, NC 27599-7440, USA.

E-mail address: sgolden@email.unc.edu (S.D. Golden).

<https://doi.org/10.1016/j.pmedr.2019.101005>

Received 17 June 2019; Received in revised form 15 September 2019; Accepted 27 September 2019

Available online 31 October 2019

2211-3355/© 2019 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

number of retailers within a geographic area (e.g., census tract, school buffer) divided by the number of residents, land area or roadway miles (PhenX Tobacco Regulatory Project, 2018). These approaches are relatively easy to calculate and interpret but ignore retailers in neighboring geographic areas. Yet consumers likely cross administrative boundaries (e.g., census tracts or counties) in their daily travels (Kirchner et al., 2013). Furthermore, relative travel costs may be higher for consumers in urban areas who travel fewer miles per day overall (Santos et al., 2009). Other researchers employ more sophisticated adaptive kernel estimation measures of tobacco retailer density that account for surrounding population density, and recommend analyses stratified by urbanicity (Carlos et al., 2010; Rodriguez et al., 2013).

Following these recommendations, the current study estimates tobacco retailer density for all US counties and examines how tobacco retailer density and smoking co-vary geographically using data for all 50 US states and the District of Columbia (DC) in 2012. The analyses compare results using adaptive kernel density measures with a more common ratio measure of retailer density and test whether associations differ for metropolitan and non-metropolitan counties.

2. Materials & methods

The study outcome is county-level, age-standardized prevalence of cigarette smoking among US adults in 2012, which was derived from the Behavioral Risk Factor Surveillance System (BRFSS) and published by Dwyer-Lindgren and colleagues (Dwyer-Lindgren et al., 2014). BRFSS is a system of telephone surveys that collects state data about health behaviors, including smoking. Respondents report whether they have smoked at least 100 cigarettes in their lifetime and if so, whether they currently smoke cigarettes on some or all days. By applying small area estimation models to the individual-level BRFSS data from the 3141 counties or county equivalents in the US, weighting by county demographic information, and merging estimates for small counties, Dwyer-Lindgren's team estimated annual county-level smoking prevalence measures for 3127 counties between 1996 and 2012. We used the 2012 prevalence measures as they were the most recent year for which the estimates were calculated.

2.1. Tobacco retailer density

The US has no national license system for tobacco retailers, and only 36 states and the District of Columbia (DC) require tobacco retailer licensing (State Tobacco Control Laws & Policies Database, 2019). We therefore identified likely tobacco retailers based on type of store using the National Establishment Time-Series (NETS), a longitudinal database developed by Walls & Associates that contains archival establishment (store) data from Dun and Bradstreet (D&B) (Kauffman, 2017). In addition to geolocation information about each store, NETS includes store type codes developed by the Census Bureau North American Industry Classification System (NAICS). Consistent with prior studies (Leas et al., 2019; Ribisl et al., 2017; Rodriguez et al., 2013), we created a list of all 344,935 stores in 2012 with one of the top ten NAICS codes based on tobacco sale revenue, and then removed retail chains that do not sell tobacco (e.g., Target), and stores without a street address. Since relatively few non-chain pharmacies sell tobacco, we only retained those pharmacies included in Drug Store News' list of top 50 pharmacy chains by sales (Retailer Pharmacy, 2018) (Table 1).

We calculated two measures of tobacco retailer density. Using geocodes in the NETS data, we totaled the number of tobacco retailers in each county, then divided this figure by the total county population and multiplied by 1000 (i.e., retailers per 1000 persons) (Carlos et al., 2010). A second measure of density was created using adaptive kernel density estimation (Shi, 2010), an analytic process previously employed in tobacco retailer density research (Kirchner et al., 2017; Rodriguez et al., 2013). The analysis fits a curved surface over each tobacco retailer, with its highest point at the retailer, sloping away in all

Table 1

Likely tobacco retailers identified (2012; N = 3127 counties in 50 US states and DC).

NAICS Code	Retailer	N
445,110	Supermarkets and other grocery (except convenience) stores: excluding Aldi, Trader Joe's, Whole Foods, and Target	127,501
445,120	Convenience stores	71,199
453,991	Tobacco stores	7947
447,110	Gasoline stations with convenience stores	33,714
452,910	Warehouse clubs and supercenters	1818
451,212	News dealers and newsstands	51
445,310	Beer, wine, and liquor stores: excluding ABC stores	37,553
446,110	Pharmacies and drug stores: limited to top 50 stores	21,028
452,112	Discount department stores: includes only Wal-Mart and Family Dollar	3648
447,190	Other gasoline stations	40,476
	Total retailers included	344,935

Note: Stores are identified based on North American Industry Classification System (NAICS) of likely tobacco retailers in the National Establishment Time Series (NETS).

directions to eventually have zero height at a specified distance or "bandwidth." Adaptive bandwidths are drawn to correspond to a specific population size, rather than a fixed distance, resulting in smaller bandwidth distances in urban areas, which may better reflect the true market for stores.

Following previous analyses (Rodriguez et al., 2013), we drew bandwidths to include 1000 people, with a limit of 25 geographic kilometers in population-sparse areas. Population data for bandwidths were from the 2012 LandScan USA (Bhaduri et al., 2007), which uses spatial analyses and satellite imagery to produce small-scale population estimates. By averaging densities within each county, we produced estimates of retailer density. As with the first density measure, the adaptive kernel estimation unit is tobacco retailers per 1000 people, although denominators may vary in counties where the 25 km distance limit was employed. The adaptive kernel density estimation was conducted in ArcHealth software obtained from Dr. Xun Shi, of Spatial Inference Enterprises, LLC (Shi, 2010). The software computes retailer density with a population or distance bandwidth and was installed in ArcMap 10.4 (Environmental Systems Research Institute, Redlands, CA, 2015). After computing the adaptive kernel density for the entire state, we computed the mean county-level kernel density.

2.2. Metropolitan area indicator

Metropolitan status was designated using the US Department of Agriculture 2013 Rural-Urban Continuum Codes (RUCC) (US Department of Agriculture, 2016), which classifies counties into nine categories based on population size. Consistent with RUCC definitions, we created a dichotomous variable by designating counties in RUCC 1-3 as metropolitan, and RUCC (4-9) as non-metropolitan.

2.3. Policy and demographic variables

Two tobacco control policies were included as state-level covariates. Cigarette excise tax rates for 2012, measured in US dollars per pack of 20 cigarettes, were downloaded from the State Tobacco Activities Tracking and Evaluation (STATE) system, a database maintained by the Centers for Disease Control and Prevention. Strength of smoke-free air law in each state and DC was measured using the American Lung Association's smoke-free grades (American Lung Association, 2017), based on all policies in existence at the end of 2012. For ease of interpretation, we compared strong (grade of A/B) vs. weak (grade of C or below) state laws, as in previous research (Morley and Pratte, 2013).

We included several county-level demographic measures likely to be associated with tobacco retailer density as control variables. In the US,

higher tobacco retailer densities have been documented in places with greater proportion of residents who are African Americans (Lee et al., 2017; Loomis et al., 2013), Latinos (Loomis et al., 2013; Rodriguez et al., 2013), and low-socioeconomic status (Lee et al., 2017). From the Area Health Resource Files, we obtained county-level estimates of the percentage of residents who were non-Hispanic Black, Hispanic, and male in all 50 US states and DC in 2012. Using 5-year estimates from the American Community Survey (ACS) (2009–2013), we computed county-level estimates for the percent of population living below the federal poverty level. We include these variables in our models, but do not list or interpret model coefficients for them because county demographic proportions were used to derive the small area estimates of smoking prevalence by Dwyer-Lindgren et al.

2.4. Data analysis

The 3127 counties for which BRFSS small area estimates of smoking prevalence have been calculated range in population size from 71 to 9,962,789. In counties with very small populations, estimates of tobacco retailer density are less stable, so we restricted the analyses to 2828 counties with population of 5000 residents or more. The analysis sample represents 90.0% of all US counties and 99.7% of the US population. In sensitivity tests, we compared models with this restricted sample to one using all available county data; the restricted sample had better model fit (results not shown).

We calculated mean tobacco retailer density estimates using both density measures, mean county smoking prevalence, and state tobacco control policy measures for all counties in the restricted sample, and for non-metropolitan and metropolitan county samples separately. To best assess the possibly non-linear relationship between higher vs. lower density areas and smoking, we categorized density into quartiles for analysis. When quartile models showed evidence of a dose-response relationships based on the Jonckheere trend test (Hollander and Wolfe, 1999), we analyzed subsequent models using a continuous density measure to estimate the association of an additional tobacco retailer per 1000 people with county smoking prevalence. We estimated mixed-effects linear models of county smoking prevalence as a function of tobacco retailer density, accounting for nesting of counties within states (intraclass correlation coefficient = 0.50). We estimated separate models for both measures of density, as well as stratified versions of the mixed-effects models to examine associations in metropolitan and non-metropolitan counties separately. All analyses were conducted in SAS 9.4 (SAS Institute, Inc., Cary, North Carolina).

3. Results

The average tobacco retailer density across the 2828 counties was 1.25 tobacco retailers per 1000 people (Table 2). Compared to non-metropolitan counties, metropolitan counties had lower smoking prevalence, tobacco retailer densities, and percentages of people living below the federal poverty line but had higher percentages of Black and Hispanic residents. State cigarette tax rates were also higher, on average, in metropolitan counties, which indicates the metropolitan counties were more likely than non-metropolitan counties to be located in states with higher tax rates. Difference in smoke-free air grade by type of county was not statistically significant.

In 2012, the age-standardized smoking prevalence averaged across all counties was 23.8%, with higher prevalence in non-metropolitan counties than in metropolitan counties (Table 2). This prevalence is higher than the 2012 national smoking prevalence of 18.1% (Agaku et al., 2014) because our estimate represents the average of all 2828 counties (many of which were non-metropolitan) unadjusted for population size.

3.1. Mixed-effects models

Tobacco retailer density was significantly associated with county smoking in both the unadjusted models (Table 3, Models 1 and 2) and models that included demographic and policy covariates (Models 3 and 4), although the magnitude of the effect was smaller in the adjusted models. Results were similar across both measures of tobacco retailer density, but the ratio measure analysis had better model fit statistics. Therefore, we focus on the more easily interpretable model that measures density as the number of retailers divided by the county population, adjusting for covariates (Model 3).

Compared to counties with the lowest tobacco retailer density, counties in the 2nd, 3rd and 4th quartiles had smoking prevalence that was 0.72, 0.94 and 0.86 percentage points higher, respectively. After controlling for density, demographic characteristics and state tobacco control policies, average smoking prevalence in metropolitan counties was 0.74 percentage points lower than in non-metropolitan counties ($p < 0.001$). A \$1.00 higher state cigarette excise tax was associated with a lower county smoking prevalence (coefficient = -0.91, $p < 0.001$) as was having strong instead of weak state smoke-free air laws (coefficient = -1.36; $p = 0.025$).

3.2. Stratified models

In the stratified models, the magnitude of the associations between tobacco retailer density and smoking prevalence were larger in

Table 2

Descriptive statistics for age-standardized county-level adult smoking prevalence and state-level predictors (2012; N = 2828 counties in 50 US states and DC).

	Total (N = 2828)	Metropolitan (n = 1146)	Non-metropolitan (n = 1682)
	Mean/% (range)	Mean/% (range)	Mean/% (range)
Smoking prevalence	23.8 (7.8–41.2)	22.3 (7.8–32.7)	24.8 (9.4–41.2)**
Retailer density			
Retailers per 1000 pop	1.25 (0.25–4.53)	1.11 (0.25–2.67)	1.36 (0.30–4.53)**
Adaptive kernel	0.60 (0.00–8.37)	0.48 (0.10–1.19)	0.69 (0.00–8.37)**
County demographics (%)			
Male	50.0 (43.0–69.9)	49.5 (43.0–65.6)	50.3 (44.6–69.9)**
Black (non-Hispanic)	9.6 (0.1–85.2)	10.9 (0.2–77.8)	8.6 (0.1–85.2)**
Hispanic	8.4 (0.3–95.6)	9.2 (0.5–95.4)	7.9 (0.3–95.6)**
Below federal poverty level	16.2 (3.5–51.6)	14.3 (3.5–34.0)	17.5 (4.3–51.6)**
State tobacco policy			
Cigarette tax (\$)	1.15 (0.17–4.35)	1.22 (0.17–4.35)	1.11 (0.17–4.35)**
Smoke-free air grade			
Strong (A-B)	48.0%	47.8%	48.2%
Weak (C-F)	52.0%	52.2%	51.8%

* $p < 0.05$; ** $p < 0.01$ in *t*-test or chi-square tests comparing metropolitan and non-metropolitan counties.

Table 3

Mixed effects models of tobacco retailer density and county-level adult smoking prevalence (2012; N = 2828 counties in 50 US states and DC).

	Unadjusted		Adjusted	
	Model 1(per 1000)	Model 2(kernel density)	Model 3(per 1000)	Model 4(kernel density)
<i>LEVEL 1 (n = 2828) Retailer Density (range)[†]</i>				
Q1 (0.25–0.96) ref	–	–	–	–
Q2 (0.97–1.21)	1.196**	1.019**	0.724**	0.298*
Q3 (1.22–1.56)	1.768**	1.775**	0.944**	0.511**
Q4 (1.56–4.53)	2.184**	1.823**	0.862**	0.416*
<i>Urbanicity</i>				
Metropolitan	–	–	–0.743**	–0.813**
Non-metropolitan ref	–	–	–	–
<i>LEVEL 2 (n = 51) State Tobacco Policy</i>				
Cigarette tax (\$)	–	–	–0.911**	–0.874**
Smoke-free air grade				
Strong (A-B)	–	–	–1.363*	–1.440*
Weak (C-F) ref	–	–	–	–
<i>MODEL FIT</i>				
AIC			13071.2	13112.9
BIC			13075.0	13116.8

* $p < 0.05$; ** $p < 0.01$.[†] Density ranges describe tobacco retailers per 1000 population. Models 3 and 4 also control for four county demographic variables: the percent of the population that is African American, Hispanic, male and below the federal poverty level.

metropolitan counties (Table 4). Compared to the lowest density counties, counties in the 2nd, 3rd and 4th density quartiles had smoking prevalence that was 1.04, 1.44 and 1.91 percentage points higher, respectively, when controlling for demographic and policy variables (Table 4, Model 3). The Jonckheere trend test confirmed a dose–response relationship with $Z = 12.906$ ($p < 0.0001$). In subsequent analyses with a continuous measure of density, an additional tobacco retailer per 1000 population was associated with a 1.79 percentage point increase in county smoking prevalence in metropolitan counties (results not shown). In non-metropolitan counties, however, we observed no association between tobacco retailer density and county-level smoking prevalence. State tobacco control policies were similarly associated with smoking prevalence in all stratified models.

4. Discussion

This study documents a positive association between two county-level measures of tobacco retailer density and adult smoking prevalence in 2012. Counties with one or more tobacco retailers per 1000 people had significantly higher smoking prevalence than those with fewer, and

smoking prevalence in the most retailer-dense counties was 0.86 percentage points higher than those in the least retailer dense counties. These findings build on previous research that document associations between tobacco retailer density and smoking behaviors in smaller US geographies and population subsets (Schleicher et al., 2016; Kirchner et al., 2017; Cantrell et al., 2016; Pearce et al., 2016). Furthermore, the results illustrate associations between tobacco retailer density and smoking in advance of many of the innovative tobacco retailer density reduction efforts, serving as a pre-policy “baseline” assessment that could inform the dissemination of such policy initiatives.

In places with high tobacco retailer density, smokers invest relatively few resources in traveling to purchase cigarettes. In a US-based simulation model of a policy to reduce the number of tobacco retailers that incorporated travel costs, a 50% retailer reduction was associated with a 2–7% increase in costs, depending on neighborhood type (Luke et al., 2017). In a different simulation model, a 95% retailer reduction in New Zealand was associated with a 20% cost increase in rural areas, and a 10% cost increase elsewhere (Pearson et al., 2015). Higher tobacco retailer density may also increase consumer exposure to tobacco marketing at stores (Loomis et al., 2012); the average retailer has nearly

Table 4

Stratified mixed effects models of tobacco retailer density and county-level adult smoking prevalence by metropolitan (n = 1146) vs. non-metropolitan (n = 1682) designation (2012; N = 2828 counties in 50 US states and DC).

	Unadjusted		Adjusted	
	Model 1 (Metropolitan)	Model 2 (Non-metropolitan)	Model 3 (Metropolitan)	Model 4 (Non-metropolitan)
<i>LEVEL 1 (n = 2828) Retailer Density (range)[†]</i>				
Q1 (0.25–0.96) ref	–	–	–	–
Q2 (0.96–1.21)	1.657**	0.161	1.041**	0.141
Q3 (1.22–1.56)	2.151**	0.271	1.444**	0.319
Q4 (1.56–4.53)	3.132**	0.270	1.913**	0.175
<i>LEVEL 2 (n = 51) State Tobacco Policy</i>				
Cigarette tax (\$)	–	–	–0.917**	–0.938**
Smoke-free air grade				
Strong (A-B)	–	–	–1.437*	–1.500*
Weak (C-F) ref	–	–	–	–

* $p < 0.05$; ** $p < 0.01$.[†] Tobacco retailer density measures retailers per 1000 population. Models 3 and 4 also control for four county demographic variables: the percent of the population that is African American, Hispanic, male and below the federal poverty level.

30 tobacco marketing materials (Ribisl et al., 2017). Adults' exposure to retail tobacco marketing, including price promotions, is associated with smoking (El-Toukhy et al., 2018) and reduced success in trying to quit in high income areas (Chaiton et al., 2018).

The association between tobacco retailer density (retailers per 1000 people) and county-level smoking prevalence was not significant in non-metropolitan counties, however it was particularly strong, and exhibited a dose-response relationship, in metropolitan counties. This geographic difference only held for tobacco retailer density; the associations of smoking prevalence with county demographics, state cigarette taxes and smoke-free air laws were similar in both metropolitan and non-metropolitan areas. More than 267 million people, or 85.5% of our study population, lived in metropolitan counties, so higher tobacco retailer density may pose a risk for most people in the US.

Although our results did not document a statistically significant association between tobacco retailer density and smoking prevalence in non-metropolitan counties, the retail environment remains a concern in these areas, where smoking prevalence is higher, and reductions in smoking have been smaller than in more urban places (Doogan et al., 2017). We documented significantly more tobacco retailers per 1000 residents in nonmetropolitan counties than in metropolitan ones. This is the opposite of the finding of another national study of retailer density that included only four store types, and analyzed census tracts (Rodriguez et al., 2013), rather than counties, suggesting the type of store and unit of analysis may be an important consideration. Different types of tobacco retailers may provide different levels of tobacco use risk. A store audit study conducted in 2230 stores across the US in 2012 documented more tobacco marketing at gas and convenience stores than most other retailer types (Ribisl et al., 2017) and a second national study documented cheaper cigarette prices at pharmacies compared to other tobacco retailers (Henriksen et al., 2016). Store type composition differs in rural and urban areas (Vias, 2004). A national food retail study found all food store types are less available in rural communities, with particularly limited access to chain supermarkets (Powell et al., 2007). Future research could examine whether the composition of tobacco retailer store types, especially those stores more likely to heavily market tobacco products, varies by urbanicity.

Alternatively, travel distances, and the perceived costs associated with them, may differ in metropolitan vs. non-metropolitan areas. People in rural (or non-metropolitan) counties drive more miles, but spend less total time driving, than do people in more urban counties, so traveling further to reach another tobacco retailer may pose a lesser burden in rural counties (Summary of Travel Trends, 2017). Geolocation data has been used to track smokers' behaviors in metropolitan areas (Kirchner et al., 2013); additional studies that include non-metropolitan tobacco users may uncover key travel patterns differences.

Finally, the risks conferred by tobacco retailer density may vary in rural and urban areas. Using 2007 data for census tracts, Rodriguez and colleagues found that associations between area racial and ethnic composition and tobacco retailer density were stronger in urban compared to rural areas (Rodriguez et al., 2013). Tobacco industry documents reveal marketing efforts to target racial and ethnic minorities, and research has documented more tobacco marketing and lower tobacco prices in neighborhoods with more African American residents (Ribisl et al., 2017) or schoolchildren (Henriksen et al., 2017). Although we controlled for racial composition, it is possible that stronger associations of density and smoking in urban areas reflect greater exposure to tobacco marketing.

Results using the adaptive kernel estimator of tobacco retailer density were similar to those found using the more straightforward estimate of retailer density as a basic ratio of retailers to population size, though the magnitudes of the effects were slightly smaller. For health departments or tobacco control practitioners with limited capacity to conduct kernel density estimates, this suggests using simpler, ratio measures of tobacco retailer density may be an effective way to track change in density over time and its association with tobacco use at

the county level. Ratio measures are recommended in the PhenX Toolkit for Tobacco Regulatory Science (PhenX Tobacco Regulatory Project, 2018). Our analyses were conducted at the county level because estimates of smoking prevalence for sub-county geographies are not widely available. Tobacco retailer density varies within counties and cities, so kernel density estimation could be important for analyses of sub-county areas or when comparing predictors or outcomes of density across different places.

Some US jurisdictions have strengthened local tobacco licensing ordinances to reduce the density of tobacco retailers (Ackerman et al., 2017). Licensing laws give governments the regulatory power to restrict licenses for violations and limit eligibility to sell tobacco products. In 2014, the City and County of San Francisco, California adopted a policy that limits the number of tobacco sale permits in each of the city's supervisorial districts, prohibits licensing new stores within 500 feet of a school or another tobacco retailer, and prohibits new licenses until disparities in number of retailers per district are eliminated (Ackerman et al., 2017). In 2016, Philadelphia, Pennsylvania adopted a similar regulation that increased tobacco licensing fees, limited available permits by district, and restricted retailers from operating near schools (City of Philadelphia – Department of Public Health. Regulation Relating to Tobacco Retailing, 2016). Tobacco retailer density might also be reduced by limiting the types of stores that can sell tobacco. Like Australia, the United Kingdom and most provinces in Canada, the state of Massachusetts banned tobacco sales in pharmacies in 2018, and a similar policy would reduce tobacco retailer density by as much as 29% in North Carolina (Myers et al., 2015).

Overall, our findings could inform tobacco retailer density reduction efforts, especially in metropolitan counties, where the majority of the US population lives. If the presence of tobacco retailers drives cigarette smoking, our analyses provide support for investigating density reduction policies as promising tobacco control strategies. The magnitude of the association between tobacco retailer density and smoking prevalence (0.86 percentage points in highest versus lowest quartile) was similar to the magnitude of the association between smoking prevalence and an evidence-based tobacco control strategy, cigarette excise taxes (0.91 percentage points for each \$1.00 increment).

The main limitation of this study is the cross-sectional analysis, which cannot determine whether the presence of retailers facilitates smoking or if retailers choose to locate stores in areas with more smokers. Longitudinal data that track tobacco retailer density and smoking over time are needed to better establish temporality and directionality of the relationships between tobacco retailer density and cigarette smoking, and strengthen the evidence base for density reduction policies. Several other study limitations are important caveats to our findings. In the absence of national tobacco retailer licensing, we estimate the density of likely (but unverified) tobacco retailers, although such measures have high concordance with state licensing data in other studies (Rodriguez et al., 2013). Some cities, like San Francisco and several Massachusetts jurisdictions, had implemented bans on tobacco sales in pharmacies by 2012, but our county-level analysis prevented us from incorporating these laws in our data. Without fine-grained spatial data from BRFSS respondents, we can only assess retailer concentration in a relatively large area (county), which could differ from retailer accessibility in the spaces most salient to potential smokers. Furthermore, small area estimates of county smoking prevalence may not fully account for all contextual factors (Zhang et al., 2015), and may also be imprecise in more rural areas with a smaller number of BRFSS respondents (Laura Dwyer-Lindgren et al., 2013). Finally, our study only assessed cigarette smoking prevalence; the role of tobacco retailer density in initiation, use and cessation of any tobacco product warrants future study.

5. Conclusions

A dose-response relationship between tobacco retailer density and

adult smoking prevalence existed in US metropolitan counties, controlling for population demographics, cigarette excise tax and strength of smoke-free air laws. Jurisdictions interested in new mechanisms for reducing smoking prevalence and disparities in cigarette smoking among priority populations might benefit from considering strategies to reduce tobacco retailer density. Rigorous evaluations of existing policies are needed to provide stronger evidence for licensing and retailer reduction policies. In those places where tobacco retailer licenses are not currently required, establishing a tobacco retailer licensing system is a critical first step to monitor and control the tobacco industry's influence in the retail environment.

Funding statement

Research reported in this publication was supported by the National Cancer Institute of the National Institutes of Health under Award numbers P01 CA225597 and U01 CA154281. Work on this study was also supported in part by the Cancer Information and Population Health Resource (CIPHR) at the UNC Lineberger Comprehensive Cancer Center with funding provided by the University Cancer Research Fund (UCRF) via the State of North Carolina. The funders had no involvement in the study design, collection, analysis, writing, or interpretation.

Acknowledgements

We would like to thank Dr. Xun Shi for his assistance with adaptive kernel density estimation, and Nina Schleicher for her assistance with the NETS data. Work on this study was also supported in part by the Cancer Information and Population Health Resource (CIPHR) at the UNC Lineberger Comprehensive Cancer Center with funding provided by the University Cancer Research Fund (UCRF) via the State of North Carolina. The funders had no involvement in the study design, collection, analysis, writing, or interpretation.

Conflict of Interest

KM Ribisl serves as an expert consultant in litigation against tobacco companies.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.pmedr.2019.101005>.

References

Ackerman, A., Etow, A., Bartel, S., Ribisl, K.M., 2017. Reducing the Density and Number of Tobacco Retailers: Policy Solutions and Legal Issues. *Nicotine Tob Res.* 19 (2), 133–140. <https://doi.org/10.1093/ntr/ntw124>.

Agaku, I.T., King, B.A., Dube, S.R., 2014. Current cigarette smoking among adults — United States, 2005–2012. *Morb. Mortality Wkly. Report Surveillance Summ.* 63 (2), 29–48. <https://www.cdc.gov/mmwr/pdf/wk/mm6302.pdf>.

American Lung Association. State of the Air. Chicago, Illinois: American Lung Association; 2013. Retrieved from: <http://www.stateoftheair.org/2013/assets/ala-sota-2013.pdf>. Accessed December 13, 2017.

Bhaduri, B., Bright, E., Coleman, P., Urban, M.L., 2007. LandScan USA: a high-resolution geospatial and temporal modeling approach for population distribution and dynamics. *GeoJ.* 69 (1–2), 103–117. <https://doi.org/10.1007/s10708-007-9105-9>.

Cantrell, J., Pearson, J.L., Anesetti-Rothermel, A., Xiao, H., Kirchner, T.R., Vallone, D., 2016. Tobacco retail outlet density and young adult tobacco initiation. *Nicotine Tob. Res.* 18 (2), 130–137. <https://doi.org/10.1093/ntr/ntv036>.

Carlos, H.A., Shi, X., Sargent, J., Tanski, S., Berke, E.M., 2010. Density estimation and adaptive bandwidths: a primer for public health practitioners. *Int. J. Health Geogr.* 9, 39. <https://doi.org/10.1186/1476-072x-9-39>.

Chaiton, M.O., McCreedy, G., Cohen, J., 2018. Tobacco retail availability and risk of relapse among smokers who make a quit attempt: a population-based cohort study. *Tob. Control.* 27 (2), 163–169. <https://doi.org/10.1136/tobaccocontrol-2016-053490>.

City of Philadelphia – Department of Public Health. Regulation Relating to Tobacco Retailing. 2016; <http://www.phila.gov/health/pdfs/TobaccoRetailingRegulation.pdf>. Accessed February 24, 2017.

Clemens, T., Dibben, C., Pearce, J., Shortt, N.K., 2018. Neighbourhood tobacco supply and individual maternal smoking during pregnancy: a fixed-effects longitudinal analysis using routine data. *Tob. Control.* <https://doi.org/10.1136/tobaccocontrol-2018-054422>.

Doogan, N.J., Roberts, M.E., Wewers, M.E., et al., 2017. A growing geographic disparity: rural and urban cigarette smoking trends in the United States. *Prev. Med.* 104, 79–85. <https://doi.org/10.1016/j.ypmed.2017.03.011>.

Dwyer-Lindgren, L., Mokdad, A.H., Srebotnjak, T., Flaxman, A.D., Hansen, G.M., Murray, C.J., 2014. Cigarette smoking prevalence in US counties: 1996–2012. *Popul. Health Metr.* 12 (1), 5. <https://doi.org/10.1186/1478-7954-12-5>.

El-Toukhy, S., Choi, K., Hitchman, S.C., et al., 2018. Banning tobacco price promotions, smoking-related beliefs and behaviour: findings from the International Tobacco Control Four Country (ITC 4C) Survey. *Tob. Control.* 27, 310–318.

Henriksen, L., Schleicher, N.C., Barker, D.C., Liu, Y., Chaloupka, F.J., 2016. Prices for tobacco and nontobacco products in pharmacies versus other stores: results from retail marketing surveillance in California and in the United States. *Am. J. Public Health* 106 (10), 1858–1864. <https://doi.org/10.2105/AJPH.2016.303306>.

Henriksen, L., Andersen-Rodgers, E., Zhang, X., et al., 2017. Neighborhood variation in the price of cheap tobacco products in California: results from healthy stores for a healthy community. *Nicotine Tob. Res.* 19 (11), 1330–1337. <https://doi.org/10.1093/ntr/ntx089>.

Hollander, M., Wolfe, D., 1999. *Nonparametric Statistical Methods*, second ed. John Wiley & Sons, New York, NY.

Kauffman. National Establishment TimeSeries (NETS) Database. Kansas City, MO: Kauffman; 2016. Retrieved from: file:///Users/amandakong/Downloads/NETS_data_overview.pdf. Accessed December 13, 2017.

Kirchner, T.R., Cantrell, J., Anesetti-Rothermel, A., Ganz, O., Vallone, D.M., Abrams, D.B., 2013. Geospatial exposure to point-of-sale tobacco: real-time craving and smoking-cessation outcomes. *Am. J. Prev. Med.* 45 (4), 379–385. <https://doi.org/10.1016/j.amepre.2013.05.016>.

Kirchner, T.R., Anesetti-Rothermel, A., Bennett, M., et al., 2017. Tobacco outlet density and converted versus native non-daily cigarette use in a national US sample. *Tob. Control.* 26 (1), 85–91. <https://doi.org/10.1136/tobaccocontrol-2015-052487>.

Laura Dwyer-Lindgren, G.F., Engell, Rebecca E., Fleming, Thomas D., Lim, Stephen S., Murray, Christopher J.L., Mokdad, A.H., 2013. Prevalence of physical activity and obesity in US counties, 2001–2011: a road map for action. *Popul. Health Metr.* 11 (7), 1–11. <https://doi.org/10.1186/1478-7954-11-7>.

Leas, E.C., Schleicher, N.C., Prochaska, J.J., Henriksen, L., 2019. Place-based inequity in smoking prevalence in the largest cities in the United States. *JAMA Intern. Med.* <https://doi.org/10.1001/jamainternmed.2018.5990>.

Lee, J.G., Sun, D.L., Schleicher, N.M., Ribisl, K.M., Luke, D.A., Henriksen, L., 2017. Inequalities in tobacco outlet density by race, ethnicity and socioeconomic status, 2012, USA: results from the ASPIRE Study. *J. Epidemiol. Community Health* 71 (5), 487–492. <https://doi.org/10.1136/jech-2016-208475>.

Loomis, B.R., Kim, A.E., Busey, A.H., Farrelly, M.C., Willett, J.G., Juster, H.R., 2012. The density of tobacco retailers and its association with attitudes toward smoking, exposure to point-of-sale tobacco advertising, cigarette purchasing, and smoking among New York youth. *Prev. Med.* 55 (5), 468–474. <https://doi.org/10.1016/j.ypmed.2012.08.014>.

Loomis, B.R., Kim, A.E., Goetz, J.L., Juster, H.R., 2013. Density of tobacco retailers and its association with sociodemographic characteristics of communities across New York. *Public Health* 127 (4), 333–338. <https://doi.org/10.1016/j.puhe.2013.01.013>.

Luke, D.A., Hammond, R.A., Combs, T., et al., 2017. Tobacco town: computational modeling of policy options to reduce tobacco retailer density. *Am. J. Public Health* 107 (5), 740–746. <https://doi.org/10.2105/ajph.2017.303685>.

Morley, C.P., Pratte, M.A., 2013. State-level tobacco control and adult smoking rate in the United States: an ecological analysis of structural factors. *J. Public Health Manag. Pract.* 19 (6), E20–E27. <https://doi.org/10.1097/PHH.0b013e31828000de>.

Myers, A.E., Hall, M.G., Isgett, L.F., Ribisl, K.M., 2015. A comparison of three policy approaches for tobacco retailer reduction. *Prev. Med.* 74, 67–73. <https://doi.org/10.1016/j.ypmed.2015.01.025>.

Pearce, J., Hiscock, R., Moon, G., Barnett, R., 2009. The neighbourhood effects of geographical access to tobacco retailers on individual smoking behaviour. *J. Epidemiol. Community Health* 63 (1), 69–77. <https://doi.org/10.1136/jech.2007.070656>.

Pearce, J., Rind, E., Shortt, N., Tisch, C., Mitchell, R., 2016. Tobacco retail environments and social inequalities in individual-level smoking and cessation among Scottish adults. *Nicotine Tob. Res.* 18 (2), 138–146. <https://doi.org/10.1093/ntr/ntv089>.

Pearson, A.L., van der Deen, F.S., Wilson, N., Cobiac, L., Blakely, T., 2015. Theoretical impacts of a range of major tobacco retail outlet reduction interventions: modelling results in a country with a smoke-free nation goal. *Tob. Control.* 24 (e1), e32–e38. <https://doi.org/10.1136/tobaccocontrol-2013-051362>.

PhenX Tobacco Regulatory Project. PhenX Toolkit. PhenX Tobacco Regulatory Project 2018. Retrieved from: <https://www.phenxtoolkit.org/index.php?pageLink=about.trc>. Accessed March 30, 2018.

Powell, L.M., Slater, S., Mirtcheva, D., Bao, Y., Chaloupka, F.J., 2007. Food store availability and neighborhood characteristics in the United States. *Prev. Med.* 44 (3), 189–195. <https://doi.org/10.1016/j.ypmed.2006.08.008>.

Retailer Pharmacy 50/2010. Drug Store News; 2010. Retrieved from: https://www.drugstorenews.com/wp-content/uploads/2017/12/AnnualReport_April2010.pdf. Accessed November 1, 2018.

Ribisl, K.M., D'Angelo, H., Feld, A.L., et al., 2017. Disparities in tobacco marketing and product availability at the point of sale: results of a national study. *Prev. Med.* 105, 381–388. <https://doi.org/10.1016/j.ypmed.2017.04.010>.

Rodriguez, D., Carlos, H.A., Adachi-Mejia, A.M., Berke, E.M., Sargent, J.D., 2013. Predictors of tobacco outlet density nationwide: a geographic analysis. *Tob. Control.* 22 (5), 349–355. <https://doi.org/10.1136/tobaccocontrol-2011-050120>.

Santos, A., McGuckin, N., Nakamoto, H.Y., Gray, D., Liss, S. Summary of travel trends: 2009 National Household Travel Survey. Washington, DC: U.S. Department of Transportation; 2011. Retrieved from: <https://nhts.orl.gov/2009/pub/stt.pdf>. Accessed March 30, 2018.

Schleicher, N.C., Johnson, T.O., Fortmann, S.P., Henriksen, L., 2016. Tobacco outlet density near home and school: associations with smoking and norms among US teens. *Prev. Med.* 91, 287–293. <https://doi.org/10.1016/j.ypmed.2016.08.027>.

Shi, X., 2010. Selection of bandwidth type and adjustment side in kernel density estimation over inhomogeneous backgrounds. *Int. J. Geograph. Inf. Sci.* 24 (5), 643–660. <https://doi.org/10.1080/13658810902950625>.

State and Community Tobacco Control Research. Point-of-Sale Report to the Nation: The

- Tobacco Retail and Policy Landscape. St. Louis, MO: State and Community Tobacco Control Research; 2014. Retrieved from: https://cphss.wustl.edu/Products/Documents/ASPiRE_2014_ReportToTheNation.pdf. Accessed January 2, 2016.
- State and Community Tobacco Control Research. Point-of-Sale Report to the Nation: Realizing the Power of States and Communities to Change the Tobacco Retail and Policy Landscape. St. Louis, MO: State and Community Tobacco Control Research; 2016. Retrieved from: https://cphss.wustl.edu/Products/ProductsDocuments/ASPiRE_2016_ReportToTheNation.pdf. Accessed November 2, 2017.
- State Tobacco Control Laws & Policies Database. Chicago, IL: American Lung Association; 2018. Retrieved from: <http://lungusa2.org/slati/searchresults.php>. Accessed January 25, 2019.
- Summary of Travel Trends: 2017 National Household Travel Survey. Washington DC: U.S. Department of Transportation; 2017. Retrieved from: https://nhts.ornl.gov/assets/2017_nhts_summary_travel_trends.pdf. Accessed April 30, 2019.
- U.S. Department of Health and Human Services. The health consequences of smoking-50 years of progress: A report of the Surgeon General. Atlanta, GA: Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health; 2014.
- US Department of Agriculture. Rural-urban continuum codes. 2016; <https://www.ers.usda.gov/data-products/rural-urban-continuum-codes>. Accessed November 21, 2017.
- Vias, A.C., 2004. Bigger stores, more stores, or no stores: paths of retail restructuring in rural America. *J. Rural Stud.* 20 (3), 303–318. <https://doi.org/10.1016/j.jrurstud.2003.10.003>.
- Zhang, X., Holt, J.B., Yun, S., Lu, H., Greenlund, K.J., Croft, J.B., 2015. Validation of multilevel regression and poststratification methodology for small area estimation of health indicators from the behavioral risk factor surveillance system. *Am. J. Epidemiol.* 182 (2), 127–137. <https://doi.org/10.1093/aje/kwv002>.