Sociodemographic Inequities in Tobacco Retailer Density: Do Neighboring Places Matter?

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CONFLICTS OF INTEREST
KMR serves as an expert consultant in litigation against tobacco and e-cigarette companies.

INTRODUCTION

The physical or built environment includes both health-promoting and health-harming resources. The resources that are available to an individual may then influence how they experience their neighborhoods, which in turn may shape one's health behaviors and related health outcomes (Diez Roux and Mair, 2010, Srinivasan et al., 2003, Kelder, 2015, Bernard et al., 2007). Cigarette smoking is the leading cause of preventable death and tobacco use causes more than 8 million deaths per year worldwide (World Health Organization, 2021). Tobacco products sold at retail outlets are a health-harming resource: reducing the availability of tobacco products in the retail environment is an important target for reducing tobacco use and related harms (Kong and King, 2020). Tobacco retailer density is a measure of the availability of tobacco retailers in a geographic area, and it is associated with several adult and youth smoking behaviors in the United States (U.S.) and internationally (Valiente et al., 2020, Marsh et al., 2020, Nuyts et al., 2019, Lee JG, 2021) and with tobacco-related health outcomes (Kong et al., 2021a, Galiatsatos et al., 2018, Lipton and Banerjee, 2007, Lipton et al., 2009, Farley et al., 2006). In places where there is greater tobacco retailer density, there may be lower travel costs to obtain tobacco (Luke et al., 2017) and greater exposure to tobacco-related marketing (Robertson et al., 2015, Robertson et al., 2016, Paynter and Edwards, 2009)

Systemic racism and discriminatory processes such as residential segregation, housing discrimination, and zoning regulations have resulted in racial, ethnic, and socioeconomic groups being stratified and sorted into neighborhoods (Massey and Denton, 1988, Williams and Collins, 2001, Lipsitz, 2007, Diez Roux and Mair, 2010). Both people and places are racialized (Inwood and Yarbrough, 2010, Neely and Samura, 2011, Lipsitz, 2007), resulting in population groups having differential access to material and social resources that may impact health (Diez Roux

and Mair, 2010, Bernard et al., 2007, Pratto et al., 2006). Additionally, socioeconomic resources and people living in poverty have increasingly become geographically concentrated (Massey, 1996, Iceland and Hernandez, 2017).

Retail redlining is described as "a spatially discriminatory practice among retailers, of not serving certain areas, based on their ethnic-minority composition…" (D'Rozario and Williams, 2005). This concept has also been used to examine whether U.S. discount dollar stores, which sell low-cost but unhealthy foods, may be more likely to locate in racial and ethnically minoritized and lower economically resourced neighborhoods (Shannon, 2021). The process of retail redlining can also be extended to understanding spatially patterned sociodemographic inequities in the availability of retailers that sell other health-harming commodities, such as tobacco products. For example, an inequitable distribution of neighborhood tobacco retailer density may partially be due to historical tobacco industry efforts to segment consumers and target products and marketing by certain shared sociodemographic characteristics (Grier and Kumanyika, 2010). Tobacco industry documents reveal that Philip Morris, the largest tobacco company in the U.S., created an Integrated Retail Sociodemographic Database Micro-Marketing Tool that examined retailer locations and calculated a 'potential index' to estimate how likely a tobacco product would perform in a region (Philip Morris USA, 1997). Some of the factors that went into calculating this potential index included consumer preferences for certain tobacco products, as well as individual-level and area-level sociodemographics (e.g., race, ethnicity, income) that were then matched to create trade areas for products.

Several studies have indeed documented neighborhood racial, ethnic, and socioeconomic inequities in tobacco retailer density (Lee et al., 2017, Rodriguez et al., 2014, Rodriguez et al., 2013) and marketing (Lee et al., 2015). Two national-level U.S. studies found that tract-level

tobacco retailer density was positively associated with the proportion of non-Hispanic Black residents, Hispanic or Latino residents, and poverty in 2000 (Rodriguez et al., 2013) and 2018 (Kong et al., 2021b). Outside the U.S., higher tobacco retailer density has also been documented in neighborhoods with greater socioeconomic deprivation and disadvantage, for example, in Scotland (Shortt et al., 2015), Germany (Schneider and Gruber, 2013), and Australia (Wood et al., 2013).

While census tracts are imperfect proxies for neighborhoods, they are commonly used in U.S. place-based health research. Census tracts are federally defined U.S. administrative boundaries that are designed to facilitate stable geographic comparisons over time (U.S. Department of Commerce, 1994). Tracts are additionally intended to capture homogeneous population characteristics and generally have an average population size of 4000 residents (typically range from 1,200-8,000 people) (U.S. Department of Commerce, 1994). Prior studies have focused on documenting tobacco retailer density inequities *within* a census tract. However, tracts are not isolated from one another, and scholars have indicated a need to consider the context and interconnectedness of geographic units (Matthews and Yang, 2013). For example, researchers could consider attributes of neighboring census tracts, which might be just a 5-10 minute walk from a focal census tract.

Spatial dependence, or spatial autocorrelation describes the phenomena that the values at one location depend on values at other nearby locations (and vice versa), such as proximal surrounding neighbors (Fortheringham and Rogerson, 1993, LeSage and Pace, 2009, Anselin, 2003). The segregation of population groups across space paired with the tobacco industry's legacy of targeting minoritized neighborhoods (Yerger et al., 2007, Kostygina et al., 2016, Iglesias-Rios and Parascandola, 2013) highlights the importance of considering both local and

nearby locations to best understand inequities in tobacco retailer density across space. Residential segregation by sociodemographic characteristics may have resulted in tracts with similar sociodemographics being next to one another over time. Sociodemographics within a spatial unit may thus be associated with retailer density both within the spatial unit *and* in its adjacent neighboring areas. To the best of our knowledge, only one research study has considered this approach: in a sample of five Maryland counties with a predominately white population, the average income of neighboring census tracts was negatively associated with focal tract tobacco retailer density (Fakunle et al., 2018).

In this research, we apply a spatial perspective to explore whether the racial, ethnic, and socioeconomic composition of a census tract may be associated with tobacco retailer density in neighboring tracts for the entire U.S. We hypothesize that a higher percent of systemically disadvantaged populations within a census tract will be associated with greater retailer density both within the census tract and in its adjacent neighboring tracts. Evidence of these associations may further build momentum for policymakers to identify neighborhoods with concentrated risk, and prioritize the design and implementation of pro-equity policies that can reduce inequities in neighborhood tobacco retailer density in local areas and more widely across space.

METHODS

Sociodemographic Data for Focal and Neighboring Tracts

We conceptualize race and ethnicity as social constructs resulting from discriminatory systems that have created and sustained group-based hierarchies to advantage and minoritize certain groups (Pratto et al., 2006, Ford and Harawa, 2010, Krieger, 2012). We downloaded census tract population estimates of the percent of residents who were non-Hispanic white (white), Black or African American (Black), or Hispanic or Latino ethnicity, based on self-report

categories for all 50 states and the District of Columbia (D.C.). We additionally included three tract-level economic measures: the percent of residents living below 150% of the federal poverty level (FPL), median household income, and the Gini Index of income inequality. The Gini coefficient ranges from 0 (perfect equality, or all households have the same income) to 1 (perfect inequality, or only one household earns all income) and helps capture the distribution of household income within a tract (U.S. Census Bureau, 2016). All data were downloaded from the 2014-2018 American Community Survey (ACS) (U.S. Census Bureau (Social Explorer), 2018). Percent non-Hispanic Black, Hispanic or Latino, non-Hispanic white, and residents living below 150% of the federal poverty level (FPL) were scaled to 10s (1-unit increase represents a 10-percentage point increase); Gini income index of inequality was scaled to 0.1; median household income was scaled to $10,000.

Tobacco Retailer Density Data

As no national tobacco retailer licensing system in the U.S. exists, we created a 2018 list of probable tobacco retailers based on store types, similar to previous work (Rodriguez et al., 2013, Golden et al., 2020) and described in more detail elsewhere (Kong et al., 2021b). In short, the U.S. Census Bureau uses North American Industry Classification System (NAICS) codes to categorize retail establishments into a retailer type. Using tobacco product sales data from the latest 2017 Economic U.S. Census, we identified a total of ten NAICS codes (e.g., gasoline stations with convenience stores; pharmacies; tobacco stores) that accounted for approximately 99% of all tobacco product sales at retail outlets (United States Census Bureau, 2017). Using these codes, we identified likely tobacco retailers in ReferenceUSA (RefUSA), a database of business establishments that includes store names, addresses, NAICS codes, and codes for retailer sub-types for each retailer.

We included all probable tobacco retailer store types rather than just those types that sell the largest amounts of tobacco products as jurisdictions (e.g., San Francisco, California) focused on reducing overall tobacco retailer density include all tobacco retailer store types in their policies (ChangeLab Solutions, 2019, Ackerman et al., 2017). However, retailer sub-types (e.g., specialty food markets, independent pharmacies) and certain retailers known to not sell tobacco products (e.g., Target, Whole Foods, Trader Joes) were excluded from the data.

Tiger/Line census tract boundary files were downloaded from the U.S. Census Bureau. We used a spatial join in ArcMap 10.7.1 to assign each retailer to its respective census tract and then summed the total number tobacco retailers within each tract. Using land area data from the 5-year ACS data, we calculated the number of tobacco retailers per square mile. We used a land area-based measure as this may better capture the physical and spatial accessibility of retailers at the tract level as compared to per capita measures (Richardson et al., 2015, Pridemore and Grubesic, 2011).

Analytic Sample

In 2018, there were 72,377 populated census tracts that had urbanicity data in the U.S. We excluded tracts with fewer than 1000 people (n=748) as census tracts are intended to range from 1200-8000 people. We investigated the distribution of calculated values of density and excluded 2 outliers (e.g., 410 retailers per square mile) and those tracts with no sociodemographic data due to Census Bureau suppression (n=208). Finally, 10 tracts did not have a neighboring tract, resulting in a final analytic sample of 71,409 tracts (98.7% of all populated tracts).

Analysis

Non-Spatial Regression

We fit non-spatial linear regression models for each tract-level sociodemographic characteristic. As the distribution of tobacco retailer density is patterned by urbanicity (Golden et al., 2020, Kong et al., 2021b), we included controls for tract urbanicity in all models. We used three-level (Urban, Large Rural City/Town, Small and Isolated Small Rural Town) U.S. Department of Agriculture Rural-Urban Commuting Area (RUCA) codes that take into account population density, urbanization, and commuting patterns (United States Department of Agriculture, 2016).

However, we chose not to fit models that controlled (or adjusted) for other area sociodemographic characteristics. Discriminatory processes that produce segregation by race and ethnicity also produce it by socioeconomic status; therefore, statistically controlling for neighborhood sociodemographics that are correlated with one another may not be informative. By modeling each sociodemographic variable separately, we separately examined associations for variables that may exhibit collinearity in the regression context (e.g., median household income, residents living in poverty), and the study results may better inform policymakers on which communities to prioritize for retail tobacco product reduction strategies. In sensitivity tests, we included log transformations of retailer density; model fit and residual plots did not substantially improve. Therefore, we used results from the linear models given ease of interpretation.

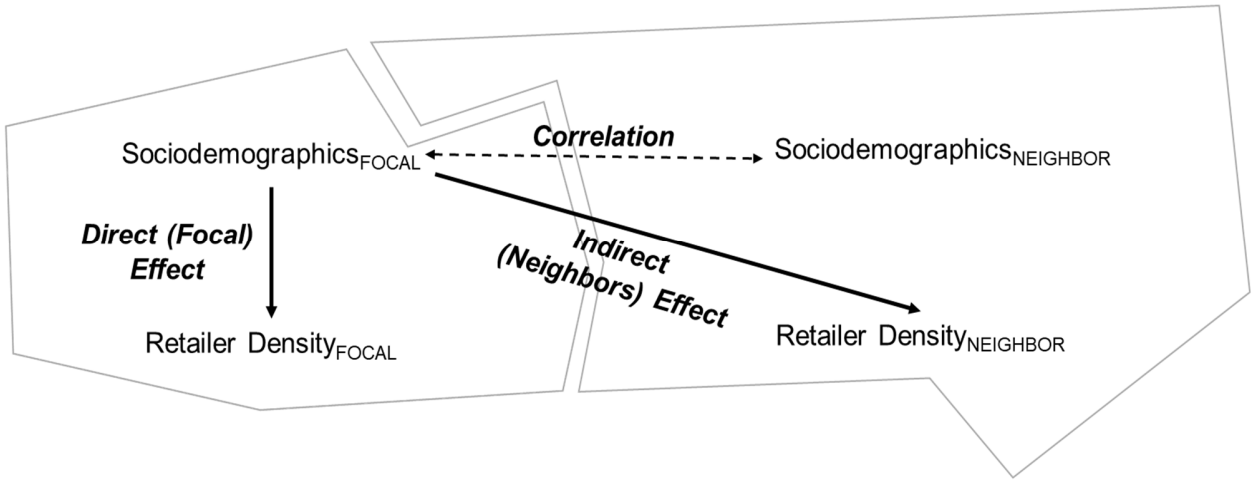
Spatial Autocorrelation and Regression

We calculated a Global Moran's I statistic for each variable to test whether values of each variable were spatially autocorrelated (values range from -1 to 1 where 1 represents perfect positive spatial autocorrelation) (Moran, 1948). Next, we used the Spatial Durbin Error Model (SDEM) to evaluate spatial dependence of each unadjusted association described prior. The

SDEM is a spatial econometric model that extends conventional regression models by testing for and modeling spatial dependence among geographic areas (LeSage, 2008). Ignoring this spatial dependence may result in biased results, similar to multilevel studies that do not account for nesting of individuals within neighborhoods (Merlo et al., 2005, LeSage, 2008). Rather than treating the spatial dependence among observations as a statistical nuisance, in a SDEM, there are several spatial effects that can be meaningfully interpreted as described below (LeSage and Pace, 2009).

In a SDEM, the *direct (focal) effect* is a summary measure, representing the average impact on retailer density in a focal tract when the sociodemographic characteristics of the focal tract increases. The *indirect (neighbors) effect* represents the average impact from a focal tract increasing its sociodemographic characteristics on the retailer density of all other neighboring tracts. As the focal and neighboring effects are simultaneously modeled, these spatial effects are adjusted for one another. In cases where there is no spatial dependence, the beta estimate from a non-spatial regression and the estimated direct effect from a SDEM will be the same or similar. However, when the sociodemographic characteristics of tracts are correlated due to spatial dependence (e.g., higher median household income in a focal tract is associated with higher median household income in its neighbors), the non-spatial beta may be under- or overestimated because some of this association is actually attributable to the indirect neighboring effect (LeSage and Pace, 2009, LeSage, 2008). Of particular interest for this study is whether there are indirect effects for inequities (e.g., median household income within a focal tract is associated with the average retailer density in its neighbors). Figure 1 shows a conceptual model of the effects.

Figure 1. Focal (Direct) and Neighboring (Indirect) Effects of Spatial Durbin Error Model (SDEM) for two census tracts.



Note: This figure is a simplified example to illustrate the direct and indirect effects between a focal tract and a single adjacent neighbor. Not all statistical correlations are depicted.

A strength of the SDEM is that it incorporates a spatially lagged error term that may reduce model bias due to spatial dependence of the error terms often reflecting omitted variables (e.g., local tobacco control policies, smoking prevalence) that are spatially dependent across geographic areas (Sparks and Sparks, 2010). Summing the direct, indirect, and associated error results in the *total effect,* which measures the average total cumulative impact on retailer density in a typical focal tract if all tracts increased their sociodemographic values. We used GeoDa (Anselin et al., 2006) to generate a Queen's contiguity matrix to define a focal tract's "neighbors" (i.e. all tracts that share a vertex or edge with the focal tract) and specified row-standardized spatial weights to account for the varying number of adjacent neighbors (Anselin, 2002). The results represent an averaging of the neighboring values. We used R and the spdep and spatialreg packages for all analyses (Bivand and Piras, 2015, Bivand and Wong, 2018).

Importantly, we acknowledge that this study is cross-sectional, so 'impacts' or 'effects' represent correlations between the spatialization of certain social groups (represented through tract-level sociodemographic composition) and tobacco retailer density. Within a spatial system,

cross-sectional data may represent a 'steady state' where indirect effects are a feature of this system: spatial effects can be interpreted as capturing movement to the next steady state (LeSage and Pace, 2009, LeSage, 2008, LeSage and Dominguez, 2012). See LeSage and Pace for an in-depth discussion on using spatial econometric modeling for cross-sectional data (LeSage and Pace, 2009, LeSage, 2008)

RESULTS

Tract-level sociodemographic and tobacco retailer density characteristics are summarized in Table 1. There was wide variation within all sociodemographic variables, and the average number of retailers per square mile in a census tract was 4.86. Each focal tract had an average of roughly 6 neighbors.

Table 1. Sociodemographic and Tobacco Retailer Density Characteristics of Census Tract Neighborhoods, United States, 2018 (N=71,409)

Variables	Mean/Percent (SD)	Range
Race and Ethnicity		
Percent non-Hispanic Black	13.3 (21.4)	0-100
Percent Hispanic or Latino	16.5 (21.4)	0-100
Percent non-Hispanic white	61.8 (29.9)	0-100
Socioeconomic Status		
Percent living below 150% FPL	24.4 (15.6)	0-100
Median household income ($)	64,461 (32,039)	2499-250,001
Gini index of income inequality	0.42 (0.06)	0.06-0.89
Retailers per square mile	4.86 (12.2)	0-281.6
Urbanicity		
Urban	82.8%	-
Large Rural City/Town	8.7%	-
Small and Isolated Small Rural Town	8.5%	-
Adjacent neighboring tracts	6.2	1-26

Non-Spatial Linear Regression

Regression results for the non-spatial and spatial models are presented in Table 3. In non-spatial models, we found that a 10-percentage point increase in both Black (b=0.42, $p<0.001$) and Hispanic or Latino residents (b=1.18, $p<0.001$) was associated with greater tobacco retailer

density. To put this into further perspective, the median land area in our analytic sample was 1.90 square miles, so a 10-percentage point increase in Black and Hispanic or Latino residents was associated with 0.80 and 2.24 more retailers in a tract of median size, respectively. In contrast, a 10-percentage point increase in percent of white residents was associated with fewer retailers per square mile ($b=-1.07$, $p<0.001$).

Table 2. Non-Spatial Regression and Spatial Durbin Error Model Associations of Sociodemographic Characteristics with Tobacco Retailer Density, United States, 2018 (N=71,409)

Models	Non-Spatial b (SE)		Spatial b (SE)	
Non-Hispanic Black				
Non-spatial estimate	0.42 (0.02)	***	-	
Direct (Focal)	-		0.07 (0.03)	*
Indirect (Neighbors)	-		0.35 (0.06)	***
Total	-		0.42 (0.05)	***
Hispanic or Latino				
Non-spatial estimate	1.18 (0.02)	***	-	
Direct (Focal)	-		0.95 (0.04)	***
Indirect (Neighbors)	-		0.39 (0.06)	***
Total	-		1.34 (0.05)	***
Non-Hispanic white				
Non-spatial estimate	-1.07 (0.02)	***	-	
Direct (Focal)	-		-0.55 (0.03)	***
Indirect (Neighbors)	-		-0.57 (0.04)	***
Total	-		-1.12 (0.04)	***
Living below 150% FPL				
Non-spatial estimate	1.56 (0.03)	***	--	
Direct (Focal)	-		0.99 (0.03)	***
Indirect (Neighbors)	-		0.91 (0.07)	***
Total	-		1.90 (0.07)	***
Gini income index of inequality				
Non-spatial estimate	3.35 (0.07)	***	-	
Direct (Focal)	-		0.95 (0.06)	***
Indirect (Neighbors)	-		2.95 (0.16)	***
Total	-		3.90 (0.19)	***
Median household income ($10,000)				
Non-spatial estimate	-0.45 (0.01)	***	-	
Direct (Focal)	-		-0.54 (0.02)	***
Indirect (Neighbors)	-		-0.15 (0.03)	***
Total	-		-0.68 (0.04)	***

Note: Six separate models (one for each sociodemographic variable) were fit using both non-spatial linear regression and spatial regression, totaling 12 models. All models controlled for tract urbanicity. Percent non-Hispanic Black, Hispanic or Latino, non-Hispanic white, and residents living below 150% of the federal poverty level (FPL) were scaled to 10s (1-unit increase represents a 10-percentage point increase); Gini income index of inequality was scaled to 0.1; median household income was scaled to $10,000. Tobacco retailer density was operationalized as the number of retailers per square mile in a census tract.

FPL = Federal Poverty Level

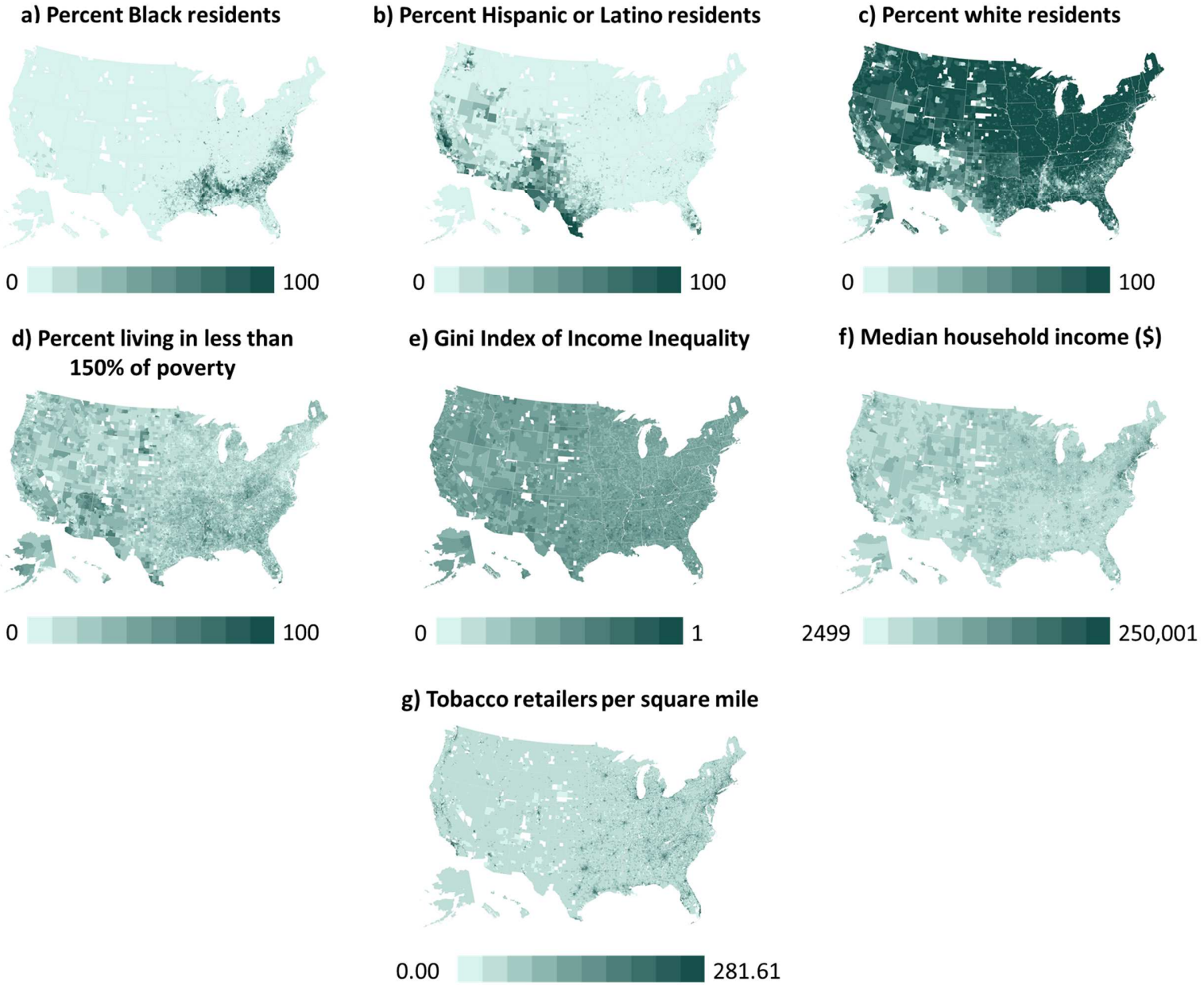
$^{*}p<0.05$, $^{**}p<0.01$; $^{***}p<0.001$

We also document inequities in retailer density for all three socioeconomic measures in the non-spatial model results. The percentage of residents living below 150% FPL was positively associated with retailer density ($b=1.56$, $p<0.001$), as was income inequality ($b=3.35$, $p<0.001$). Median household income was negatively associated tobacco retailer density ($b=-0.45$, $p<0.001$).

Spatial Autocorrelation and Spatial Regression

The tract-level sociodemographic variables and retailer density are mapped in Figure 2.

Figure 2. Maps of Sociodemographic Variables and Tobacco Retailer Density, United States, 2018 (N=71,409)



Note: Maps were created by calculating ten equal intervals for the range (shown in legend) of each census tract sociodemographic variable and ten quantiles for the range of tobacco retailer density.

Moran's I values ranged from 0.36-0.86 (Table 3), which indicates moderate to very high spatial autocorrelation. In other words, lower and higher values of each variable tended to cluster together geographically, indicating the need for spatial regression methods to estimate unbiased coefficients.

Table 3. Moran's I Values for Tract-Level Variables, United States, 2018 (N=71,409)

Variables	**I**
Race and Ethnicity	
Percent Black	0.81
Percent Hispanic or Latino	0.86
Percent non-Hispanic white	0.84
Socioeconomic Status	
Percent living below 150% FPL	0.61
Gini index of income inequality	0.36
Median household income ($)	0.69
Retailers per square mile	0.57

Note: All Moran's I were statistically significant, $p<0.001$
FPL = Federal Poverty Level

Race and Ethnicity

We next fit SDEMs to examine and interpret the spatial dependence in the documented non-spatial associations described previously (Table 2). A 10-percentage point increase in the Black population was associated with 0.07 ($p<0.05$) more retailers per square mile within a focal tract and 0.35 ($p<0.001$) more retailers per square mile in its neighbors. That the non-spatial estimate ($b=0.42$, $p<0.001$) was much larger than this direct effect further confirms that percent of Black residents is positively correlated across space: an increase in percent Black within a tract results in greater tobacco retailer density both within a tract *and* in its neighbors.

For Hispanic or Latino composition, we saw similar positive associations. A greater percent of Hispanic or Latino residents was associated with greater retailer density within a focal tract ($b=0.95$, $p<0.05$), and this effect spilled over to neighbors as well: a 10-percentage

point increase in Hispanic or Latino residents was associated with a 0.39 ($p<0.001$) increase in retailer density in neighbors. Summarizing and accounting for both of these spatial processes, the total effect was 1.34 ($p<0.001$), which is larger than the inequity documented in the non-spatial regression estimate ($b=1.18$, $p<0.001$).

We observed inverse associations for percent white. Within a focal tract, a 10 percent increase in the white population was on average, associated with 0.55 fewer retailers per square mile ($p<0.001$). This same level of change would further decrease density by 0.57 ($p<0.001$) in the neighboring tracts, resulting in a total effect of -1.12 retailers per square mile ($p<0.001$).

Socioeconomic Status

We observed focal and neighboring tract inequities in tobacco retailer density for all tract-level socioeconomic measures. A 10-percentage point increase in poverty was associated with 0.99 ($p<0.001$) more retailers per square mile within a focal tract and 0.91 ($p<0.001$) more retailers per square mile in its neighbors. For income inequality, a 0.1 increase was associated with an increase in retailer density both within a tract ($b=0.95$, $p<0.001$) and in its neighbors ($b=2.95$, $p<0.001$). In contrast, greater median household income in a focal tract was associated with fewer retailers per square mile within the tract ($b=-0.54$, $p<0.001$) and in its neighbors ($b=-0.15$, $p<0.05$).

DISCUSSION

Our study provides preliminary evidence that the sociodemographics of a region are associated with tobacco retailer density both in that region and also for neighboring regions. Overall, all sociodemographic variables exhibited high positive spatial autocorrelation consistent with our assumption that residential segregation by sociodemographic characteristics may have resulted in tracts with similar sociodemographics being next to one another over time. While the

directionality of estimates from the spatial regression models was identical to those estimated using non-spatial regression, we found that the overall magnitude of inequities is often underestimated if the spatial dependence of sociodemographic variables between focal tracts and their neighbors are not taken into consideration.

For example, we found that higher percent of both Black residents and Hispanic or Latino residents was associated with greater tobacco retailer density within a tract and in its neighbors. These inequities are similar to findings documented in both local (Schneider et al., 2005, Hyland et al., 2003) and national-level studies assessing census-tract level inequities in tobacco retailer density (Kong et al., 2021b, Lee et al., 2017, Rodriguez et al., 2013). Additionally, by summarizing the direct and indirect effects, we found that the total effect for percent Hispanic or Latino (b=1.34) was actually larger than the non-spatial regression estimate (b=1.18).

In contrast to these associations, as percent of non-Hispanic white residents increased in a tract, average retailer density decreased both within a tract and in its neighbors. Smoking prevalence is higher for white adults than both Black and Hispanic or Latino adults (Cornelius et al., 2020). Therefore, spatial inequities resulting in more tobacco retailers in Black and Hispanic or Latino neighborhoods are unlikely to be entirely a product of consumer demand. That there is greater tobacco retailer availability in tracts with a higher proportion of Black and Hispanic or Latino individuals and neighboring tracts reflects unjust processes, such as discriminatory retail (D'Rozario and Williams, 2005) and historical redlining (Schwartz et al., 2021, Kong et al., 2018), which may explain some of these observed inequities.

We also document inequities by three measures of socioeconomic status. Poverty and income inequality demonstrated positive focal and neighboring inequities in tobacco retailer density. In contrast, greater focal tract median household income was associated with decreased

tobacco retailer density within a tract and in its neighbors. The total effect, which was larger than the non-spatial estimate, signifies that socioeconomic inequities are also underestimated if neighboring places are not taken into account. These socioeconomic inequities are consistent with the only other study to examine neighboring sociodemographic effects, which found that greater median household income was associated with a decrease in tobacco retailer density (Fakunle et al., 2018). Tobacco retailer density and point-of-sale tobacco marketing are both associated with tobacco use (Robertson et al., 2016, Robertson et al., 2015, Valiente et al., 2020, Marsh et al., 2020), and increased retailer density in neighborhoods with lower socioeconomic resources may be contributing to persistent socioeconomic inequities in tobacco use (Campaign for Tobacco-Free Kids, 2021, Mills et al., 2020).

The tobacco industry has targeted tobacco products at the point of sale to economically disadvantaged, Black, and Latino and Hispanic individuals and communities (Yerger et al., 2007, Kostygina et al., 2016, Iglesias-Rios and Parascandola, 2013, Brown-Johnson et al., 2014). Our study findings suggest that prioritizing policies that reduce retail tobacco product availability in interconnected geographic areas made up of a higher proportion of these residents might be most impactful for reducing inequities in tobacco retailer density. Some of our results also indicated that the indirect effect was larger than the direct effect (non-Hispanic Black, non-Hispanic white, Gini index). Widespread geographic areas with high racialized and socioeconomic segregation may also be correlated with commercial land use and zoning regulations that allow (or prohibit) retailers that sell tobacco products (Ashe et al., 2003, Siegel et al., 2021, Vyas et al., 2020), which could potentially lead to increased competition and an overconcentration of tobacco retailers over time. Assessments of inequities in tobacco retailer density have been used to justify policies to reduce tobacco retailer and to track their impact (ChangeLab Solutions, 2019,

Ackerman et al., 2017). For example, community leaders examined racialized and socioeconomic inequities in the number of tobacco retailers in supervisorial districts in San Francisco, California and found that the lowest income neighborhood had 180 tobacco retailers while the highest income neighborhood had just 37 tobacco retailers (San Francisco Tobacco-Free Project, 2016). To address these inequities, the city passed a policy to cap the number of retailers selling tobacco products to 45 in each supervisorial district. Similarly, New York City (Schroth, 2019) and Philadelphia have implemented policies to reduce inequities (Lawman, 2019). Importantly, however, some policies to reduce retail tobacco product availability may have stronger pro-equity impacts (e.g., prohibiting tobacco retailers near schools) than others (e.g., pharmacy bans) (Glasser and Roberts, 2021, Caryl et al., 2020b, Kong et al., 2021b, Giovenco et al., 2019a): local assessments are needed, and jurisdictions should consider how to intentionally design equity into place-based tobacco control policies.

Spatial analyses such as the ones used in this study may more comprehensively capture associations between area sociodemographic characteristics and tobacco retailer density and may be useful to researchers and practitioners looking to assess and track inequities in the retail environment over time. While we used census tracts as a measure of a focal and neighboring spaces, other area units may be more appropriate in specific places, such as census block groups or locally-recognized neighborhoods. Regardless of the area units chosen, our study results suggest that future studies may need to consider the sociodemographic composition of neighboring regions.

Our study findings also underscore the need for future research examining how individuals move across space and are exposed to tobacco retailers (Caryl et al., 2020a, Shareck et al., 2020). While much of place-based health research in the U.S. uses census tracts as a proxy

for neighborhoods, individuals do not just stay within their census tracts (Matthews and Yang, 2013, Diez-Roux, 2008). Results from our study suggest that an individual living in a higher poverty census tract may potentially be exposed to greater tobacco retailer density both within their tract and when they travel outside of it, consistent with findings of youth residing in socioeconomically deprived areas in Scotland (Caryl et al., 2020a). Without considering this movement, researchers and policymakers are likely to underestimate people's potential exposure to tobacco retailers.

The spatial methods employed here may also be useful for future studies that do not have the capacity to collect global positioning system data or individually-tailored activity space data but that want to consider the contextual interdependence across space. While we focus on assessing the spatial dependence of sociodemographic characteristics in shedding light on observed inequities in tobacco retailer density, these methods may be most useful for understanding how spatial dependence of contextual characteristics, such as neighboring tobacco retailer density or local tobacco control policies, may be associated with tobacco use and related disease outcomes across space and at other geographic scales, such as the county.

Finally, several considerations should be made when interpreting the results of this study. First, data from this study are cross-sectional and therefore, we cannot make any claims about temporality or causality. Regardless, tobacco products are not a health-promoting resource, and it is a public health concern that there is a disproportionately greater availability in some neighborhoods that the tobacco industry has historically targeted. Second, although we identified retailers based on store types that are most likely to sell tobacco, this list may include retailers that do not sell tobacco, or there could be tobacco retailers missing; however, we have no reason to believe that this error is systematic. Though national validation of business establishment

databases has not been conducted, two regional studies have indicated good validation (D'Angelo et al., 2014, Rodriguez et al., 2013). Given that some studies have indicated that patterns in sociodemographic inequities of vape shop density are different compared to what has been documented with retailer density of conventional tobacco retailers (Dai et al., 2017, Giovenco et al., 2016, Giovenco et al., 2019b), we conducted a sensitivity test and removed 3798 retailers that RefUSA classified with SIC code "599306 Electronic Cigarettes." Results were unchanged (not shown); however, future research and protocols focused on the validation of vape shop lists, especially nationally, are needed (Giovenco, 2018). Finally, our study includes a near census of all tracts in the U.S. and is statistically overpowered so caution should be taken when interpreting small associations. At the same time, a major strength of this study is that it is national in scope, and this near census of tracts is likely close to estimating the true population parameters.

Conclusions

This is the first study to investigate how census tract racial, ethnic, and socioeconomic characteristics may be associated with neighboring tobacco retailer density above and beyond those observed within a tract at the national U.S. level. The neighboring characteristics of an area may be important for understanding the full magnitude of observed inequities in tobacco retailer density, as we document local and regional inequities in tobacco retailer density by neighborhood composition of race, ethnicity, and socioeconomic status. Studies that do not consider the spatial interdependence of geographic regions may actually be underestimating observed inequities. Understanding the different aspects of a neighborhood space that are partly attributable to these sociodemographic inequities may help local jurisdictions better define and

prioritize certain neighborhoods when designing and tracking the impact of pro-equity policies that reduce retail tobacco product availability.

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