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Predicting geographical variation in health-related quality of life

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ABSTRACT

Goods and services provided by businesses can either promote health or represent an additional risk factor. We assessed the association between business pattern indicators and the prevalence of adult obesity, diabetes, physical inactivity, fair or poor health and frequent physical and mental distress. Data on business types were obtained from the 2013 U.S. Census Bureau County Business Patterns. County health data were obtained from the Centers for Disease Control and Prevention Diabetes Interactive Atlas, Behavior Risk Factor Surveillance System and Fatality Analysis Reporting System. We explored the relationship at county level using the global (Ordinary Least Square regression) and local (Geographically Weighted Regression (GWR)) models in 3108 U.S. counties. Density of full service restaurants and fitness centers was associated with a significant decrease in adult obesity, diabetes, fair or poor health, physical inactivity, physical and mental distress. Conversely, density of payday loan centers was associated with an increase in these adverse health outcomes. However, our GWR models revealed substantial geographical variations in these relationships across the U.S. counties. Better understanding of the association between area-level structures and important health outcomes at the local level is important for developing targeted context-specific policy interventions. Full service restaurants and fitness centers may provide places for people to access higher quality food, socialize and exercise. Conversely, payday loans provide an expensive form of short-term credit and this debt may degrade an individual or family's ability to achieve or maintain health. Our study emphasizes the influence of local built environment characteristics on important health outcomes.

1. Introduction

1.1. Background

Geography is an important determinant of health. Where we live, including the social, political, economic, and built environment impacts health and creates health inequities (Bostic et al., 2012; Marmot et al., 2008; Blas et al., 2008). County-level contextual factors (e.g., socioeconomic status, public health policy, and access to health care) have been associated with coronary heart disease (Roux et al., 2001), health related quality of life (Jia et al., 2009), and obesity (Black, 2014). Disadvantaged neighborhoods may have fewer resources that support physical activity and healthy diets. Residents in poorer neighborhoods tend to have fewer recreational facilities, higher crime rates, and insufficient police protection, which constrain physical activity outdoors (Yen and Kaplan, 1998; Ross, 2000). Poor and minority neighborhoods have fewer large supermarkets than wealthy and majority white neighborhoods (Morland et al., 2002a). Healthy foods are more abundant and affordable at large supermarkets than at convenience stores or neighborhood grocery stores. Studies have documented increased fruit and vegetable consumption with more supermarket availability (Morland et al., 2002b). Poor neighborhoods, which have been labeled "food deserts," also tend to have more fast food restaurants, which can contribute to weight gain (Lee and Cubbin, 2002). Density of fast food restaurants has been associated with higher individual-level weight (Mehta and Chang, 2008). Poorer dietary practices have been observed among youth and adults living in disadvantaged neighborhoods compared to those living in better off neighborhoods, even after accounting for individual socioeconomic status (SES) (Diez-Roux et al., 1999).

Several studies have documented spatial variations in the prevalence of adverse health outcomes such as obesity and diabetes across the U.S. (Black, 2014; Hipp and Chalise, 2015). Furthermore, these studies found these chronic diseases correlate with poverty and physical activity across the U.S. However, there is paucity of information on whether spatial variations in these chronic conditions are associated with spatial variations in the density of food outlets (fast food restaurants, full service restaurants) and other area-level business patterns. Understanding the influence of local business patterns on health outcomes could help customize targeted prevention and intervention programs for chronic health outcomes. The present study explored the

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geographical variation in the association between prevalence of health outcomes such as obesity, diabetes, physical inactivity, frequent physical and mental distress and density of area level business patterns by employing Geographically Weighted Regression (GWR). GWR, an extension of Ordinary Least Squares regression (OLS), has been used extensively in health studies (Acharya et al., 2018; Corner et al., 2013) and has also been adopted in studies on obesity and diabetes (Black, 2014; Hipp and Chalise, 2015). GWR models allow exploration of spatially non-stationary relationships between each predictor and health outcomes (Black, 2014; Hipp and Chalise, 2015).

1.2. Study aims and hypotheses

In this study, we examined geographical variation in health-related quality of life using area-level business patterns and demographic characteristics. We hypothesize that areas with more full service restaurants, fitness centers, grocery stores, and nature parks will have better health, whereas areas with more payday loan places (as an indicator of poverty and economic exploitation), alcohol outlets, and limited-service restaurants (i.e., fast food places) will have worse health-related quality of life. We use GWR to further assess the geographic heterogeneity in the relationship between business patterns and health outcomes through estimation of local, rather than global, parameter estimates.

2. Methods

2.1. Business data

Data on business types at the county level were obtained from the 2013 U.S. Census Bureau County business patterns accessed via American FactFinder (U.S. Census Bureau, 2013). The following North American Industry Classification System (NAICS) codes were utilized to categorize businesses: 722410 (drinking places (alcoholic beverages); these places are also known as bars, taverns, night clubs and primarily serve alcohol and may have limited food services) and 722511 (full-service restaurants; these include for instance, diners, steakhouses). Fast food was defined by the following NAICS codes: 722513 (limited-service restaurants; these include carryout restaurants, drive-in restaurants and other fast food restaurants) and 722515 (snack and non-alcoholic beverage bars). We also tracked supermarkets and grocery stores (NAICS code: 445110), fitness and recreational sports centers (NAICS code: 713940), and nature parks (NAICS code: 712190).

2.2. County-level health outcomes

All business data were then aggregated to the county-level to compare with county-level health outcomes. County health data were obtained from data from the CDC Diabetes Interactive Atlas, Behavior Risk Factor Surveillance System (BRFSS) and Fatality Analysis Reporting System (Centers for Disease Control and Prevention (CDC), 2014; Centers for Disease Control and Prevention (CDC), 2016; Fatality Analysis Reporting System, 2012-2016). *Adult obesity:* is the percentage of the adult population (age 20 and older) that reported a body mass index (BMI) greater than or equal to 30 kg/m^2. *Diabetes:* is the prevalence of diagnosed diabetes and is based on the response to the survey question, "Has a doctor ever told you that you have diabetes?" *Fair or Poor Health*: is the percentage of adult survey respondents who rated their health "fair" or "poor" in response to the survey question: "In general, would you say that your health is excellent, very good, good, fair, or poor? *Physical inactivity:* is the percentage of adults of age 20 and over reporting no leisure-time physical activity. "*Poor mental health days or mental distress*: This measure is based on survey responses to the question: "Thinking about your mental health, which includes stress, depression, and problems with emotions, for how many days during the past 30 days was your mental health not good?" The value in our analytic dataset is the average number of days a county's adult respondents reported that their mental health was not good. *Poor Physical Health Days or physical distress* is based on survey responses to the question: "Thinking about your physical health, which includes physical illness and injury, for how many days during the past 30 days was your physical health not good?" The value in our analytic dataset is the average number of days a county's adult respondents reported that their physical health was not good. These measures of unhealthy days have high retest reliability (Andresen et al., 2003). Additionally, a study investigating the validity of these measures found that counties with more unhealthy days were likely to have higher unemployment, poverty, percentage of adults who did not complete high school, mortality rates, and prevalence of disability than counties with fewer unhealthy days (Jia et al., 2004). Geographic information system shapefiles of U.S. counties were downloaded from the US Census Bureau Topographically Integrated Geographic Encoding and Referencing files (U.S. Census Bureau, 2018).

2.3. Analytic approach

Business pattern characteristics were categorized into quantities. In OLS regression models, we used business patterns indicators to predict health outcomes across 3108 U.S. counties. Models were run separately for each health outcome. Sample size varied due to missing outcome or predictor variables. County-level demographic characteristics were obtained from the 2010–2014 American Community Survey 5-year estimates and included the following: median age, and percentage non-Hispanic white, and an economic disadvantage factor score derived from the following characteristics: percent female-headed households, percent families living in poverty, unemployment rate, percent college graduates (reverse coded), and median family income (reverse coded) (American Community Survey 5-year Estimates, 2010-2014). In addition, models controlled for the following covariates obtained from the Robert Wood Johnson Foundation's County Health Rankings: violent crime rate, number of primary care physicians per 100,000 population and percentage of county population not proficient in English. There was no multicollinearity between the independent variables evaluated using the variance inflation factor (O'brien, 2007). We evaluated statistical significance at $p < 0.05$. OLS regressions were performed using R software (Team RC, n.d.).

Geographically weighted regression (GWR) was performed to explore local association between health outcomes and the predictor variables (Brunsdon et al., 1996). OLS models assume statistical independence of observations and spatial stationarity of the relationship between health outcome and predictor variables (Brunsdon et al., 1996; O'Sullivan, 2003). However, proximate observations often exhibit stronger relationships, which result in spatial autocorrelation and biased parameter estimates (Black, 2014; Hipp and Chalise, 2015). GWR model relaxes these assumptions and performs multiple regressions so that there is one regression for each spatial data point (e.g., county) (An et al., 2017). GWR assigns higher weight to observations closer in proximity to a particular data point and produces a range of coefficients for each spatial data point (An et al., 2017). As a measure of spatial autocorrelation, we calculated Moran's I of the residuals estimated from the OLS regressions and GWR models across the U.S. counties. The GWR models were run separately for each health outcome and were adjusted for the same covariates described above as the OLS models. GWRs were performed using ArcGIS10.5. The study was approved by the University of Maryland Institutional Review Board.

3. Results

Table 1 presents the summary statistics for both the dependent and the independent variables. The mean density (per 10,000 population) of businesses were 7.60 for full service restaurants, 0.69 for fitness centers, 0.04 for nature parks, 2.51 for grocery stores, 1.79 for alcohol outlets,

Table 1
Descriptive statistics, county level.

	Number of counties	Mean (standard deviation)
2013 business patterns (density per 10,000 population)[a]		
Full service restaurants	3108	7.90 (6.08)
Fitness centers	3108	0.69 (0.73)
Nature parks	3108	0.04 (0.26)
Grocery stores	3108	2.51 (2.07)
Alcohol places	3108	1.79 (2.94)
Payday loan centers	3108	0.41 (0.58)
Limited service restaurants	3108	5.85 (3.20)
2014–2016 county health outcomes[b]		
Percent obesity	3108	31.48 (4.50)
Percent diabetes	3108	11.41 (2.50)
Percent fair or poor health	3108	17.48 (4.70)
Leisure-time physical inactivity	3108	26.87 (5.17)
Percent motor vehicle deaths with alcohol	3108	29.92 (15.39)
Percent excessive drinking	3108	17.38 (3.24)
Frequent physical distress (average days)	3108	12.00 (2.30)
Frequent mental distress (average days)	3108	12.21 (1.87)

[a] Data sources for health outcomes: 2014 CDC Diabetes Interactive Atlas for prevalence of obesity, diabetes, and leisure-time physical activity; 2016 Behavioral Risk Factor Surveillance System for fair or poor health, percent excessive drinking, percent of adults reporting poor mental health and physical health days; 2012-2016 Fatality Analysis Reporting System for percent motor vehicle deaths with alcohol involvement.

[b] Business data obtained from 2013 County Business Patterns. Business categories calculated as the number of business establishments per 10,000 population.

0.41 for payday loan centers and 5.85 for limited service restaurants. On average, 31.48% of a county's population was obese and 11.41% of a county's population was diabetic. The physically inactive population and population with fair or poor health, on average, accounted for 26.87% of the county population and 17.48% of the county population. On average, a county's population had frequent physical and mental distress for 12.00 days and 12.21 days respectively. In a county, on average, 29.92% of the motor vehicle deaths were due to alcohol involvement and on average 17.38% of a county's population reported excessive drinking. Fig. 1 shows variation in these health outcomes across the contiguous U.S. counties. Overall, the percentage of population with obesity, diabetes and physical inactivity was much higher in southeastern and Midwestern counties as compared to those in other regions. There was a higher percentage of population with frequent physical and mental distress and with fair or poor health in southeastern and southwestern counties as compared to those in other regions.

3.1. Business patterns

Tables 2 reports the range of local coefficient estimates for business pattern indicators and other predictor variables from GWR models for obesity; eTables 1–5 report the GWR estimates for the remaining health outcomes. The estimated change in county adult obesity resulting from one standard deviation increase in the density of full service restaurants, fitness centers, payday loan centers, limited service restaurants, grocery stores, nature parks and alcohol outlets ranged from a decrease of 2.05%, 0.75%, 0.29%, 0.59%, 1.03%, 0.90%, and 1.88% to an increase of 0.20%, 0.16%, 1.31%, 0.92%, 1.37%, 0.86%, and 2.35% across U.S. counties respectively (Table 2).

Overall, statistically significant inverse associations between full service restaurants and adult obesity, diabetes, fair or poor health and physical inactivity occupied approximately 76%, 64%, 46% and 47% of all county-specific estimates after controlling for other county characteristics. None of the U.S. counties showed a significant positive association between full service restaurants and these health outcomes. Statistically significant inverse associations between full service restaurants and physical distress and mental distress accounted for approximately 40% and 29% of all county-specific coefficient estimates, whereas statistically significant positive associations accounted for merely 5% and 7% respectively. Statistically significant inverse associations between fitness centers and adult obesity, diabetes, fair or poor health, physical inactivity, physical distress and mental distress accounted for approximately 26%, 42%, 17%, 50%, 1.6% and 5.2% of all county-specific coefficient estimates. None of the U.S. counties showed a significant positive association between fitness centers and these health outcomes.

Statistically significant positive associations between payday loan centers and adult obesity, diabetes, fair or poor health, physical inactivity, physical distress and mental distress accounted for approximately 48%, 48.3%, 26.5%, 26% 33% and 35% of all county-specific coefficient estimates. None of the U.S. counties showed a significant inverse association between payday loan centers and prevalence of adult obesity and diabetes. A statistically significant inverse association between payday loan centers and fair/poor health, physical inactivity, physical distress and mental distress was found in approximately 14%, 5%, 23% and 33% of the U.S. counties respectively.

While a statistically significant positive association between limited service restaurants and adult obesity, diabetes, fair or poor health, physical inactivity, physical distress and mental distress was present in approximately 16%, 21%, 19%, 20%, 15% and 28% of the U.S. counties respectively, a statistically significant inverse association between limited service restaurants and these health outcomes was present in several counties. We found a statistically significant positive association between grocery stores and obesity, diabetes, fair or poor health, physical inactivity, physical distress, and mental distress in approximately 8%, 17%, 42%, 22%, 39% and 33% of the U.S. counties and a statistically significant inverse association between grocery stores and these health outcomes in several counties. A statistically significant inverse association between alcohol outlets and health outcomes was present in several U.S. counties. GWR models revealed a significant inverse association between nature parks and physical inactivity in approximately 12% of the U.S. counties.

eTables 6–8 summarize the results from OLS regression models. Decrease in the density of full service restaurants and fitness centers and increase in the density of payday loan places was associated with an increase in the county-level prevalence of adult obesity, diabetes, fair or poor health, physical inactivity, physical distress and mental distress. Decrease in the density of grocery stores was associated with an increase in county-level prevalence of diabetes, frequent physical and mental distress. Decrease in the density of nature parks was associated with an increase in the county-level prevalence of fair/poor health and physical inactivity. Counties within the highest tertile of density of alcohol outlets were associated with 2.76% increase in binge or heavy drinking and 5.57% increase in motor vehicle deaths with alcohol involvement in comparison with the lowest tertile of density of alcohol outlets. However, more alcohol outlets was also associated with lower chronic disease, physical inactivity, and mental and physical distress. Increase in the density of limited service restaurants was associated with an increase in the county-level prevalence of diabetes and frequent mental distress (eTables 6–8).

Substantial geographical variations were observed in the estimated coefficients of business pattern indicators for all the health outcomes (eFigures 2–7). The residuals from the OLS models were spatially autocorrelated indicating that the county level prevalence of health outcomes were spatially dependent across the US states (eFigure 1). The estimated values of Moran's I of the residuals from OLS models indicated substantial geographical variation across the U.S. counties that were not explained by global OLS models (eTable 9). As suggested by

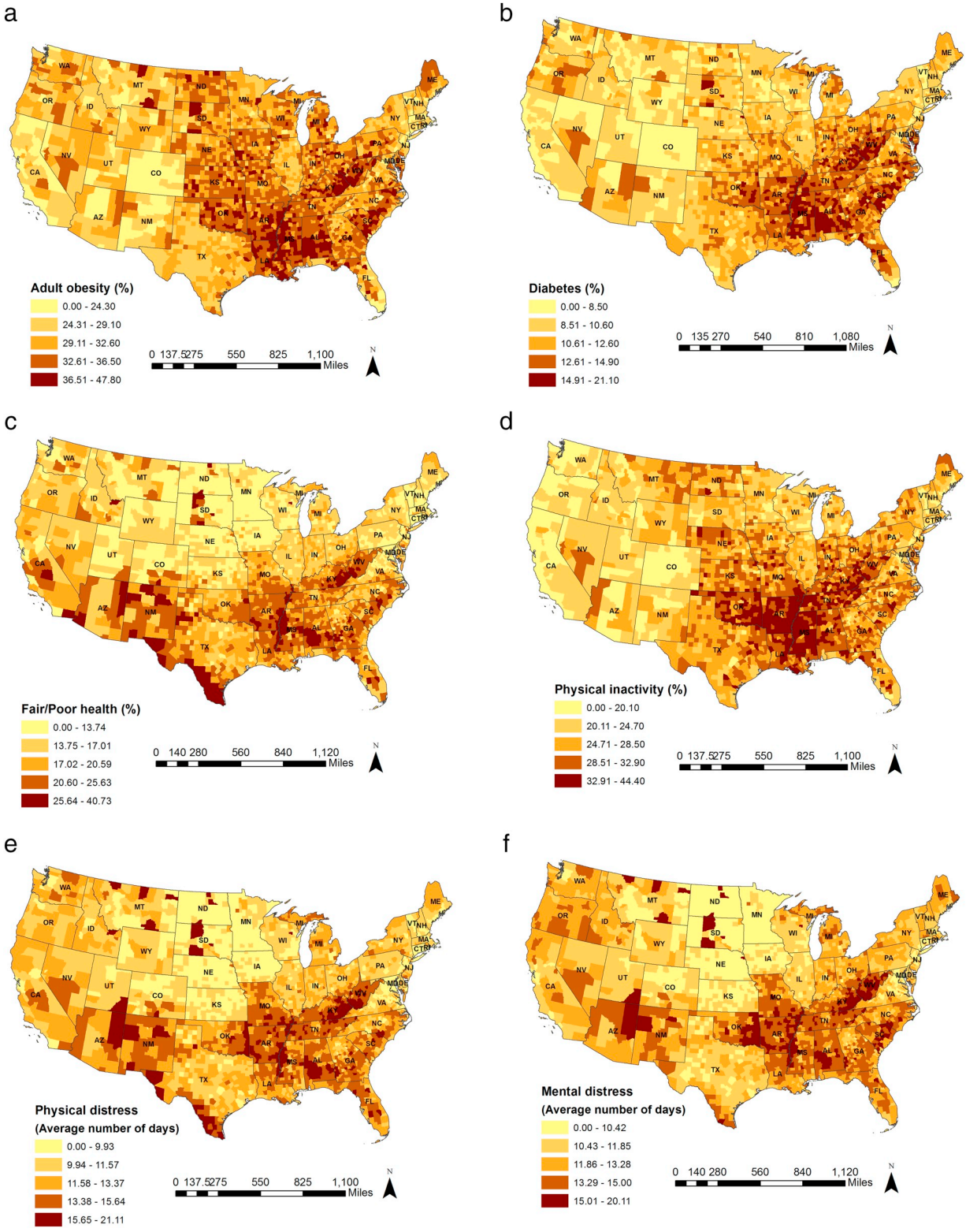

Fig. 1. National distribution of health outcomes (unadjusted for county characteristics), county level; (a) Adult obesity; (b) Diabetes; (c) Fair/Poor health; (d) Physical inactivity; (e) Physical distress; and (f) Mental distress.

Moran's I of the residuals estimated from GWR models, the spatial autocorrelation in GWR models was reduced though not completely eliminated as compared to the OLS models (eTable 10). Compared to the OLS models, the AIC value for GWR models were greatly reduced, indicating a better fit of data using GWR for all the health outcomes. Adjusted R^2 based on the OLS regression for adult obesity, diabetes, fair or poor health, physical inactivity, physical distress and mental distress was 0.46, 0.61, 0.79, 0.47, 0.74 and 0.71 respectively. Adjusted R^2 based on the GWR ranged from 0.20 to 0.63, 0.45 to 0.70, 0.62 to 0.86, 0.32 to 0.61, 0.62 to 0.82 and 0.58 to 0.82 for adult obesity, diabetes, fair or poor health, physical inactivity, and frequent physical and mental distress respectively (Fig. 2).

Table 2
Partial results from the GWR model for adult obesity, county level.

	Coefficient range		Percentage of counties by 95% of *t*-statistic		
	Min	Max	$t \leq -1.96$	$-1.96 < t < 1.96$	$t \geq 1.96$
Intercept	26.52	33.74	0.00	0.00	100.00
Full service restaurants	−2.05	0.20	76.45	23.55	0.00
Fitness centers	−0.75	0.16	26.32	73.68	0.00
Nature parks	−0.90	0.86	1.77	94.05	4.18
Grocery stores	−1.03	1.37	11.65	80.15	8.20
Alcohol outlets	−1.88	2.35	14.70	60.46	24.84
Payday loan centers	−0.29	1.31	0.00	51.87	48.13
Fast food restaurants	−0.59	0.92	8.08	75.45	16.47
% < 18 years old	−0.29	2.93	0.00	33.33	66.67
% 65 years and older	−1.18	2.63	46.01	33.14	20.85
% Hispanic	−6.46	4.03	59.62	39.06	1.32
% non-Hispanic black	−5.35	0.24	34.65	65.35	0.00
% non-Hispanic Asian	−2.30	−0.08	95.82	4.18	0.00
% American Indian/Alaskan	−8.73	4.21	2.16	50.29	47.55
Economic disadvantage	−1.02	2.50	1.51	17.60	80.89
% not proficient in English	−2.07	2.26	4.02	65.51	30.47
Violent crime rate	−0.61	1.34	5.47	52.80	41.73
Primary care physicians	−1.39	0.29	47.39	52.61	0.00

4. Discussion

Unique attributes of counties such as built environment features, local policies, contexts and programs influence the burden of disabilities and chronic disease in the population (Black, 2014; Hipp and Chalise, 2015). This study assessed the association between county health outcomes and business pattern indicators (full service restaurants, limited service restaurants, grocery stores, fitness centers, nature parks, payday loan places and alcohol outlets), after adjusting for various county-level characteristics, using both global and local regression (OLS and GWR) models. GWR models revealed the existence of substantial geographical variations in the association between aforementioned health outcomes and business pattern indicators across the U.S. counties. These spatially varying relationships suggest the possible need to have geographically tailored policies and programs to address specific health outcomes in specific counties. Intervening on certain business patterns may be more effective in some counties compared to others.

Local food environments comprising of food stores and food serving places have been shown to be associated with people's dietary choices (Morland et al., 2002b; Haynes-Maslow and Leone, 2017). Results from our GWR models showed that there existed a significant inverse association between full service restaurants and the prevalence of health outcomes such as adult obesity, diabetes, fair or poor health and physical inactivity in a proportion of the U.S. counties. None of the U.S. counties showed a significant positive association between full service restaurants and these health outcomes. Our findings are consistent with the findings from previous county-level studies, which documented an inverse relationship between full service restaurants and prevalence of obesity and diabetes (Haynes-Maslow and Leone, 2017; Ahern et al., 2011).

However, we observed spatial variation in the association between full service restaurants and the prevalence of physical distress and mental distress across the U.S. counties. For instance, we found a statistically significant inverse association between full service restaurants and frequent physical distress in counties in the western, northeastern, southeastern region and in Nebraska and Kansas and a statistically significant positive association between full service restaurants and frequent physical distress in the counties in Mississippi, Louisiana, Arkansas and Texas.

Consumption of fast food and density of fast food outlets has been shown to be positively associated with the county-level prevalence of obesity and diabetes (Haynes-Maslow and Leone, 2017; Salois, 2012; Ahern et al., 2011). We found a spatial variation in the association between limited service/fast food restaurants and prevalence of obesity and diabetes. While a statistically significant positive association between limited service restaurants and obesity was observed in the counties in Northeastern region and in Colorado, New Mexico, Illinois, Indiana, Kentucky, Missouri, Arkansas, Mississippi, Tennessee, a statistically significant inverse association was observed in counties in Texas and Oklahoma. Several studies have suggested the influence of distance and availability on the prevalence of adverse health outcomes. Residing further away from healthier food outlets and closer to fast food restaurants is likely to result in reduced access to healthier foods and unhealthy dietary habits (Morland et al., 2002b; Salois, 2012; Block et al., 2004; Moore and Diez Roux, 2006; Powell et al., 2007). Similar geographical variation was observed in the relationship between limited service restaurants and other health outcomes such as diabetes, fair or poor health, physical inactivity, physical and mental distress across the U.S. counties. In our study, spatially varying patterns were also observed in the association between the density of grocery stores and adverse health outcomes. Other studies have reported mixed findings regarding association between density of grocery stores and county-level prevalence of obesity and diabetes (Haynes-Maslow and Leone, 2017; AlHasan and Eberth, 2015; Ahern et al., 2011).

The GWR models also revealed a significant inverse association between density of fitness centers and the prevalence of adult obesity, diabetes, fair or poor health and physical inactivity in a proportion of the U.S. counties. Our findings are consistent with the findings from studies conducted by Pitts and colleagues and Salois, which documented an inverse association between county-level prevalence of obesity and diabetes and density of recreational and fitness facilities (Salois, 2012; Pitts et al., 2013). Several other studies have documented favorable effects of availability of fitness centers and recreational facilities on physical activity, blood pressure and body weight (Shah et al., 2018; Roux et al., 2007; Sallis et al., 1990).

Previous studies have suggested a positive association between payday loan or similar short-term loans and a range of worse health outcomes such as obesity, high blood pressure, and poor psychological health (Sweet et al., 2018; Münster et al., 2009; Pollack and Lynch, 2009; Sweet et al., 2013). Payday loans provide an expensive form of short-term credit and this debt may degrade an individual's ability to achieve or maintain health. In our study, the results from GWR models showed that there was a statistically significant positive association between payday loan places and obesity and diabetes in counties in the Midwestern, southeastern and western region. None of the U.S. counties

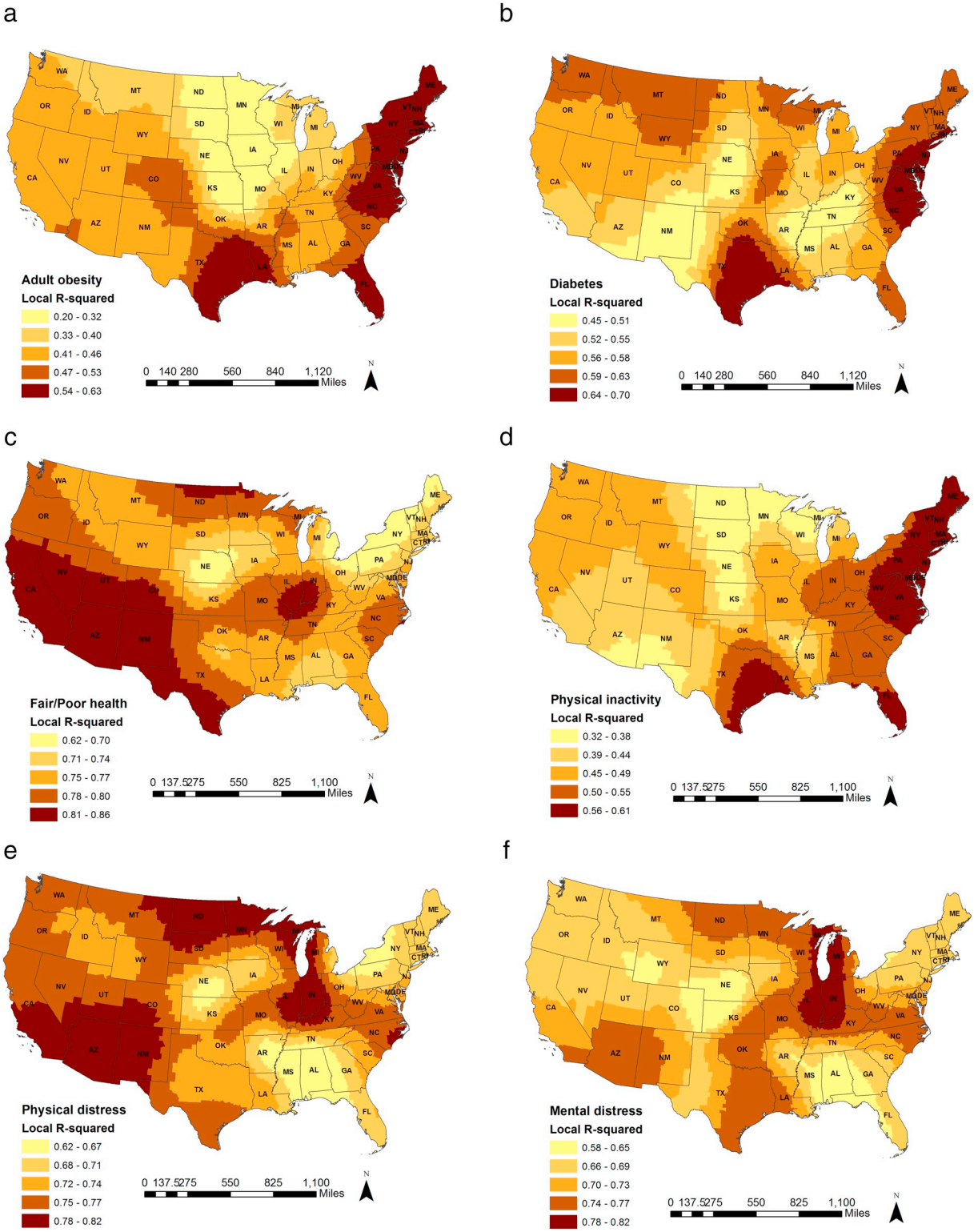

Fig. 2. Local R^2 values from the GWR models; (a) Adult obesity; (b) Diabetes; (c) Fair/Poor health; (d) Physical inactivity; (e) Physical distress; and (f) Mental distress.

showed a significant inverse association between payday loan centers and adult obesity and diabetes. However, spatial variation was observed in the association between density of payday loan places and prevalence of other health outcomes such as fair or poor health, physical inactivity, physical distress and mental distress.

4.1. Study strengths and limitations

This study used GWR to examine spatial heterogeneities in the relationship between business pattern indicators and adverse health outcomes. The advantage of using GWR over the OLS model is that GWR models allow examining the impact of predictors and geographical location on important health outcomes and produces

location-specific estimates. The examination of spatial variation in the association between business pattern indicators and important health outcomes can help to identify high-risk regions for targeted prevention strategies. Our regression models accounted for important potential confounders such as county compositional characteristics and health care resources.

There are some limitations in this study. The GWR models (with all the predictor variables included) explained less than half of the variance in the county-level prevalence of adult obesity, diabetes and physical inactivity in large geographic areas in the Western and Midwestern U.S. This suggests that several factors associated with the county-level prevalence of these health outcomes in these geographic areas were missing from our models. Another limitation of this study is that the data was aggregated at the county level and therefore we cannot make generalizations about individuals or other levels of aggregation. Since the present study was cross-sectional, we cannot make conclusions about causality.

5. Conclusions

In this study, we examined the potential impact of type commercial entities in an area on the health outcomes of that area. Results revealed full service restaurants and fitness centers as being associated with reductions in chronic disease burden. On the other hand, density of payday loan centers was found to be associated with an increase in chronic disease burden. Relationships between outcomes and business patterns varied substantially across the U.S. Better understanding of the association between area-level structures and important health outcomes at the local level is important for developing targeted context-specific policy interventions.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2019.05.030.

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