Health & Place 33 (2015) 19–24

Contents lists available at ScienceDirect

Health & Place

journal homepage: www.elsevier.com/locate/healthplace

Association of food environment and food retailers with obesity in US adults

Renfei Yan [a], Nathaniel D. Bastian [a], Paul M. Griffin [b,*]

[a] Department of Industrial & Manufacturing Engineering, Penn State University, 310 Leonhard Building, University Park, PA 16802, USA
[b] School of Industrial & Systems Engineering, Georgia Tech, 755 Ferst Drive, Atlanta, GA 30332, USA

ARTICLE INFO

Article history:
Received 28 October 2013
Received in revised form
4 February 2015
Accepted 6 February 2015

Keywords:
Food environment
Food retailers
Obesity rate

ABSTRACT

The food environment has been shown to be a factor affecting the obesity rate. We studied the association of density of food retailer type with obesity rate in U.S. adults in local regions controlling for socioeconomic factors. Parametric nonlinear regression was used on publically available data (year=2009) at the county level. We used the results of this association to estimate the impact of the addition of a new food retailer type in a geographic region. Obesity rate increased in supercenters (0.25–0.28%) and convenience stores (0.05%) and decreased in grocery stores (0.08%) and specialized food stores (0.27–0.36%). The marginal measures estimated in this work could be useful in identifying regions where interventions based on food retailer type would be most effective.

1. Introduction

The prevalence of obesity in the United States has increased dramatically over the past two decades (Flegal et al., 2002; Nguyen and El-Serag 2010). In 2008, 32 states had obesity prevalence greater than 25%, while in 1990 no state had prevalence greater than 15% (Nguyen and El-Serag, 2010). In 2010, 35.7% of U.S. adults and 16.9% of children and adolescents were obese (Ogden et al., 2012). Obesity substantially increases the risks of heart disease, stroke, type-2 diabetes, and certain types of cancer (National Institutes of Health 1998). Individuals who are obese have significantly worsened health-related quality of life, and they are also more likely to have a functional limitation (Fontaine and Barofsky, 2001; Swallen et al., 2005). In addition, the annual medical costs for people who are obese were $1429 higher than those of normal weight in 2006 (Finkelstein et al., 2009).

Several studies have found that the disparities in the local food environment are a major contributor to poor diet and obesity (Block et al., 2004; Caspi et al., 2012; Chen et al., 2010; Evans et al., 2010; Franco et al., 2008; Larson et al., 2009; Pearce et al., 2007; Walker et al., 2010). The food environment, which is complex and multi-level in that it includes virtually all potential determinants of what people eat, is often influenced at the local level by the distribution of food retailers by type, relative prices of different food products, healthfulness and quality of food products, car ownership, and public transit access (Nguyen and El-Serag, 2010; Morland et al., 2002). The community food environment consists of the location, type, number and accessibility of food outlets (grocery stores, convenience stores, restaurants), while the consumer food environment is what consumers encounter around the places they purchase food. Minority and lower-income populations have greater difficulties in accessing high-quality fresh food, and the influence from food environment tends to be higher than their counterparts (Chen et al., 2010; Morland et al., 2002; Moore and Roux, 2006; Zenk et al., 2006; Powell et al., 2007). Further, persons living in rural areas have fewer supermarkets and grocery stores, and they generally need to travel longer distance to stores, as compared to those live in metropolitan areas (Powell et al., 2007; Ver Ploeg et al., 2009; Morton and Blanchard, 2007; Moore et al., 2008; Michimi and Wimberly, 2010; Liese et al., 2007).

Supermarkets and large grocery stores, which offer a wide variety of high-quality foods at lower prices, have been extensively studied in relation to obesity prevalence (Block and Kouba, 2006; Krukowski et al., 2010); health outcomes improve with increasing accessibility to supermarkets and grocery stores (Chen et al., 2010; Morland and Evenson, 2009; Brown et al., 2008; Moore et al., 2008; Morland et al., 2006). On the other hand, increased accessibility to convenience stores is generally associated with lowered fresh food intake and worse health conditions (Morland and Evenson 2009; Brown et al., 2008; Morland et al., 2006; Galvez et al., 2009; Jago et al., 2007). Studies of other types of stores, such as specialized food stores, are relatively limited, and differ in their conclusions (Moore and Roux, 2006; Block and Kouba, 2006; Morland and Evenson, 2009; Galvez et al., 2009; Evans et al., 2012).

Affordability of food is another important factor since the changes in relative prices of different foods affect demand.

* Corresponding author. Tel.: +1 404 894 2364; fax: +1 404 385 6178.
E-mail address: pgriffin@gatech.edu (P.M. Griffin).

http://dx.doi.org/10.1016/j.healthplace.2015.02.004
1353-8292/

The consumption of energy dense and nutrient poor foods by low-income groups may be explained in part by those foods being less expensive and most resistant to inflation than nutrient rich foods (Liese et al., 2007). The relative difference in cost between healthy and unhealthy foods is higher in lower-income areas (Block and Kouba, 2006; Evans et al., 2012). Further, the cost of a healthier basket accounts for a significant portion of low-income consumers' food budgets (Jetter and Cassady, 2006). Some have suggested that taxing energy-dense, low nutrition food while providing subsidies to healthy food alternatives may help to control the increasing obesity rate (Powell et al., 2010).

The cause of the disparities in accessibility and affordability is a complex problem. For a variety of reasons, large food retailers are less likely to establish stores in poor communities (Cummins and Macintyre, 2002). The trend of supermarket chain stores moving locations from urban to suburban areas has effectively created “food deserts” in the inner city (Block and Kouba, 2006). The lack of convenient transportation results in traveling significant distances for both rural, low-income and urban residents for access to healthy and affordable food retailers (Eisenhauer, 2001; Sharkey and Horel, 2008; Clarke et al., 2002). As a result, people living in those areas have to rely on small grocery or convenience stores that usually supply a limited range of food at premium prices.

The majority of the previous studies on food environment and health outcomes have focused on selected counties or certain regional areas with data collected from a selective population (Chen et al., 2010; Moore et al., Jacobs; Morland and Evenson, 2009; Brown et al., 2008; Galvez et al., 2009), while very few have been conducted at a national level (Michimi and Wimberly, 2010). In this study, the obesity rate in U.S. adults is modeled using county level data via parametric nonlinear regression in order to identify nationally representative insights on food environmental effects. Several types of food retailers are included in the model: supercenters, supermarkets, convenience stores and specialized food stores. The relative price of healthy and unhealthy food, proximity and car ownership, and food assistance are also included into the model. Socioeconomic factors are also controlled for at the county level. The marginal effect of having additional food retailer types on obesity is estimated from the association determined from the nonlinear regression model.

2. Methods

We used county-level data from the U.S. Department of Agriculture (USDA), American Community Survey (ACS), Centers for Disease Control and Prevention (CDC), and U.S. Census Bureau County Business Patterns (CBP) for food environment, food assistance programs, and characteristics by county type (metropolitan or non-metropolitan). Socioeconomic factors including race, income, unemployment, and age are controlled for at the county level. The response variable for the study is county level obesity rate from the CDC (Centers for Disease Control and Prevention, 2014), where adults are defined as obese if their body mass index is 30 or higher. The complete variable list and corresponding summary statistics are shown in Table 1.

Obesity rate, food environment, and most sociodemographic variables differed based on metro versus non-metro counties (Table 1). For this reason, we analyzed them seperately. This is also consistent with previous literature (Powell et al., 2007; Morton and Blanchard, 2007; Michimi and Wimberly, 2010). Metro areas are defined for all urbanized areas regardless of total area population. Outlying counties are also classified as metro if they are economically tied to the central counties, as measured by the share of workers commuting on a daily basis to the central counties. Non-metro counties are outside the boundaries of metro areas and have no cities with 50,000 residents or more.

The North American Classification System (NAICS) is used by CBP to classify stores into four types. These include: (i) warehouse and supercenters (NAICS: 451910), (ii) supermarkets and grocery stores (NAICS: 445110), (iii) convenience stores (NAICS: 445120), and (iv)

Table 1
Description of data and summary statistics.

Variable	Description	Metro (*N*=1972)	Non-metro (*N*=1069)	
		Mean (SD)	**Mean (SD)**	**Data Source**
Response variable				
Obesity rate	Adult obesity rate	29.51 (4.21)	30.57 (3.92)*	CDC, 2009
0.5				
Food environment				
Low access to stores	% of Households, with no car and low access to supermarket or large grocery store	2.38 (1.57)	3.48 (3.72)*	USDA, 2010
Supercenters	Supercenters and club stores/1000 pop	0.02 (0.01)	0.02 (0.02)	CBP, 2009
Grocery stores	Supermarkets and grocery stores/1000 pop	0.18 (0.09)	0.33 (0.28)*	CBP, 2009
Convenience stores	Convenience stores/1000 pop	0.47 (0.19)	0.68 (0.35)*	CBP, 2009
Specialized food stores	Specialized food stores/1000 pop	0.06 (0.05)	0.06 (0.09)	CBP, 2009
Price ratio (milk to sodas)	Ratio of price of low-fat milk to price of sodas	0.92 (0.14)	0.90 (0.12)*	USDA, 2010
0.5				
Food assistance				
SNAP authorized stores	SNAP-authorized stores/1000 pop	0.60 (0.26)	0.90 (0.49)*	USDA, 2008
WIC authorized stores	WIC-authorized stores/1000 pop	0.16 (0.09)	0.34 (0.30)*	USDA, 2008
0.5				
Demographic characteristic				
Race ratio	Ratio of white to non-white population	7.75 (9.50)	13.13 (13.64)*	US Census, 2010
Population density	Population density (per square mile)	671.19 (2909.66)	45.50 (102.39)*	US Census, 2010
Median age	Median age	37.46 (4.07)	40.64 (5.10)*	ACS-5yr, 2009
Education less than high school	% Education less than high school graduate (aged 25–64)	12.31 (5.91)	14.60 (7.69)*	ACS-5yr, 2009
Unemployment rate	Unemployment rate (> 15, civilian)	6.93 (2.12)	6.80 (3.52)	ACS-5yr, 2009
Poverty rate	Poverty rate	14.60 (5.27)	17.62 (6.18)*	US Census, 2010
Sex ratio	Males per females of total population	97.98 (7.27)	100.78 (13.40)*	ACS-5yr, 2009

* Difference in means of metro and non-metro significant at $p=0.05$.

specialized food stores (NAICS: 4452xx). According to this classification, supermarkets and grocery stores are primarily engaged in retailing a general line of foods, while warehouses and supercenters also sell merchandise such as apparel, furniture, and appliances. Convenience stores are primarily engaged in retailing a limited line of goods that generally includes milk, bread, soda, and snacks. Finally, specialized food stores include fruit and vegetable markets, meat markets, and fish and seafood markets.

Two federal food assistances programs are considered, the Supplemental Nutrition Assistance Program (SNAP) and the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) Program. SNAP provides benefits to low-income households in the form of debit cards that can be used to purchase food items at authorized retailers. Food retailers are eligible for SNAP if they continuously sell four staple food groups (meat, poultry or fish; bread or cereal; vegetables or fruit; dairy products) and either (i) at least two of these staples must be in perishable form or (ii) over half of sales revenue comes from eligible staple foods. WIC provides support to states for supplemental foods for low-income pregnant women and to children up to age five who have nutritional risk. Each state authorizes food retailers to accept WIC based on type of food sold, price, and business integrity of the owner. WIC does not include direct distribution contractors in Mississippi (MS), while Vermont (VT) uses home delivery contractors for most foods and began authorizing WIC retail stores in 2009 for fruits and vegetables. Because of these differences, we excluded data from these two states. County level data for SNAP and WIC Programs was obtained from the USDA.

Counties with population densities in the range of 0.1–2500 per square mile were used. In addition to MS and VT being excluded due to different WIC policy, 30 counties were removed for missing values, and three counties were identified as outliers and were excluded, leaving 1015 observations for metro areas and 1930 for non-metro areas.

Since the rate of obesity is slightly negatively skewed (skewness is -0.35 and -0.28 for non-metro and metro areas, respectively), we used a Box–Cox transformation expressed by,

$$y' = \begin{cases} \frac{y^{\lambda}-1}{\lambda} & if\ \lambda > 0 \\ \log(y) & if\ \lambda = 0 \end{cases}.$$

Note that the value of λ was chosen that maximized the log-likelihood function ($\lambda = 2.00$ for non-metro areas and $\lambda = 1.75$ for metro areas), and the reported results in the subsequent section have already been re-transformed back to the original response variable form.

Parametric nonlinear regression was used with obesity as the response and food environment, food assistance, and demographics as the independent variables. Four common shapes were used to model the independent variables: (i) linear, (ii) logarithmic, (iii) quadratic, and (iv) sigmoid (s-shaped). Note that correct functional forms were determined after the Box-Cox transformation of the response variable. The logistic growth model was used to model the s-shaped function due to the relatively low number of parameters required for estimation. The model is expressed as

$$y = g_0 + g_1 \frac{1}{1 + e^{-(x-\lambda)\cdot\alpha}} + u$$

where y is the transformed value of x plus a standard uniformly distributed residual term, u. Four parameters need to be estimated: the rate of change, α, denotes the value where the rate of change reaches its maximum λ (i.e., the inflection point), and the lower and upper asymptotes g_0 and $g_0 + g_1$. We assume that all y values follow a normal distribution.

We fit the specified models by maximizing an approximation to the likelihood. An Adaptive Gaussian Quadrature method (Pinheiro and Bates, 1995) is used to approximate the likelihood. The parameters are estimated iteratively to achieve the opimal value. For each predictor, we used Quasi-Newton methods for fitting the parametric model to the independent variable data. The parametric shapes performed well except for the case of sex ratio in the non-metro model. In this case, the conjugate gradient methods was applied instead. Akaike information criterion (AIC) was used to measure of the relative quality of the model.

We tested for spatial autocorrelation using Moran's I (Moran, 1950) and Geary's C (Geary, 1954). In both cases, two counties were defined as neighbors if the distance between their population centers did not exceed 20 km. The marginal effect on obesity based on food store type in a geographic region was estimated, *ceteris parabis*. This was accomplished by adding an additional store type to the resulting parametric model, keeping all other parameters constant and measuring the percent change in obesity.

3. Results

The results of the parametric nonlinear regression analysis are provided in Table 2. The transformation type and parameters are shown for each independent variable that remained significant. In addition, the regression coefficients and resulting p-values are also provided. The adjusted R^2 values for non-metro counties is 0.3452 and for metro counties is 0.4614. The distribution histograms of the residuals are shown in Fig. 1 of the Appendix. Neither test for spatial autocorrelation was significant. For Moran's I, observed $I = 0.04$ (expected $I = 0.00$) and $\Pr > |Z| = 0.47$. For Geary's C, observed $C = 0.99$ (expected $C = 1.00$) and $\Pr > |Z| = 0.96$.

Several factors were found to be associated with obesity rate from the regression analysis. For non-metropolitan regions, we found obesity to be positively associated with lower store accessibilty and car ownership, lower education level, lower sex ratio of male to female, and lower population density. We also found obesity to be positively associated with higher price ratio of milk to sodas, higher unemployment rate, higher poverty rate, higher level of WIC authorized stores, higher median age, higher population density and a higher proportion of whites to non-whites. The density of food retailer type also had an association with obesity for metropolitan regions. Specifically, specialized food store density was negatively associated with obesity while supercenter density was positively associated with obesity.

For metropolitan regions, the association of obesity rate with both specialized food store and supercenter density was in the same direction as for non-metropolitan regions. In addition, grocery store density was found to have a negative association with obesity rate while convenience store density was found to have a positive effect. This is consistent with previous literature (Moore and Roux, 2006; Powell et al., 2007; Michimi and Wimberly, 2010).

There were some differences between metropolitan and non-metropolitan regions. For metropolitan regions, SNAP authorized store density was found to be positively associated with obesity rate. As with the case for WIC authorized store density in non-metropolitan regions, this may be due to the specific targeting of high risk populations. Further, population density was negatively associated with obesity rate.

Table 3 shows estimated percent change in obesity rate and corresponding 95% confidence interval for a geographic area by adding a food store for each of the four types. As mentioned previously, for metropolitan regions the density of all four food store types were significant, while for non-metropolitan regions only supercenter and specialized food store density were significant. Based on the associations, we estimate that for a metropolitan region the location of a supercenter would increase obesity by between 26 and 30 persons per 10,000, the location of a grocery story would decrease obesity by between 7 and 8 persons

Table 2
Transformations and coefficients of the parametric nonlinear regression model.

Variable	Transformation*	Coefficient	*p*-value
NON-METRO ($N=1897$, adjusted $R^2=0.3452$)			
Intercept	/	363.4259	< .0001
Low access to stores	Sigmoid(8.021,56.824,5.330,0.817)	1.10004	< .0001
Supercenters	log(0.001,16.658,2.481)	1.27024	0.0282
Specialized food stores	Sigmoid(02.445,25.491,0.062,53.909)	0.89092	0.0001
WIC authorized stores	Sigmoid(− 28.121,81.991,0.222,5.386)	0.90055	< .0001
Race ratio	Sigmoid(2.732,25.523,18.138,0.435)	1.02482	< .0001
Unemployment rate	Sigmoid(26.068,104.59,11.761,0.519)	0.97823	< .0001
Poverty rate	Sigmoid(− 196.72,331.85, − 11.299,0.032)	1.05044	< .0001
Sex ratio	Sigmoid(− 26.95,96.64,0.08,75.51)	1.16536	0.0024
Price ratio	Polynomial(− 586.1,1568.75, − 778.37)	1.05359	< .0001
Population density	Polynomial(− 2.843,1.018, − 0.005)	0.85275	< .0001
Median age	Polynomial(− 444.34,17.036, − 0.500)	1.06743	< .0001
0.5			
METRO ($N=1000$, adjusted $R^2=0.4614$)			
Intercept	/	112.2676	< 0.0001
Low access to stores	Log (0,2.885,9.436)	1.01798	< 0.0001
Supercenters	Sigmoid (− 0.085,4.558,0.018,186.83)	0.68409	0.0447
Grocery stores	Sigmoid (18.911, − 25.128, − 0.059,9.56)	0.96864	0.021
Convenience stores	Sigmoid(− 12.957,23.373,0.217,15.667)	1.07434	< 0.0001
Specialized stores	Sigmoid(2.357, − 11.885,0.051,32.372)	1.07201	< 0.0001
Race ratio	Sigmoid(0.665,6.765,12.736)	1.1423	< 0.0001
Unemployment rate	Linear(0.653,2.223)	0.99005	< 0.0001
Population density	Linear(− 0.117, − 0.0005)	0.88485	0.0006
SNAP authorized stores	Sigmoid(− 0.916,17.103,0.495,4.741)	1.00806	< 0.0001
Median age	Polynomial(− 1.8591,8.5118, − 0.124)	1.00445	< 0.0001

Note: $Linear(a,b)=a+b\cdot x$
$Polynomial(a,b,c,d)=a+b\cdot x+cx^2$
$Sigmoid(g_0,g_1,\lambda,\alpha)=g_0+g_1\frac{1}{1+e^{-(x-\lambda)\cdot\alpha}}$
$Log(s,a,b)=a+b\log(x+s)$

Table 3
Marginal effect (adding one additional store) on obesity rate by food store type controlling for other store types, food environment variables, and sociodemographic variables.

Type of food store	Metro ($N=1000$)			Non-metro ($N=1897$)		
	Mean (%)	95% CI (%)		Mean (%)	95% CI (%)	
Supercenters	0.28	(0.26,	0.30)	0.25	(0.24,	0.26%
Grocery stores	− 0.08	(− 0.07,	− 0.08)	/	(/	/)
Convenience stores	0.05	(0.04,	0.05)	/	(/	/)
Specialized food stores	− 0.27	(− 0.25,	− 0.30)	− 0.36	(− 0.35,	− 0.38)

per 10,000, the location of a convenience store would increase obesity by between 4 and 5 persons per 10,000, and the location of specialized food store would decrease obesity by between 25 and 30 persons per 10,000. For a non-metropolitan region, we estimate that the location of a supercenter would increase obesity by between 24 and 26 persons per 10,000 and the location of specialized food store would decrease obesity rate by between 35 and 38 persons per 10,000.

The percentage change in obesity rate by the addition of a food store type was estimated from the assocation for each county in the U.S. These results are shown in Fig. 1. Five response levels were used for each map, where quantiles were used to decide range for each level. Note that “not included” is for all counties in Mississippi and Vermont as well as those counties for which there were missing values. Since grocery stores and convenience stores were only significant for metropolitan regions, the marginal effect was not estimated for non-metropolitan counties for these cases. The complete numerical results for each county are provided in the online Appendix.

4. Conclusions

The density of food retailer type was found to be associated with obesity rate even after controlling for food environment, food assistance programs, and socioeconomic characteristics. In particular, we found that in metropolitan areas obesity rate was positively associated with both supercenter and convenience store density, and negatively associated with both grocery store and specialized food store density. In non-metropolitan areas, we found that obesity rate was positively associated with supercenter density and negatively associated with specialized food store density. We also estimated the marginal effect of the introduction of a food store type in geographic region.

The positive association of supercenter density with obesity is in agreement with Courtemanche and Carden (2011) who used data from the Behavioral Risk Factor Surveillance Systems matched with Walmart locations and entry data to estimate that an additional supercenter per 100,000 residents increases BMI by 0.24 units. Possible explanations include the offering of cheap food that does not support a healthy lifestyle (Hausman and Leibtag, 2007), the increase of self-control problems in the presence of cheaper food (Cutler et al., 2003), and lower prices for a wide range of items that lead to a sedentary lifestyle (Basker and Noel, 2009). Health insurance risk pooling may also play a role in reducing the cost of obesity and, hence, encourage shopping at supercenters (Bhattacharya and Sood, 2007). For non-metropolitan areas, it is likely that WIC authorized store density is positively associated with obesity since these are targeted very specifically to high risk populations.

Although the southeastern and midwest regions of the U.S. have the greatest levels of obesity (Centers for Disease Control and Prevention, 2013), Fig. 1 shows that food store type has the greatest impact in the middle west region of the U.S. The Reinvestment Fund developed a limited supermarket access measure based on travel distances to reach a supermarket, population density, and car

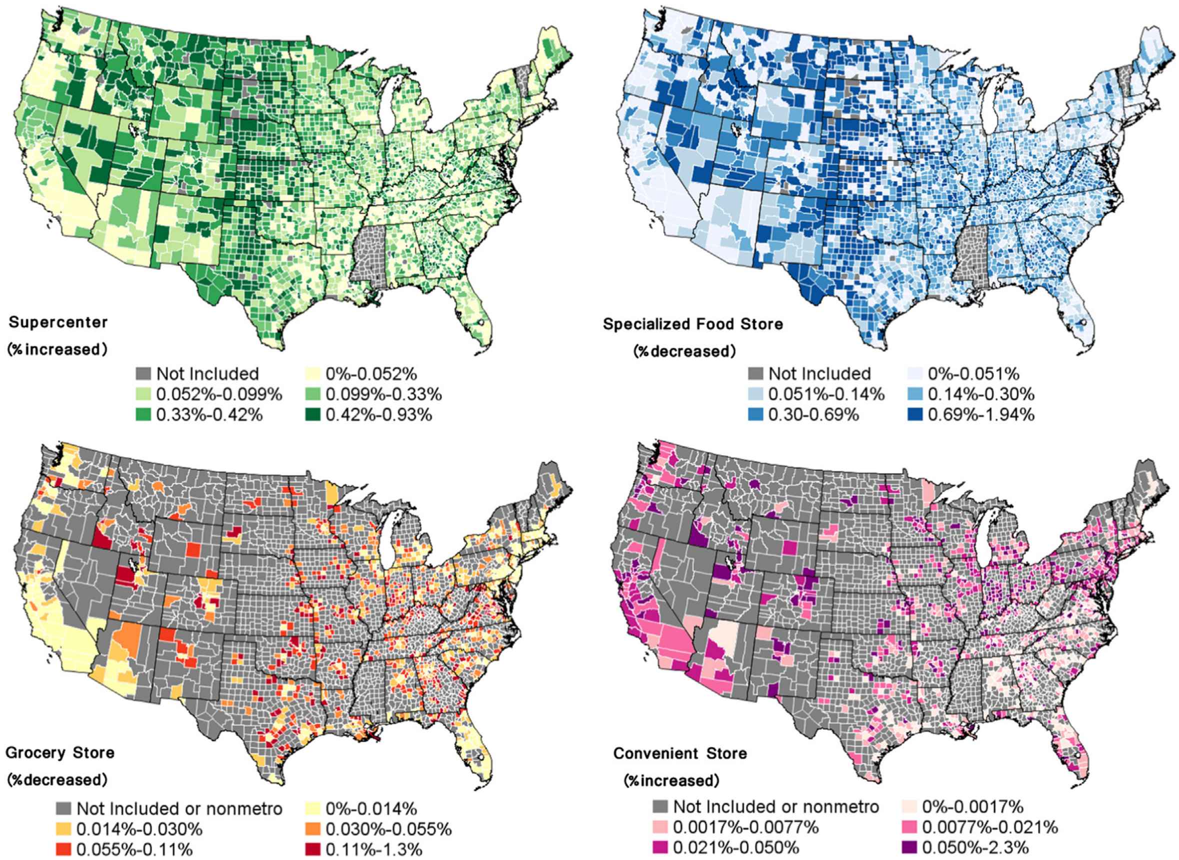

Fig. 1. Marginal effect on adult obesity rate (% change) by type of food store.

ownership rates (The Reinvestment Fund, 2011). The counties that they identified as having limited access match closely with our results. This implies that the most effective intervention policies that employ the introduction of food stores would be those designed in a way that focuses on limited access regions rather than simply focusing on regions with high obesity rates.

Several of the associations that we discovered are in agreement with previous work. These include the positive association of obesity with lower store access (Moore and Roux, 2006; Walker et al., 2010; Morland et al., 2002; Moore and Roux, 2006; Zenk et al., 2006; Powell et al., 2007; Ver Ploeg et al., 2009; Morton and Blanchard, 2007;Michimi and Wimberly, 2010; Liese et al., 2007; Morland and Evenson, 2009; Brown et al., 2008; Moore et al., 2008; Morland et al., 2006), lower car ownership (Morland et al., 2002), higher unemployment and poverty rate (Block and Kouba, 2006; Evans et al., 2012), and a higher proportion of whites to non-whites (Chen et al., 2010; Morland et al., 2002; Moore and Roux, 2006; Zenk et al., 2006; Powell et al., 2007). However, this work adds to the existing literature in several ways. First, unlike previous studies (Franco et al., 2008; Larson et al., 2009; Pearce et al., 2007; Morland et al., 2002; Moore and Roux, 2006; Zenk et al., 2006; Powell et al., 2007;Morland and Evenson, 2009; Brown et al., 2008; Moore et al., 2008; Morland et al., 2006), the analysis was done at the national level rather than for local regions. Second, we included specialized food store density and found that regardless of county classification, it is negatively associated with obesity. Note that the previous literature was not in agreement on this impact (Moore and Roux, 2006; Block and Kouba, 2006; Morland and Evenson, 2009; Galvez et al., 2009; Evans et al., 2012). Finally, this is the first work to use the associations found to estimate the marginal impact of introducing different types of food stores into communities.

The marginal effect measures can be useful in designing effective interventions based on food retailer type. Several organizations such as the U.S. Department of Agriculture are encouraging the introduction of grocery stores and specialized food stores (United States Department of Agriculture, 2013). These measures would help to determine the best allocation of limited financial resources to reduce obesity levels.

There are several limitations to our study that should be mentioned. Most importantly, the study used cross-sectional data, so we cannot directly infer causation in the results. Although we considered "global" spatial correlation in the analysis, we did not consider "local" correlation; one might use multi-level modeling to deal with unmeasured residual regional confounding. Further, we did not have data on store proximity by distance and, therefore, used store density, low accessibility, and percentage of car ownership as a proxy. We also assumed that individuals in a geographic area shopped in stores in their area and that they did not cross regions. Note that counties are an arbitrary boundary. Previous literature is mixed on the severity of this limitation. Brown et al., (2008) found no major differences in their results when they included surrounding areas as shopping possibilities when compared to not allowing crossing regions while Chen et al., (2010) found that for census tract data the results did matter. Another limitation is that we did not include restaurant data in our model, which is an important component of the food environment. Although we controlled for socioeconomic factors, we did not explicitly consider regional effects in the model due to the limited sample size. Moreover, we used publically available data, which may be subject to error (Sharkey and Horel, 2008). Given that we considered only metropolitan and non-metropolitan counties in our analysis, a limitation is that this approach may be restrictive and lead to failure of discovering important relationship in the data.

Appendix. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.healthplace.2015.02.004.

References

Basker, E., Noel, M., 2009. The evolving food chain: competitive effects of Wal-Mart's entry into the supercenter industry. J. Econ. Manag. Strateg. 18 (4), 977–1009.

Bhattacharya, J., Sood, N., 2007. Health insurance and the obesity externality. Adv. Health Econ. Health Serv. Res. 17, 279–318.

Block, D., Kouba, J., 2006. A comparison of the availability and affordability of a market basket in two communities in the Chicago area. Public Health Nutr. 9 (07), 837–845.

Block, J.P., Scribner, R.A., DeSalvo, K.B., 2004. Fast food, race/ethnicity, and income: a geographic analysis. Am. J. Prev. Med. 27 (3), 211–217.

Brown, A.F., Vargas, R.B., Ang, A., Pebley, A.R., 2008. The neighborhood food resource environment and the health of residents with chronic conditions. J. Gen. Intern. Med. 23 (8), 1137–1144.

Caspi, C.E., Sorensen, G., Subramanian, S.V., Kawachi, I., 2012. The local food environment and diet: a systematic review. Health Place 18 (5), 1172–1187.

Centers for Disease Control and Prevention, 2013. Adult Obesity Facts. CDC ⟨http://www.cdc.gov/obesity/data/adult.html⟩.

Centers for Disease Control and Prevention, 2014. Diabetes and Obesity Interactive Atlas. CDC ⟨http://www.cdc.gov/diabetes/atlas/countydata/atlas.html⟩.

Chen, S., R.J.G.M, Florax., Snyder, S., Miller, CC., 2010. Obesity and access to chain grocers. Econ. Geogr. 86 (4), 431–452.

Clarke, G., Eyre, H., Guy, C., 2002. Deriving indicators of access to food retail provision in British cities: studies of Cardiff, Leeds and Bradford. Urban Stud. 39 (11), 2041–2060.

Courtemanche, C., Carden, A., 2011. Supersizing supercenters? The impact of Wal-Mart supercenters on body mass index and obesity. J. Urban Econ. 69 (2), 165–181.

Cummins, S., Macintyre, S., 2002. Food deserts—evidence and assumption in health policy making. Br. Med. J. 325 (7361), 436–438.

Cutler, D., Glaeser, E., Shapiro, J., 2003. Why have Americans become more obese? J. Econ. Perspect. 17, 93–118.

Eisenhauer, E., 2001. In poor health: supermarket redlining and urban nutrition. GeoJournal 53 (2), 125–133.

Evans, A.E., Jennings, R., Smiley, A.W., Medina, J.L., Sharma, S.V., Rutledge, R., Stigler, M.H., Hoelscher, D.M., 2012. Introduction of farm stands in low-income communities increasses fruit and vegetable among community residents. Health Place 18 (5), 1137–1143.

Evans, G.W., Wells, N.M., Schamberg, M.A., 2010. The role of the environment in socio-economic status and obesity, Obesity Prevention. Academic Press, New York, pp. 713–725, Chapter 57.

Finkelstein, E.A., Trogdon, J.G., Cohen, J.W., Dietz, W., 2009. Annual medical spending attributable to obesity: payer-and service-specific estimates. Health Aff. 28 (5), w822–w831.

Flegal, K.M., Carrol, M.D., Ogden, C.L., Johnson, C.L., 2002. Prevalence and trends in obesity among US Adults, 1999–2000. J. Am. Med. Assoc. 288 (14), 1723–1727.

Fontaine, K., Barofsky, I., 2001. Obesity and health-related quality of life. Obes. Rev. 2 (3), 173–182.

Franco, M., Rouz, AVD., Glass, TA., Caballero, B., Brancati, FL., 2008. Neighorhood characteristics and availability of healthy foods in Baltimore. Am. J. Prev. Med. 35 (6), 561–567.

Galvez, M.P., Hong, L., Choi, E., Liao, L., Godbold, J., Brenner, B., 2009. Childhood obesity and neighborhood food store availability in an inner city community. Acad. Pediatr. 9 (5), 339–343.

Geary, R.C., 1954. The contiguity ratio and statistical mapping. Statistician 5 (3), 115–145.

Hausman, J., Leibtag, E., 2007. Consumer benefits from increased competition in shopping outlets: measure the effect of Wal-Mart. J. Appl. Econ. 22 (7), 1157–1177.

Jago, R., Baranowski, T., Baranowski, J.C., Cullen, K.W., Thompson, D., 2007. Distance to food stores & adolescent male fruit and vegetable consumption: mediation effects. Int. J. Behav. Nutr. Phys. 4 (1), 36–45.

Jetter, K.M., Cassady, D.L., 2006. The availability and cost of healthier food alternatives. Am. J. Prev. Med. 30 (1), 38–44.

Krukowski, R.A., West, D.S., Harvey-Berino, J., Prewitt, T.E., 2010. Neighborhood impact on healthy food availability and pricing in food stores. J. Community Health 35 (3), 315–320.

Larson, N.I., Story, M.T., Nelson, M.C., 2009. Neighborhood environments: disparities in access to healthy foods in the U.S. Am. J. Prev. Med. 36 (1), 74–81.

Liese, A.D., Weis, K.E., Pluto, D., Smith, E., Lawson, A., 2007. Food store types, availability, and cost of foods in a rural environments. J. Am. Dietetic Assoc. 107 (11), 1916–1923.

Michimi, A., Wimberly, M.C., 2010. Associations of supermarket accessibility with obesity and fruit and vegetable consumption in the conterminous United States. Int. J. Health Geophys. 9 (49), 94–112.

Moore, L.V., Roux, A.V.D., 2006. Associations of neighborhood characteristics with the location and type of food stores. Am. J. Public Health 96 (2), 325–331.

Moore, L.V., Roux, A.V.D., Nettleton, J.A., Jacobs, D.R., 2008. Associations of the local food environment with diet quality - a comparison of assessments based on surveys and geographic information systems the multi-ethnic study of atherosclerosis. Am. J. Epidemiol. 167 (8), 917–924.

Moran, P.A.P., 1950. Notes on continuous stochastic phenomena. Biometrika 37 (1), 17–23.

Morland, K., Wing, S., Roux, A.V.D., Poole, C., 2002. Neighborhood characteristics associated with the location of food stores and food service places. Am. J. Prev. Med. 22 (1), 23–29.

Morland, K., Roux, AVD., Wing, S., 2006. Supermarkets, other food stores, and obesity: the atherosclerosis risk in communities study. Am. J. Prev. Med. 30 (4), 333–339.

Morland, K.B., Evenson, K.R., 2009. Obesity prevalence and the local food environment. Health Place 15 (2), 491–495.

Morton, L.W., Blanchard, T.C., 2007. Starved for access: life in rural America's food deserts. Rural Realities 1 (4), 1–10.

National Institutes of Health, 1998. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults: the evidence report. Obes Res 6 (Suppl. 2), S51–S209.

Nguyen, D.M., El-Serag, H.B., 2010. The epidemiology of obesity. Gasroenterol. Clin. N. Am. 39 (1), 1–7.

Ogden, C.L., Carrol, M.D., Kit, B.K., Flegal, K.M., 2012. Prevalence of Obesity in the United States, 2009–2010 NCHS data brief, No 82. National Center for Health Statistics, Hyattsville, MD.

Pearce, J., Blakely, T., Witten, K., Bartie, P., 2007. Neighborhood deprivation and access to fast-food retailing: a national study. Am. J. Prev. Med. 32 (5), 375–382.

Pinheiro, J.C., Bates, D.M., 1995. Approximations to the log-likelihood function in the nonlinear mixed-effects model. J. Comput. Graph. Stat. 4 (1), 12–35.

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.

Powell, L.M., Han, E., Chaloupka, F.J., 2010. Economic contextual factors, food consumption, and obesity among US adolescents. J. Nutr. 140 (6), 1175–1180.

Sharkey, J.R., Horel, S., 2008. Neighborhood socioeconomic deprivation and minority composition are associated with better potential spatial access to the ground-truthed food environment in a large rural area. J. Nutr. 138 (3), 620–627.

Swallen, K.C., Reither, E.N., Haas, S.A., Meier, A.M., 2005. Overweight, obesity, and health-related quality of life among adolescents: the National Longitudinal Study of Adolescent Health. Pediatrics 115 (2), 340–347.

The Reinvestment Fund, 2011. Identifying optimal areas for supermarket development, Financing Healthy Food Options: Implementation Handbook. TRF.

United States Department of Agriculture, 2013. Grant Opportunities. USDA ⟨http://apps.ams.usda.gov/fooddeserts/grantOpportunities.aspx⟩.

Ver Ploeg, M., Breneman, V., Farrigan, T., Hamrick, K., Hopkins, D., Kaufman, P., et al., 2009. Access to affordable and nutritions food: measureing and understanding food deserts and their consequences. Report to Congress. USDA Administrative Publication no. (AP-036).

Walker, R.E., Keane, C.R., Burke, J.G., 2010. Disparities and access to healthy food in the United States: a review of food deserts literature. Health Place 16 (5), 876–884.

Zenk, S.N., Shulz, A.H., Israel, B.A., James, S.A., Bao, S., Wilson, M.L., 2006. Fruit and vegetable access differs by community racial composition and socioeconomic position in Detroit, Michigan. Ethn. Dis 16 (1), 275–280.