Article

Urban Studies

Urban Studies
2020, Vol. 57(8) 1660–1675

DOI: 10.1177/0042098019841540
journals.sagepub.com/home/usj
SAGE

Urban sprawl and the emergence of food deserts in the USA

Shima Hamidi
University of Texas at Arlington, USA

Abstract
Providing access to a variety of healthy and affordable foods has been the goal of several federal and state policy initiatives in the USA. The first step towards the successful implementation of these initiatives is to identify food deserts and to understand the mechanism by which food deserts arise. This national-level study investigates the association between urban sprawl and the emergence of food deserts at both regional and neighbourhood levels. Multilevel analysis is used to model the likelihood of a census tract being a food desert, controlling for sociodemographic and built environmental characteristics. We find that urban sprawl, measured via a compactness index, holds a significant association with the likelihood of a census tract being a food desert. Specifically, a one unit increase in the compactness index is associated with a 5.6% decrease in the odds of a census tract being a food desert. In conclusion, we recommend increasing the land use density, mix and walkability of neighbourhoods to create a supportive and attractive environment for food retailers in which to invest.

Keywords
compactness, food accessibility, food deserts, urban sprawl

摘要
提供各种健康和负担得起的食品是美国联邦和各州的一些政策举措的目标。成功实施这些举措的第一步是确定“食物沙漠”（food desert）并了解食物沙漠的产生过程。这项全国范围内的研究在区域和街区层面探究了城市扩张与食物沙漠的出现之间的关系。我们在剔除社会人口统计学和建筑环境特征影响的前提下。采用多级分析来模拟人口普查区作为食物沙漠的可能性。我们发现，用密集度指数衡量的城市扩张与人口普查区成为食物沙漠的可能性密切相关。具体而言，这种关联是密集度指数每增加一个单位，人口普查区作为食物沙漠的几率就下降5.6%。作为结论，我们建议增加街区的土地利用密度，混合性和步行性，以便为食品零售商创造支持性和富吸引力的投资环境。

关键词
密集度、食物可及性、食物沙漠、城市扩张

Received May 2018; accepted March 2019

Corresponding author:
Shima Hamidi, College of Architecture, Planning and Public Affairs, University of Texas at Arlington, 601 W Nedderman Drive, Arlington, TN 76019, USA.
Email: shima.hamidi@uta.edu

Introduction

Obesity is the second-leading preventable cause of death in the USA (Stewart et al., 2009). If current trends continue, obesity and physical inactivity may soon overtake tobacco use as the top preventable cause of death (Danaei et al., 2009; Mokdad et al., 2004). Absent broader policy interventions in the realm of nutrition and the promotion of physical activity among children and families, the current generation of children in the USA may ultimately face a significant decline in their overall life expectancy as a result of obesity-related diseases that are largely preventable (Olshansky et al., 2005).

Consumer access to supermarkets and other healthy food outlets is generally associated with lower rates of obesity (Block et al., 2011; Bodor et al., 2010; Gibson, 2011; Gregson, 2011; Hutchinson et al., 2012; Inagami et al., 2009; Jeffery et al., 2006; Mehta and Chang et al., 2008; Morland et al., 2006) and chronic diseases, such as diabetes, cancer and heart disease (Hendrickson et al., 2006; Smith and Morton, 2009). Access to healthy food becomes particularly essential for low-income households and other vulnerable populations who may have limited transportation options and limited financial resources (Jetter and Cassady, 2006). In addition, these vulnerable populations often live in lower-income neighbourhoods that are less likely to have the sort of full-service grocery outlets that provide high-quality, fresh and healthy foods – a gap that directly affects their ability to choose healthy food options (Jetter and Cassady, 2006; Larson et al., 2009).

Providing access to a variety of healthy and affordable foods has been the goal of several federal and state-level policy initiatives in the USA. One of these, the Healthy Food Financing Initiative (HFFI) at the US Department of Health and Human Services, works with large retailers and communities to secure commitments to build stores in designated 'food deserts' (Holzman, 2010). However, scholarly analyses of the HFFI programme have cast doubts on the effectiveness of the programme on increasing vulnerable households' consumption of healthy foods and reducing diet-related health problems (Allcott et al., 2017; Fan et al., 2018).

An essential first step towards implementing these initiatives is to identify food deserts and understand the characteristics associated with them. The US Department of Agriculture (USDA) has developed the Food Desert Locator as an innovative tool that identifies food deserts at the census tract level across the nation (USDA, 2009, 2013). The USDA defines a 'food desert' as a low-income area where a significant number of residents live more than 1 mile (in urban areas) or more than 10 miles (in rural areas) from a supermarket, big-box supercentre (large American chain of retail establishments such as Walmart and Target stores), or other large grocery store. While the Food Desert Locator aims to bring awareness to the issue and inform policy efforts such as the Let's Move initiative championed by former First Lady Michelle Obama and the USDA, it is ultimately an assessment tool rather than a diagnostic one. It identifies where food deserts exist in the USA, but it does not identify the mechanisms by which food deserts arise, or the socioeconomic and environmental factors associated with them. There is also little empirical evidence on the relationship between urban sprawl and the emergence of food deserts across the urban fabric of American cities.

Existing literature points to the significance of population density as an indicator of a neighbourhood's food desert status – neighbourhoods with higher population densities are more likely to support the presence of healthy food outlets such as supermarkets and grocery stores (Dutko et al., 2012). However, density alone is an insufficient indicator of a neighbourhood's vitality and ability to sustain health-promoting grocery outlets.

Urban form, in addition to population density, also accounts for an area's employment density, degree of land use mix and street layout (cul-de-sac patterns versus grid-street patterns). Compact neighbourhoods (with grid-street patterns, ample sidewalk connectivity and mixed land uses) arguably offer a more pedestrian-friendly environment that is better connected, more walkable and more conducive to street-level commercial outlets than suburban neighbourhoods that feature auto-oriented design, single-use zoning and greater (non-walkable) distances between residential and commercial areas. In theory, therefore, residents in a compact neighbourhood are more likely to have access to healthy food outlets within a walkable distance (Cannuscio et al., 2014) than their suburban peers. Still, little empirical evidence exists in the literature on the mechanism of food desert emergence and its association with urban form.

This study addresses this gap by examining the relationship between urban sprawl and the emergence of food deserts. We use census-tract-level data from the USDA's Food Desert Locator as our measure of food desert location, and the recently released Compactness Indices from Smart Growth America's *Costs of Sprawl* (Ewing and Hamidi, 2017) as our measure of urban form. We also develop a census-tract-level measure of compactness to test the relationship between urban sprawl and the emergence of food deserts at both the neighbourhood and MSA levels.

Literature review

According to the literature, the main characteristic of urban sprawl is poor accessibility to jobs and other major destinations (Ewing and Hamidi, 2015). The grocery store is one of the essential destinations for virtually every household in the USA, as food is the third-largest item in the typical American household budget (after housing and transportation costs). Also, while some research has questioned the effects of access to grocery stores on obesity rates, primarily in the short term (Dubowitz et al., 2015; Elbel et al., 2015), the majority of previous studies found this relationship to be negative and significant (Mackenbach et al., 2014). These studies point to characteristics of the built environment, such as access to healthy food outlets in a given neighbourhood, as key determinants of the residents' dietary behaviours. In other words, the food environment in the immediate neighbourhood affects the kind of food that residents eat (Casey et al., 2008; Lake and Townshend, 2006).

Existing research also shows that low-income households and ethnic minorities face more significant geographic barriers to accessing grocers in the broader community and are often forced to rely chiefly on the food environment in their immediate neighbourhood (Algert et al., 2006; Baker et al., 2006; Morland and Filomena, 2007; Larson et al., 2009; Zenk et al., 2005). This can be explained through reduced transportation options (households may have no vehicle or public transit system available to them) and tighter financial constraints, as well as other factors (Jetter and Cassady, 2006). The literature indicates that the location and availability of supermarkets and grocery stores that offer high-quality, fresh and healthy foods are typically insufficient in lower-income neighbourhoods, which directly affects residents' ability to choose healthful options (Jetter and Cassady, 2006; Larson et al., 2009).

The key unanswered question on this issue is whether and to what extent urban sprawl plays a role on the increasing emergence of food deserts in the USA. The popularity of – and reliance on – private automobiles as the main mode of transportation has made urban sprawl a significant feature of the American urban landscape in the last half-century. High rates of automobile ownership and easy availability of peripheral land allowed wealthier households to move outward from central cities toward suburban areas. With them moved many supermarkets and grocery stores that once served central cities (Donohue, 1997; Duany et al., 2000; Pothukuchi, 2005).

Consequently, this migration of major supermarkets and food retailers has led to the emergence of so-called 'food deserts' in those central city areas dominated by low-income households (Mead, 2008). A longitudinal study on the evolution of food deserts in Ontario, Canada, found that spatial inequalities in access to supermarkets had increased over time. In 1961, more than 75% of the inner-city population lived within 1 km of a supermarket, giving them easy access to a variety of foods. By 2005, that number was less than 20% (Larsen and Gilliland, 2008).

Yet, the impact of sprawl on the emergence of urban food deserts is not limited to the decline of central urban areas. Sprawl further increases income segregation as well (Nelson et al., 2004; Wheeler, 2006). One of the main characteristics of sprawl is low-density, single-use development (Ewing and Hamidi, 2015). Neighbourhoods of this type generally do not offer a mix of housing types, and higher home prices in suburban areas often prevent a mixing of income and social classes in those neighbourhoods. Wheeler (2006) conducted a statistical analysis inquiring if urban decentralisation and income inequality were associated with one another. The study found an inverse relationship between urban density and the degree of income inequality within metropolitan areas, suggesting that as cities spread out, they became increasingly segregated by income (Wheeler, 2006). Again, food retailers and supermarket chains follow wealthier people in order to maximise their profits. These findings are consistent with previous studies that also found food deserts are most often located in older urban neighbourhoods with greater percentages of both low-income households and ethnic-minority households, leaving residents with poor access to vegetables, fruits and other healthy foods (Morland et al., 2002; Weinberg, 2000).

While there are many reasons to believe that urban sprawl is significantly associated with the emergence of urban food deserts, little empirical evidence exists in the literature, particularly at the national scale, on whether and how metropolitan sprawl relates to this topic. This knowledge gap has been due mostly to the lack of national-scale data on food deserts.

Food Desert Locator

The Food Desert Locator, developed by the USDA's Economic Research Service (ERS), is a tool designed to assist efforts to expand accessibility to healthy food in designated food deserts. The data come from the FARA (Food Access Research Atlas), a USDA-funded resource that maps low-income households' access to food retailers. Information on grocery retailers' location, size and offerings is derived from 2010 TDLinx data and the USDA-funded STARS (Store Tracking and Redemption System) programme. Household income data used in the FARA come from 2008–2012 American Community Survey data sets. The FARA contains a comprehensive and proprietary directory of supermarkets and large grocery stores. A 'supermarket,' defined as a large grocery retailer generating at least US$2 million in sales per year, while also containing a range of distinct food departments (including produce) offering healthy foods (Fan et al., 2018; US Department of Agriculture, 2013).

According to the USDA, food deserts are neighbourhoods (defined by FARA and this project as census tracts) that are 'low-income' and have 'low access' to a retail supply of healthy foods. A tract is considered low-income: (1) if more than 20% of residents live below the poverty line, (2) if the tract's median family income is less than or equal to 80% of the state-wide median family income, or (3) if the tract has a median family income less than or equal to 80% of the MSA's median family income. A tract is considered to be low access if at least 500 people and/or at least 33% of the census tract's population reside more than 1 mile (for urban tracts) or 10 miles (for rural tracts) from a supermarket or large grocery store (US Department of Agriculture, 2013). This is the most widely used definition of a food desert by the USDA. Other definitions include a neighbourhood (census tract) that is only 'low access' or a census tract that is 'low access' for children or for seniors.

In this analysis, a census tract is considered a food desert if it meets the definition of having 'low access' to healthy food suppliers, regardless of the income considerations. Under these criteria, a census tract is assigned a value of 1 if it is a food desert, and a value of 0 if it is not a food desert. A total of 6529 census tracts, or about 9% of the 74,134 census tracts in the USA, meet the definition of a food desert. These food desert tracts contain 13.5 million low-income people with low access to sources of healthy food. The majority of this population, 82%, live in urban areas.

Urban sprawl index: Measuring sprawl 2014

More than a decade ago, Ewing et al. (2003) developed compactness/sprawl indices for metropolitan areas and counties, which placed compact development at one end of a continuum and urban sprawl at the other. These compactness/sprawl indices have been widely used in health research (Doyle et al., 2006; Ewing et al., 2014; Fan and Song, 2009; Griffin et al., 2012; Hamidi et al., 2018; Joshu et al., 2008; Kelly-Schwartz et al., 2004; Kim et al., 2006; Kostova, 2011; Lee et al., 2009; Plantinga and Bernell, 2007).

In a recent study, those county and metropolitan compactness indices were refined and updated to 2010 figures (Hamidi and Ewing, 2015; Hamidi et al., 2015). The refined indices, similar to the originals, have four distinct dimensions: development density, land use mix, population and employment centring, and street accessibility. However, compared with metropolitan sprawl indices from the early 2000s, these new indices incorporate more variables and have stronger construct validity.

We use these refined indices as our measure of compactness at the metropolitan level in this study. By these metrics, New York and San Francisco are the most compact regions, while Hickory, NC, and Atlanta, GA, are the most sprawling. Compactness (sprawl) scores for metropolitan areas, counties and census tracts in 2010 are available on a National Cancer Institute website.[1] Also posted there is information on the scores' derivation and validation.

Urban sprawl could impact the emergence of food deserts at not only the regional scale but also the neighbourhood level. To control for urban sprawl at both levels, we derived sprawl-like metrics for census tracts within metropolitan areas. The census tract is equivalent to an individual's neighbourhood. We used the same methodology as Hamidi and Ewing (2015) but with eight (theoretically justifiable) variables including gross population density, gross employment density, net population density of urban areas, job–population balance, degree of job mixing (entropy), average block size, intersection density and percentage of four-or-more-way intersections (see Table 1) to develop a compactness index at the census-

Table 1. Variable loadings on the census tract compactness index for 2010

Component matrix		Data sources	Factor loadings
Popden	Gross population density	Census 2010	0.666
Empden	Gross employment density	LED 2010	0.298
Urbden	Net population density of urban lands	NLCD	0.467
Jobpop	Job–population balance	LED 2010	0.486
Jobmix	Degree of job mixing (entropy)	LED 2010	0.664
Walkscore	Weighted average Walk Score	Walk Score Inc.	0.821
Smlblk	Percentage of small urban blocks	Census 2010	0.677
avgblksze	Average block size	Census 2010	−0.787
Intden	Intersection density	TomTom 2007	0.841
4way	Percentage of four-or-more-way intersections	TomTom 2007	0.621
Eigenvalue			**4.27**
Explained variance			**42.7%**

tract level. We extracted principal components from these variables using principal component analysis, a statistical technique that reduces a large number of correlated variables to a small number of factors that capture the common variance of the original data. The extracted factors, or principal components, are weighted combinations of the original variables. The higher the correlation between an original variable and a principal component, the greater the loading and the more weight the original variable is given in the overall principal component score. Factor loadings, eigenvalues and percentages of explained variance are shown in Table 1. As anticipated, population and employment density, net population density of urban lands, job–population balance, degree of job mixing, Walk Score, percentage of small blocks, intersection density and percentage of four-or-more-way intersections all load positively on the compactness factor, while average block size loads negatively. Finally, the compactness factor was transformed into a metric with a mean of 100 and a standard deviation of 25 for ease of understanding and consistency with earlier sprawl indices. Table 1 shows the list of variables measured and combined to extract a census-tract-level compactness index.

Other data and variables

The analysis controls for several confounding sociodemographic, economic and geographical variables (see Table 2). Table 2 also shows the means and standard deviations of the outcome and explanatory variables. The most widely mentioned variables in the literature are income and ethnicity. Two ethnicity variables (percentage of non-White population and percentage of Hispanic population) were downloaded from the American Community Survey (ACS) (2007–2011). The other sociodemographic variables are education, census tract population, unemployment rate and percentage of households receiving public assistance in the census tract, which were extracted from the ACS (2007–2011).

Also, to control for urban versus suburban census tracts, we included a variable measuring the distance from the population centroid of the census tract to the downtown area, with population centroids obtained from the Census Bureau.

Finally, we included two variables at the regional level to account for regional differences. The first is metropolitan population, which accounts for the size of the area. The second is our independent variable of the greatest interest – the Metropolitan Compactness Index.

Table 2. Variables used to explain the odds of a census tract being a food desert.

Name	Variable	Mean	Standard deviation
Level 1 Independent variables (census tract level)			
POPct	Census tract population	4332.43	2071.31
EDU	Percentage of population 25 years old or more with no more than high school diploma	12.66	12.17
UNEMP	Percentage of unemployed population	9.49	6.15
INC	Median household income in 1000s	55.54	27.29
NWHITE	Percentage of non-White population	31.29	25.01
HISP	Percentage of Hispanic population	16.78	21.09
VAC	Percentage of vacant housing units	9.79	7.46
DOWNTOWN	Distance from the population centroid of the census tract to downtown area	9.86	8.27
TRANSIT	Percentage of workers who commute to work using transit	3.43	5.69
INDEXct	Census tract compactness index for 2010	98.85	18.97
Level 2 Independent variables (metropolitan level)			
POPmsa	Metropolitan area population in 1000s	781,840.5	873,235
INDEXmsa	Ewing and Hamidi Metropolitan Compactness Index	97.65	23.22

Sample

The sample in this study is limited to urban census tracts in 221 medium and large metropolitan areas and metropolitan divisions where the compactness indices are available. Compactness (as opposed to sprawl) only applies to the urban context (Hamidi and Ewing, 2014). Using the same approach as Hamidi and Ewing (2014), we computed census tract compactness scores for census tracts that (1) are located in metropolitan areas and divisions and (2) have a population density of 100 persons or more per square mile. Using these criteria, this study measured census tract indices for 47,072 census tracts in the USA. Ultimately, a total of 30,337 census tracts with no missing data for the variables presented in Table 2 were included in the analysis. Focusing on urban census tracts limits the scope of the analysis, as well as the conclusions about the relationship between sprawl and the emergence of food deserts, to the urban context. At the metropolitan level, this research included a total of 221 MSAs and metropolitan divisions with a population greater than 200,000 each (2010 estimates), where the compactness indices are available (Ewing and Hamidi, 2017).

Analytical methods

The designation of 'food desert' is our dependent variable. This is a dichotomous variable (1 = yes, 0 = no). Logistical/logit modelling is used when the dependent variable is binary. As shown in Table 2, the data used in this analysis have a 'nested' structure and must be analysed accordingly. Because all census tracts located in an MSA share characteristics of that MSA, such as the compactness index, they could not be treated as independent (see Figure 1). The nesting tends to produce dependence among cases, violating the independence assumption of ordinary least squares (OLS) regression. The standard errors of regression coefficients associated with MSA characteristics based on OLS would consequently be

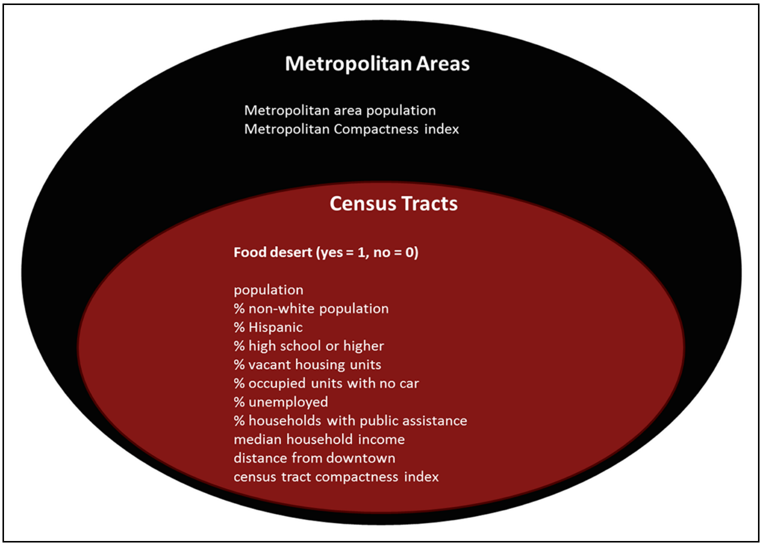

Figure 1. Conceptual framework showing the nesting structure of variables.
Source: http://www.ncsl.org/documents/labor/workingfamilies/PA_FFFI.pdf.

underestimated, and regression coefficients themselves would become inefficient (Raudenbush and Bryk, 2002).

Hierarchical or multilevel modelling (HLM or MLM) overcomes these limitations, accounting for the dependence among cases and producing more accurate coefficient and standard error estimates. Within a hierarchical model, each level in the data structure (e.g. repeated observations, individuals) is formally represented by its own sub-model. The sub-models are statistically linked. MLM accounts for dependence among observations, in this case the dependence of census tracts within a given MSA on characteristics of the MSA.

Using HLM 7, hierarchical nonlinear models were estimated for the dichotomous outcome 'being a food desert'. Hierarchical nonlinear modelling is analogous to binomial logistic modelling but handles a data structure that is multilevelled.

In this analysis, the odds of being a food desert were regressed on neighbourhood characteristics in level-1 models. The intercepts and coefficients of level-1 models were regressed on regional characteristics in level-2 models. Initially, we estimated two types of MLM models. First, we estimated 'random intercept' models by allowing only the intercepts to randomly vary across level-2 cases, while all the regression coefficients were treated as fixed. Second, we allowed both intercepts and regression coefficients to randomly vary across level-2 units. These are called random coefficient models. We found the cross-level interaction terms were not significant in the random coefficient models, which means the level-1 regression coefficients (slopes) did not vary randomly across level-2 cases (metropolitan areas). Therefore, it is not necessary to specify the regression coefficients (slopes) as random variables, and we reverted to the random intercept model. The final equation is presented as:

Level-1 model

$$Prob(Y = 1|B) = P$$
$$Log[P/(1 - P)] = B0 + B1 * (POPct) + B2 * (NWHITE) + B3 * (INC) + B4 * (UNEMP) + B5 * (EDU) + B6 * (TRANSIT) + B7 * (VAC) + B5 * (HISP) + B6 * (DOWNTOWN) + B7 * (INDEXct)$$

Level-2 model

$$B0 = G00 + G01 * (POPmsa) + G02 * (INDEXmsa) + U0$$

Results and discussion

This study aims to quantify the associations between urban sprawl, at both neighbourhood and MSA levels, and the emergence of food deserts, controlling for confounding sociodemographic and environmental factors. As shown in Table 3, the pseudo-R^2 for this model is 0.521. Pseudo-R^2s in multilevel modelling are not equivalent to R^2s in OLS regression and should not be interpreted the same way. The pseudo-R^2 bears some resemblance to the statistic used to test the hypothesis that all coefficients in the model are zero, but there is no construction by which it is a measure of how well the model predicts the outcome variable in the way that R^2 does in conventional regression analysis.

According to the best-fitted HLM model shown in Table 3, the coefficients of almost all control variables have the expected signs, and most of them are significant at the 0.001 level or beyond, with one exception, which is the census tract population (see Table 3). Once controlling for the census tract's degree of compactness, the census tract population is also significantly and positively related to the food desert status. One possible explanation is that the size of census tract (and as a result its level of attractiveness for supermarket chains)

Table 3. Logistic regression model of log odds of an urban census tract being a food desert.

Name	Variable	Coeff.	Std. error	Odd ratio	*t*-ratio	*p*-value
constant	Constant	8.244	0.456	3805.05	18.077	< 0.001
POPct	*Census Tract Population*	0.000466	0.000032	1.000466	14.467	< 0.001
EDU	*Population with education below college (%)*	0.0057	0.00387	1.00572	1.473	0.141
UNEMP	*Unemployed Population (%)*	0.00933	0.00456	1.00938	2.048	0.040
INC	*Median Household Income (000)*	−0.0152	0.00263	0.9847	−5.764	< 0.001
NWHITE	*Non-white Population (%)*	0.00172	0.00195	1.00172	0.886	0.376
HISP	*Hispanic population (%)*	−0.0177	0.00292	0.9824	−6.069	0.001
VAC	*Vacant Housing (%)*	0.00866	0.00551	1.0087	1.572	0.116
DOWNTOWN	*Distance to Downtown*	0.0182	0.00506	1.0183	3.594	0.001
TRANSIT	*Commuters using transit (%)*	−0.023	0.00413	0.9772	−5.578	< 0.001
INDEXct	*Census Tract Index*	−0.0576	0.00232	0.944	−24.855	< 0.001
POPmsa	*Metropolitan Population (000)*	−0.000356	0.000077	0.9996	−4.624	< 0.001
INDEXmsa	*Metropolitan Index*	−0.0119	0.00315	0.9882	−3.769	< 0.001
pseudo-R^2		0.642				

depends on its population but also on employment. Since population and employment together account for the degree of compactness, these findings could indicate that more populous tracts are less attractive to supermarket chains than those with more employment, to contain the same degree of compactness.

Socioeconomic factors and the emergence of food deserts

This study tested three socioeconomic status (SES) indicators including education, median income and unemployment rate and found all of them to have the expected sign and two of them (with the exception of education) to be significant. The percentage of unemployed population in census tracts and the percentage of the population 25 years old or older with less than a high school diploma are positively associated with the odds of an area being a food desert, while census tracts' median household income is negatively associated with the odds of a census tract being a food desert. The most significant SES variable is the median household income. A US$1000 increase in a census tract's median household income decreases the odds of it being a food desert by 1.5%. This suggests that communities that face a higher prevalence of social and economic deprivation are more likely to lack access to healthy food sources, confirming the findings of previous studies (Lamb et al., 2015).

In addition, from the variables that control for the ethnic minority population (the percentage of non-White and Hispanic populations), only the percentage of Hispanic population is significant, albeit with an unexpected sign. This is in disagreement with previous studies that found minority neighbourhoods have fewer supermarkets relative to White neighbourhoods (Berg and Murdoch, 2008). Moreover, this study confirms the findings of previous studies such as Dutko et al. (2012) that the percentage of vacant housing units is positively associated with the food desert status, albeit not at a significant level.

Transit access and food desert status

We used the variable 'share of commuters taking transit to work' as a proxy for the existence and quality of transit service in the neighbourhood and found it to be significantly correlated with the emergence of healthy food. Each 1% increase in share of transit commuters resulted in a 2.3% decrease in the odds of a census tract being classified as a food desert. According to the literature, transit's benefits for a neighbourhood are not limited to increasing transit ridership. Transit creates opportunities for transit-oriented development (TOD), which is 'compact, mixed use development near transit facilities with high-quality walking environments' (Cervero et al., 2004; Ewing and Hamidi, 2014), around stations. Transit, in turn, might attract supermarket chains and food retailers to bring their services to the neighbourhood. This is confirmed by our findings. Areas with a higher percentage of transit commuters are statistically less likely to be food deserts.

Urban sprawl and food desert status

Turning to the compactness indices, we found that the relationship between the compactness indices and food desert status at both regional and neighbourhood (census tract) levels is significant and has the expected signs with relatively large odd ratios. At the regional level, all other variables being equal, census tracts in more sprawling metropolitan areas are more likely to be food deserts. Each one unit increase in the Metropolitan Compactness Index decreases the odds of a census tract being a food desert by 1.2%. This might be due to the fact that urban sprawl increases income and racial segregation (Jargowsky, 2002; Nelson et al., 2004; Wheeler, 2006), thus isolating disadvantaged neighbourhoods. The location of supermarkets, like other businesses, is often in close proximity to customers with greater financial resources, leaving low-income neighbourhoods more vulnerable to becoming food deserts. The same applies to another consequence of urban sprawl: declining downtowns. Food retailers are likely to follow their wealthier customers to the suburbs, causing older neighbourhoods with lower socioeconomic status to become food deserts.

The compactness index is also highly significant at the neighbourhood (census tract) level. Indeed, the census tract compactness index is most significant when it correlates food desert status with sociodemographic characteristics. Each one unit increase in the census tract compactness index resulted in a 5.6% decrease in the odds of a census tract being a food desert. This indicates that the neighbourhood context matters a great deal, not just in terms of sociodemographic issues highlighted in the literature, but also because of characteristics of the surrounding built environment. Controlling for covariates, such as income and minority population, more sprawling neighbourhoods are more likely to be food deserts. One possible explanation is that low-density neighbourhoods do not provide enough profit for food retailers to invest. Compact neighbourhoods, on the other hand, facilitate concentration of shoppers in the vicinity of food retailers. Shoppers may be close enough to use alternative modes to gain access to food retailers. With travel modes other than the automobile (transit or walking, for example), shoppers are more likely to shop at the closest retailer.

Study limitations

Further research is needed to study access to healthy food versus unhealthy food in both urban and rural contexts. Since the USDA's Food Desert Locator only covers supermarkets and large grocery stores within areas designated as food deserts, it could not be used to study access to smaller healthy food outlets, farmers' markets, greengrocers or even access to unhealthy food outlets such as fast food restaurants, dollar stores and convenience stores. This could be relevant in those central urban areas with relatively high access to unhealthy food choices, or alternatively, those areas with low access to full-service supermarkets. A similar analysis could be carried out based on the total number of food establishments, or the ratio of grocery stores to fast food restaurants, in census tracts. Another area for further research could be investigating the emergence of food deserts with respect to the average age of housing units located in census tracts. This may bring further insight into grocery stores' accessibility in areas built before the widespread adoption of automobiles and single-use zoning. Such historical milestones in American planning can contribute to our understanding of the mechanisms by which food deserts arise. Finally, a longitudinal study would shed light on the effects of recent major demographic changes on the emergence of food deserts. More research is needed in order to better understand whether the recent trend of suburban residents relocating to urban cores in many American metro areas has had an impact on mitigating food deserts in particularly compact areas. Finally, measures of transit quality such as transit frequency and travel time to food outlets may help to establish whether transit quality influences the rise or decline of food deserts, potentially adding a vital lens of transit equity to the literature on food deserts and urban form.

Conclusions

This analysis is one of the first national attempts, in our estimation, to account for urban sprawl and other built-environment and socioeconomic characteristics of the neighbourhood to explain the likelihood of a census tract being a food desert. Previous studies have focused heavily on socioeconomic characteristics, particularly income and minority status (Berg and Murdoch, 2008; Dutko et al., 2012; Powell et al., 2007). This is also the first analysis of food deserts to account for variables at two levels of geography – census tracts and metropolitan areas – and to control for regional differences using hierarchical modelling.

This study found that, in addition to socioeconomic characteristics, urban sprawl at both neighbourhood and regional levels increases the likelihood of a census tract being a food desert. Neighbourhoods with a greater compactness index are likely to support a greater number of grocery stores and are more likely to have nearby stores in close proximity. At the regional level, more compact regions reduce racial and income segregation and do not allow older neighbourhoods to be filtered to lower socioeconomic status (Jargowsky, 2002; Nelson et al., 2004; Wheeler, 2006). While this study recognises the significant role of more compact and walkable neighbourhoods in improving access to healthy food for residents, the existing literature has also emphasised other noticeable health benefits of more compact, walkable and mixed use neighbourhoods by showing how residents of more compact neighbourhoods often have lower body mass index (BMI) values, and are less likely to suffer from chronic diseases such as high blood pressure, coronary heart disease and diabetes (Ewing et al., 2014; Garfinkel-Castro et al., 2017; Guettabi and Munasib, 2014).

Understanding the characteristics of food deserts is critical for planners and policymakers to develop policies that promote access to healthy foods and potentially reduce obesity and improve other health outcomes (Ahern et al., 2011). The goal of current policies, such as HFFI, has been to bring affordable, nutritious food to areas of low access and low income (Holzman, 2010).

One way to achieve this goal is to encourage large supermarket chains and food retailers to invest in disadvantaged neighbourhoods by offering financial incentives, such as tax breaks or building restoration initiatives (Larsen and Gilliland, 2008). The *Pennsylvania Fresh Food Financing Initiative* (FFFI) is an example of a state-wide financing programme developed to stimulate private capital investment into low-income communities (Giang et al., 2008). The FFFI aims to encourage viable supermarket operators and developers to select sites in disadvantaged areas by providing funding opportunities through grants, loans, and tax credit programmes.

While these policies can be effective for providing healthy food in existing food deserts, more systematic reforms are needed in order to effect lasting change. Another, perhaps longer-term, approach would be to create a supportive and attractive environment for food retailers to invest in disadvantaged neighbourhoods. Increasing the density, diversity of land uses and walkability of a neighbourhood is likely to increase the population and to support a greater number of grocery stores. Localities could also reform zoning or parking regulations in disadvantaged areas, particularly in their urban cores, in order to encourage major grocers to consider locating there (Larsen and Gilliland, 2008).

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Note

1. http://gis.cancer.gov/tools/urban-sprawl/.

ORCID iD

Shima Hamidi https://orcid.org/0000-0001-6717-5700

References

Ahern M, Brown C and Dukas S (2011) A national study of the association between food environments and county-level health outcomes. *Journal of Rural Health* 27(4): 367–379.

Algert SJ, Agrawal A and Lewis DS (2006) Disparities in access to fresh produce in low-income neighborhoods in Los Angeles. *American Journal of Preventive Medicine* 30(5): 365–370.

Allcott H, Diamond R and Dubé JP (2017) The geography of poverty and nutrition: Food deserts and food choices across the United States. No. w24094. National Bureau of Economic Research. Unpublished working paper.

Baker EA, Schootman M, Barnidge E, et al. (2006) The role of race and poverty in access to foods that enable individuals to adhere to dietary guidelines. *Preventing Chronic Disease* 3(3): 1–11.

Berg N and Murdoch J (2008) Access to grocery stores in Dallas. *International Journal of Behavioral and Healthcare Research* 1(1): 22–37.

Block JP, Christakis NA, O'Malley AJ, et al. (2011) Proximity to food establishments and body mass index in the Framingham heart study offspring cohort over 30 years. *American Journal of Epidemiology* 174(10): 1108–1114.

Bodor JN, Rice JC, Farley TA, et al. (2010) The association between obesity and urban food environments. *Journal of Urban Health* 87(5): 771–781.

Cannuscio CC, Hillier A, Karpyn A, et al. (2014) The social dynamics of healthy food shopping and store choice in an urban environment. *Social Science & Medicine* 122: 13–20.

Casey AA, Elliott M, Glanz K, et al. (2008) Impact of the food environment and physical activity environment on behaviors and weight status in rural US communities. *Preventive Medicine* 47(6): 600–604.

Cervero R, Murphy S, Ferrell C, et al. (2004) *Transit-Oriented Development in the United States: Experiences, Challenges, and Prospects*. Washington, DC: Transit Cooperative Research Program.

Danaei G, Ding EL, Mozaffarian D, et al. (2009) The preventable causes of death in the United States: Comparative risk assessment of dietary, lifestyle, and metabolic risk factors. *PLos Medicine* 6(4): e1000058.

Donohue RM (1997) *Abandonment and Revitalization of Central City Retailing: The Case of Grocery Stores*. Doctoral dissertation, University of Michigan.

Doyle S, Kelly-Schwartz A, Schlossberg M, et al. (2006) Active community environments and health: The relationship of walkable and safe communities to individual health. *Journal of the American Planning Association* 72(1): 19–31.

Duany A, Plater-Zyberk E and Speck J (2000) *Suburban Nation: The Rise of Sprawl and the Decline of the American Dream*. New York: North Point Press.

Dubowitz T, Ghosh-Dastidar M, Cohen D, et al. (2015) A new supermarket in a food desert: Is better health in store? Santa Monica, CA: RAND Corporation. Available at: https://www.rand.org/pubs/research_briefs/RB9874.html (accessed 15 February 2019).

Dutko P, Ver Ploeg M and Farrigan TL (2012) *Characteristics and Influential Factors of Food Deserts*. Washington, DC: US Department of Agriculture, Economic Research Service.

Elbel B, Moran A, Dixon LB, et al. (2015) Assessment of a government-subsidized supermarket in a high-need area on household food availability and children's dietary intakes. *Public Health Nutrition* 18(15): 2881–2890.

Ewing R and Hamidi S (2014) Measuring urban sprawl and validating sprawl measures. Technical Report prepared for the National Cancer Institute, National Institutes of Health, the Ford Foundation, and Smart Growth America. Available at: https://gis.cancer.gov/tools/urban-sprawl/ (accessed 15 February 2019).

Ewing R and Hamidi S (2015) Compactness versus sprawl: A review of recent evidence from the United States. *Journal of Planning Literature* 30(4): 413–432.

Ewing R and Hamidi S (2017) *Costs of Sprawl*. New York: Routledge.

Ewing R, Meakins G, Hamidi S, et al. (2014) Relationship between urban sprawl and physical activity, obesity, and morbidity – Update and refinement. *Health & Place* 26: 118–126.

Ewing R, Pendall R and Chen D (2003) Measuring sprawl and its transportation impacts. *Transportation Research Record: Journal of the Transportation Research Board* 1831(1): 175–183.

Fan L, Baylis K, Gundersen C, et al. (2018) Does a nutritious diet cost more in food deserts? *Agricultural Economics* 49(5): 587–597.

Fan Y and Song Y (2009) Is sprawl associated with a widening urban–suburban mortality gap? *Journal of Urban Health* 86(5): 708–728.

Garfinkel-Castro A, Kim K, Hamidi S, et al. (2017) Obesity and the built environment at different urban scales: Examining the literature. *Nutrition Reviews* 75(Suppl. 1): 51–61.

Giang T, Karpyn A, Laurison HB, Hillier A and Perry RD (2008) Closing the grocery gap in underserved communities: The creation of the Pennsylvania Fresh Food Financing Initiative. *Journal of Public Health Management and Practice* 14(3): 272–279.

Gibson DM (2011) The neighborhood food environment and adult weight status: Estimates from longitudinal data. *American Journal of Public Health* 101(1): 71–78.

Gregson J (2011) Poverty, sprawl, and restaurant types influence body mass index of residents in California counties. *Public Health Reports* 126(1): 141–149.

Griffin B, Eibner C, Bird CE, et al. (2012) The relationship between urban sprawl and coronary heart disease in women. *Health & Place* 20: 51–61.

Guettabi M and Munasib A (2014) Urban sprawl, obesogenic environment, and child weight. *Journal of Regional Science* 54(3): 378–401.

Hamidi S and Ewing R (2014) A longitudinal study of changes in urban sprawl between 2000 and 2010 in the United States. *Landscape and Urban Planning* 128: 72–82.

Hamidi S and Ewing R (2015) Is sprawl affordable for Americans? Exploring the association between sprawl and housing affordability. *Transportation Research Record: Journal of the Transportation Research Board* 2500: 75–79.

Hamidi S, Ewing R, Preuss I, et al. (2015) Measuring sprawl and its impacts: An update. *Journal of Planning Education and Research* 35(1): 35–50.

Hamidi S, Ewing R, Tatalovich Z, et al. (2018) Associations between urban sprawl and life expectancy in the United States. *International Journal of Environmental Research and Public Health* 15(5): 861.

Hendrickson D, Smith C and Eikenberry N (2006) Fruit and vegetable access in four low-income food desert communities in Minnesota. *Agriculture and Human Values* 23: 371–383.

Holzman DC (2010) Diet and nutrition: White House proposes Healthy Food Financing Initiative. *Environmental Health Perspectives* 118(4): 156.

Hutchinson PL, Bodor JN, Swalm CM, et al. (2012) Neighborhood food environments and obesity in southeast Louisiana. *Health & Place* 18(4): 854–860.

Inagami S, Cohen DA, Brown AF, et al. (2009) Body mass index, neighborhood fast food and restaurant concentration, and car ownership. *Journal of Urban Health* 86(5): 683–695.

Jargowsky PA (2002) Sprawl, concentration of poverty, and urban inequality. In: Squires G (ed.) *Urban Sprawl: Causes, Consequences and Policy Response*. Washington, DC: Urban Institute Press, pp. 39–72.

Jeffery RW, Baxter J, McGuire M, et al. (2006) Are fast food restaurants an environmental risk factor for obesity? *International Journal of Behavioral Nutrition and Physical Activity* 3(1): 2.

Jetter KM and Cassady DL (2006) The availability and cost of healthier food alternatives. *American Journal of Preventive Medicine* 30(1): 38–44.

Joshu CE, Boehmer TK, Ewing R, et al. (2008) An examination of personal, neighborhood and urbanization correlates of obesity in the United States. *Journal of Epidemiology and Community Health* 62: 202–208.

Kelly-Schwartz AC, Stockard J, Doyle S, et al. (2004) Is sprawl unhealthy? A multilevel analysis of the relationship of metropolitan sprawl to the health of individuals. *Journal of Planning Education and Research* 24(2): 184–196.

Kim D, Subramanian SV, Gortmaker SL, et al. (2006) US state- and county-level social capital in relation to obesity and physical inactivity: A multilevel, multivariable analysis. *Social Science & Medicine* 63(4): 1045–1059.

Kostova D (2011) Can the built environment reduce obesity? The impact of residential sprawl and neighborhood parks on obesity and physical activity. *Eastern Economic Journal* 37(3): 390–402.

Lake A and Townshend T (2006) Obesogenic environments: Exploring the built and food environments. *The Journal of the Royal Society for the Promotion of Health* 126(6): 262–267.

Lamb K, Thornton L, Cerin E, et al. (2015) Statistical approaches used to assess the equity of access to food outlets: A systematic review. *AIMS Public Health* 2(3): 358–401.

Larsen K and Gilliland J (2008) Mapping the evolution of food deserts in a Canadian city: Supermarket accessibility in London, Ontario, 1961–2005. *International Journal of Health Geographics* 7(1): 16.

Larson NI, Story MT and Nelson MC (2009) Neighborhood environments: Disparities in access to healthy foods in the U.S. *American Journal of Preventive Medicine* 36(1): 74–81.

Lee I, Ewing R and Sesso HD (2009) The built environment and physical activity levels: The Harvard Alumni Health Study. *American Journal of Preventive Medicine* 37(4): 293–298.

Mackenbach JD, Rutter H, Compernolle S, et al. (2014) Obesogenic environments: A systematic review of the association between the physical environment and adult weight status, the SPOTLIGHT project. *BMC Public Health* 14(1): 233.

Mead MN (2008) Urban issues: The sprawl of food deserts. *Environmental Health Perspectives* 116(8): 335.

Mehta NK and Chang VW (2008) Weight status and restaurant availability: A multilevel analysis. *American Journal of Preventive Medicine* 34(2): 127–133.

Mokdad AH, Marks JS, Stroup DF and Gerberding JL (2004) Actual causes of death in the United States, 2000. *JAMA* 291(10): 1238–1245.

Morland K and Filomena S (2007) Disparities in the availability of fruits and vegetables between racially segregated urban neighborhoods. *Public Health Nutrition* 10(12): 1481–1489.

Morland K, Roux AVD and Wing S (2006) Supermarkets, other food stores, and obesity: The atherosclerosis risk in communities study. *American Journal of Preventive Medicine* 30(4): 333–339.

Morland K, Wing S and Roux AD (2002) The contextual effect of the local food environment on residents' diets: The atherosclerosis risk in communities study. *American Journal of Public Health* 92(11): 1761–1768.

Nelson AC, Sanchez TW and Dawkins CJ (2004) Urban containment and residential segregation: A preliminary investigation. *Urban Studies* 41(2): 423–440.

Olshansky SJ, Passaro DJ, Hershow RC, et al. (2005) A potential decline in life expectancy in the United States in the 21st century. *New England Journal of Medicine* 352(11): 1138–1145.

Plantinga AJ and Bernell S (2007) The association between urban sprawl and obesity: Is it a two-way street? *Journal of Regional Science* 47(5): 857–879.

Pothukuchi K (2005) Attracting supermarkets to inner-city neighborhoods: Economic development outside the box. *Economic Development Quarterly* 19(3): 232–244.

Powell LM, Slater S, Mirtcheva D, et al. (2007) Food store availability and neighborhood characteristics in the United States. *Preventive Medicine* 44(3): 189–195.

Raudenbush SW and Bryk AS (2002) *Hierarchical Linear Models: Applications and Data Analysis Methods*. Thousand Oaks, CA: SAGE Publications, Inc.

Smith C and Morton L (2009) Rural food deserts: Low-income perspectives on food access in Minnesota and Iowa. *Journal of Nutrition Education and Behavior* 41(3): 176 –187.

Stewart ST, Cutler DM and Rosen AB (2009) Forecasting the effects of obesity and smoking on US life expectancy. *New England Journal of Medicine* 361(23): 2252–2260.

US Department of Agriculture (2009) *Access to Affordable and Nutritious Food: Measuring and Understanding Food Deserts and Their Consequences*. Report to Congress, AP-036, USDA, Economic Research Service. Available at: http://www.ers.usda.gov/Publications/AP/AP036/ (accessed 15 February 2019).

US Department of Agriculture (2013) Food Access Research Atlas data download and current and archived version of documentation. Available at: http://www.ers.usda.gov/data-products/food-access-research-atlas/ (accessed 15 February 2019).

Weinberg Z (2000) No place to shop: Food access lacking in the inner city. *Race, Poverty & The Environment* 7(2): 22–24.

Wheeler CH (2006) *Urban decentralization and income inequality: Is sprawl associated with rising income segregation across neighborhoods?* Federal Reserve Bank of St. Louis Working Paper Series, 2006–037.

Zenk SN, Schulz AJ, Israel BA, et al. (2005) Fruit and vegetable access differs by community racial composition and socioeconomic position in Detroit, Michigan. *Ethnicity & Disease* 16(1): 275–280.