

# A method for estimating the associations of neighborhood type with availability of sit-down restaurants and supermarkets

Ke Peng (✉ [kpeng6@hnu.edu.cn](mailto:kpeng6@hnu.edu.cn))

Hunan University <https://orcid.org/0000-0001-6708-3873>

Daniel A. Rodriguez

University of California Berkeley

Jana A. Hirsch

Drexel University

Penny Gordon-Larsen

University of North Carolina at Chapel Hill

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## Research

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# Abstract

**Background:** Although neighborhood-level access to food differs by sociodemographic factors, almost all research on neighborhoods and food access has used a single construct of neighborhood context, such as income or race. Neighborhoods possess many interrelated built environment and sociodemographic characteristics, a condition that obscures relationships between neighborhood factors and food access.

**Methods:** To account for the effects of many interrelated aspects of neighborhoods in food access, we developed a generally applicable method that used multiple measures (e.g., population density, mix of land use, and sociodemographic factors) that are easy to obtain to define six neighborhood types in 1993 in the Twin Cities Region, Minnesota. We then used mixed effects regression models to estimate differences in the relative availability of sit-down restaurants and supermarkets in 1993, 2001, and 2011 across the six neighborhood types.

**Results:** We observed a higher relative availability of sit-down restaurants in inner city neighborhoods than in urban, aging suburbs, high-income suburbs, or suburban edge neighborhoods for 2011; we did not observe these same patterns for 1993 or 2001. Using nuanced classification of neighborhood type, we found a complex and increasingly varied distribution of restaurants and food stores.

**Conclusions:** The temporal increase in sit-down restaurants in inner cities may be associated with a higher proportion of residents who eat-away-from-home, which is associated with higher calorie and fat intake.

## Introduction

Previous studies on access to healthy food have generally characterized neighborhoods by single attributes of neighborhood context [1], such as income or race. Although low-income and minority-dominant neighborhoods generally have poor access to healthy food [2], findings on this subject are inconclusive. For example, some investigators have observed that, compared with moderate and high income neighborhoods, low-income neighborhoods tend to have greater availability of fast-food restaurants [3,4] whereas other investigators have not observed a higher prevalence of fast-food restaurants in low-income neighborhoods [5,6]. In fact, we know little about neighborhoods defined by a multidimensional categorization that acknowledges the patterning of neighborhoods across many interrelated built environment and sociodemographic characteristics [7]. The types of restaurants and food stores in neighborhoods may vary by non-sociodemographic factors such as population density and land use pattern. For example, purveyors of some types of restaurants and food stores may choose to locate in poor neighborhoods because residential densities are sufficiently high to maintain demand [8].

Because neither aggregate indices of sociodemographic factors nor specific aspects of the built environment appear in isolation in neighborhoods [9], we used a novel method to classify neighborhood types using a combination of several domains. Cluster analysis can take into account a broad set of neighborhood resource variables to fully capture multiple neighborhood dimensions. Thus, cluster

analysis can be used to disentangle the mixed results derived from different neighborhood types. This measurement strategy identifies groups of neighborhoods with shared characteristics (such as population density, mix of land use, and sociodemographic factors) that may entice a restaurant or food store to locate within a neighborhood. Thus, similar to previous studies [7,9,10], we used cluster analysis as a strategy to define neighborhood types and document their patterns of restaurants and food stores.

We examined the distribution of types of restaurants and food stores within each type of neighborhood to determine whether a particular neighborhood type had relatively greater access to a specific type of restaurant or food store compared with other neighborhood types. We analyzed the Twin Cities Region of Minnesota (abbreviated as Twin Cities Region), an area of nearly three million people living in 186 communities across the seven counties of Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington. The Twin Cities Region has developed several distinctive types of neighborhoods (e.g., active downtown, vibrant urban) [11]. In addition, during the period from 1985-2010, the neighborhood environment in the Twin Cities Region became increasingly diverse in social composition and physical form [11]. Therefore, we expected that the Twin Cities Region would be an ideal case in which to observe temporal differences of, and changes in, the distribution of neighborhood food resources. We used data on business types and locations for 1993, 2001, and 2011 to examine the associations between neighborhood types, as defined by the 1993 data, and the changes in the relative availability of sit-down restaurants and supermarkets in the Twin Cities Region neighborhoods during the 1993-2011 period.

We distinguished six types of neighborhoods with distinctive built environment and sociodemographic characteristics. These neighborhoods exhibited a complex and progressively varied composition of restaurants and food stores during the 18-year period that we studied. Most notably, for the year 2011, sit-down restaurants predominated in inner cities compared with the other five neighborhood types. An opposite trend existed in 1993 and 2001. Supermarkets predominated in aging suburbs compared with urban and high-income suburbs in 2001 and 2011, but not in 1993. Although we examined only one, large geographical area, our method is general, and it can be applied easily to assess associations between built environment and sociodemographic factors and food access in any region of interest.

## Methods

### 1.1 Study area

Our study area included 2,083 census block groups defined in 2010 by the U.S. Census Bureau in the Twin Cities Region, a 7-county (Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington) area with diverse built environment and sociodemographic characteristics [11]. We used census block groups to operationalize neighborhoods. The census block group (approximate population of 1,500) is the smallest unit for which data are available on built environment and sociodemographic measures. We excluded only two census block groups in the Twin Cities Region because of missing data.

### 1.2 Relative availability of sit-down restaurants and supermarkets

We obtained food resource data from the D&B Duns Market Identifiers File (restaurant and food store Standard Industrial Classification categories; Dun & Bradstreet, Inc., Short Hills, NJ), a secondary commercial data source widely available in the U.S. We then classified the food resources according to primary eight-digit Standard Industrial Classification codes for data in years 1993, 2001, and 2011 (See Table S1 in Additional File 1).

We characterized neighborhood restaurant and food store availability by calculating the availability of sit-down restaurants (relative to total restaurants) and supermarkets (relative to total food stores). Recent reports suggest that relative availability, i.e., particular proportions of various types of retail food outlets, may be more important to diet-related behaviors than the total number of outlets because relative availability offers residents competing options [12–14]. We defined the relative availability of sit-down restaurants as the percent of sit-down restaurants relative to total sit-down and fast food restaurants in a neighborhood (abbreviated below as percent of sit-down restaurants). We defined the relative availability of supermarkets as the percent of supermarkets relative to total supermarkets, grocery stores, and convenience stores in a neighborhood (abbreviated as percent of supermarkets below). We used ArcGIS 10.3 to calculate the count of each type of food resource within each neighborhood in each observational year, and then we used the counts to calculate the percent of sit-down restaurants and supermarkets in STATA 14.0.

### 1.3 Neighborhood type

To classify neighborhood type, we used a cluster analysis that included 13 built environment and sociodemographic characteristics in 1990. Because we did not have neighborhood built environment and sociodemographic data for 1993, we assumed that the neighborhood type classified by the 1990 built environment and sociodemographic data was a valid substitute for the 1993 built environment and sociodemographic data.

#### 1.3.1 Neighborhood built environment characteristics

Neighborhood built environment characteristics included residential population density, employment population density, mix of land use, and percent of single-family housing in the neighborhood. We obtained the census population and land area size data in 1990, 2000, and 2006–2009 from the Census 1990, Census 2000, and the 2006–2009 American Community Survey. We used such data from the US Census Longitudinal Tract Database, which normalized the 1990, 2000, and 2006–2009 census data to the boundaries of census tracts in 2010. We interpolated the normalized census population density data for years from the census tract level to the census block-group level for years 1990, 2000, and 2010. We then measured residential population density as the total residential population divided by the total land area of the block group, and we measured employment population density as the total employed civilian labor force 16 years old and above divided by the total land area of the block group. We obtained data on categories and areas of different types of land uses for the creation of land use mix and percent of single-family housing from the GIS-based current land-use map in 1990, 2000, and 2010 from the Minneapolis Metropolitan Council. We measured the mix of land use using the 3-tier land use entropy

equation (with the denominator set to the static 3 land use types in the block group), which used three land use categories (residential, employment and retail) to calculate mix of land use in the block group [15]. Land use entropy ranges in value from zero (total homogeneity, with all land use in one category) to 1 (maximum heterogeneity, with an even mixture of land use). We defined the percent of single-family housing as the number of single-family housing units divided by the total number of single-family and multi-family housing units.

### 1.3.2 Neighborhood sociodemographic characteristics

Neighborhood sociodemographic characteristics included percent of population aged under 14, aged between 15 and 29, aged between 30 and 44, aged between 45 and 64, aged 65 or above, percent of education of college or above, percent of white race, percent of black race, and median household income. We retrieved all the census sociodemographic characteristics in 1990, 2000, and the 2006–2009 American Community Survey of the U.S. Census Bureau from the US Census Longitudinal Tract Database. We then interpolated the normalized census sociodemographic characteristics data from the census tract level to the census block-group level.

### 1.3.3 Cluster analyses

We first transformed each 1990 built environment and sociodemographic variable into a z-score to achieve more comparable scales and ranges; otherwise, variables with large ranges might have weighed heavier in the analysis than those with small ranges. We then used the transformed data to perform partition cluster analyses within the 13 built environment and sociodemographic characteristics, using K-means in Stata 14.0. We tested different numbers of clusters, from four to seven, and found that the best clustering solution was a six-cluster solution based on the associated cluster statistics and the interpretability of the results.

## 1.4 Covariates

Neighborhood type in 1993, while robust, did not gradually change over time and, therefore, could not be used to explain the change in percent of sit-down restaurants and supermarkets between 1993 and 2011. Thus, to represent the changes in neighborhood characteristics during that period, we added to our models variables for the changes in residential population density, median household income, percent of white race, and percent of single-family housing from 1990. We calculated the changes in residential population density in 1990, 2000, and 2006-2009 as zero, the residential population density in 2000 minus the residential population density in 1990, and the residential population density in 2006-2009 minus the residential population density in 1990, respectively. We calculated changes in median household income, percent of white race, and percent of single-family housing by the same method that we used to calculate changes in residential population density.

Sit-down restaurant purveyors may prefer to locate their restaurants in neighborhoods that already have a large number of restaurants to draw customers who may seek variety in the establishments they frequent

[16,17]. Therefore, we added the total number of sit-down restaurants and fast food restaurants as one of covariates in the sit-down restaurant model. However, supermarket purveyors may not prefer to locate in neighborhoods that already have a large number of different types of food stores as competition may reduce the likelihood of customers who tend to prefer to shop at a specific outlet [18]. Therefore, we added the total number of supermarkets, grocery stores and convenience stores as one of the covariates in the supermarket model.

## 1.5 Statistical analyses

All descriptive analyses and multivariable models were performed using Stata 14.0 (StataCorp, College Station, TX).

### 1.5.1 Descriptive statistics

We calculated means and standard deviations (for continuous variables) of neighborhood built environment characteristics, neighborhood sociodemographic characteristics, and the relative availability of sit-down restaurants and supermarkets in the neighborhood in 1990/1993, 2001 and 2011. We used one-tailed Student's t-test to test for statistically significant differences for continuous variables.

### 1.5.2 Relationship between neighborhood type and relative availability of sit-down restaurants and supermarkets

We used multivariable linear mixed effects regression models to estimate the associations between neighborhood type in 1993 and the percent of sit-down restaurants and percent of supermarkets in 1993, 2001, and 2011 (n=2,083). These models appropriately accounted for the clustered data structure of repeated measurements over time within each neighborhood. We modeled the percent of sit-down restaurants/supermarkets in each neighborhood as a function of neighborhood type in 1993, the time elapsed in years from 1993, the term for the interaction of neighborhood type in 1993 with elapsed time, and the time-varying covariates. We included random intercepts for each neighborhood in the sit-down restaurant and supermarket models to enable responses to vary within neighborhoods.

## Results

### 1.1 Descriptive statistics

Compared with 1993, in 2011, the percentages of sit-down restaurants and supermarkets in the study area increased 10.1 and 3.3 percentage points, respectively (Table 1). Our study area's population in 2011 (compared with 1993) tended to be older (45-64 or 65 or above), more non-white, more college educated or higher, and having higher household incomes. The study area had a greater population density, greater mix of land use, and greater percent of single-family housing in 2011 compared with 1993.

#### **Table 1 Selected characteristics of neighborhoods in years 1993, 2001 and 2011, Twin Cities Region**

Neighborhood characteristic	1993 <sup>a</sup>	2001	2011	Change <sup>b</sup>	P value <sup>c</sup>
Number of observations (neighborhoods)	2,083	2,083	2,083	—	—
<b>Relative availability of sit-down restaurants and supermarkets</b>					
Percent of sit-down restaurants <sup>d</sup> , mean (SD)	16.1 ± 33.1	22.7 ± 36.4	26.2 ± 36.8	10.1 ± 41.4	<0.05
Percent of supermarkets <sup>e</sup> , mean (SD)	2.0 ± 11.9	2.4 ± 12.9	5.3 ± 19.6	3.3 ± 20.1	<0.05
<b>Built environment characteristics</b>					
Residential population density, 1,000 person/km <sup>2</sup> , mean (SD)	1.5 ± 1.3	1.6 ± 1.4	1.6 ± 1.4	0.1 ± 0.4	<0.05
Employment population density, 1,000 person/km <sup>2</sup> , mean (SD)	0.8 ± 0.8	0.8 ± 0.8	0.9 ± 0.8	0.1 ± 0.3	<0.05
Mix of land use <sup>f</sup> , mean (SD)	44.2 ± 27.9	48.0 ± 29.7	53.0 ± 28.2	8.8 ± 20.4	<0.05
Percent of single-family housing <sup>g</sup> , mean (SD)	61.3 ± 33.8	63.7 ± 33.6	77.3 ± 31.5	16.3 ± 27.0	<0.05
Total sit-down restaurants and fast food restaurants, mean (SD)	0.8 ± 2.1	1.3 ± 2.6	2.1 ± 4.5	1.3 ± 3.2	<0.05
Total supermarkets, grocery stores and convenience stores, mean (SD)	0.8 ± 1.1	1.0 ± 1.3	1.0 ± 1.3	0.2 ± 1.2	<0.05
<b>Sociodemographic characteristics</b>					
<b>Age, mean (SD)</b>					
Percent of population under 14	22.2 ± 6.4	21.3 ± 6.8	19.9 ± 6.0	-2.3 ± 4.8	<0.05
Percent of population 15–29	23.7 ± 7.3	20.9 ± 7.8	21.6 ± 8.4	-2.1 ± 4.6	<0.05

Neighborhood characteristic	1993 <sup>a</sup>	2001	2011	Change <sup>b</sup>	P value <sup>c</sup>
Percent of population 30–44	27.2 ± 4.7	26.0 ± 4.8	21.9 ± 4.5	-5.3 ± 5.0	<0.05
Percent of population 45–64	16.9 ± 5.0	21.2 ± 5.4	25.8 ± 5.7	8.9 ± 5.8	<0.05
Percent of population 65 or above	9.9 ± 6.6	10.5 ± 7.3	10.8 ± 6.0	0.9 ± 5.7	<0.05
Percent of population with education level of college or above, mean (SD)	57.6 ± 15.2	66.1 ± 14.9	68.1 ± 14.3	10.5 ± 8.6	<0.05
Race, mean (SD)					
Percent of white race	91.6 ± 13.0	84.1 ± 17.1	80.8 ± 17.6	-10.8 ± 11.6	<0.05
Percent of black race	4.0 ± 9.1	6.1 ± 9.5	8.1 ± 11.1	4.1 ± 7.2	<0.05
Median household income <sup>h</sup> , \$1,000, median (SD)	38.2 ± 12.5	40.5 ± 15.1	37.1 ± 14.5	0.4 ± 7.5	<0.05
Time elapsed from 1993, year, mean (SD)	0 ± 0	8 ± 0	18 ± 0	18 ± 0	—

<sup>a</sup> Because we did not have neighborhood built environment and sociodemographic data for 1993, we assumed that data for 1990 would be valid substitutes for the missing 1993 data

<sup>b</sup> Change in neighborhood characteristics from year 1993 to 2011.

<sup>c</sup> P value for one-tailed Student's t-test of difference from years 1993 and 2011.

<sup>d</sup> Percent of sit-down restaurants relative to total sit-down restaurants and fast food restaurants.

<sup>e</sup> Percent of supermarkets relative to total supermarkets, grocery stores and convenience stores.

<sup>f</sup> The mix of land use was measured by 3-tier land use entropy (denominator set to the static 3 land use type in the census block group), which used three land use categories (residential, employment and retail) to calculate mix of land use in the block group.

<sup>g</sup> Percent of single-family housing relative to total single-family and multi-family housings.

<sup>h</sup> The median household income in 1993 and 2001 were adjusted for inflation to compare with that in 2011.

## 1.2 Results from cluster analyses: neighborhood type (Year 1993)

The six robust neighborhood types defined by the final cluster solution represented non-overlapping groupings of Twin Cities Region neighborhoods based on built environment and sociodemographic attributes in 1990 (the first observational year). These clusters included: cluster 1 - high-density urban core; cluster 2 - low-income, non-white inner city; cluster 3 - urban; cluster 4 - aging suburb; cluster 5 - high-income suburb; and cluster 6 - suburban edge.

We labeled clusters based on their most prominent built environment and sociodemographic characteristics (See Table S2 in Additional File 1). Cluster 1, “high-density urban core”, had relatively greater levels of residential and employment population densities, a greater degree of mix of land use, comparatively lower percent single-family housing, comparatively higher percent population aged between 15 and 29, and comparatively lower percent population aged under 14 compared with most of the other clusters. Cluster 2, “low-income, non-white inner city”, had moderate-to-high residential and employment population densities and comparatively higher percent non-white race population, relatively lower level of median household income and comparatively lower percent population with a college education or above compared with other clusters. Cluster 5 and Cluster 6, “high-income suburb” and “suburban edge”, had relatively lower levels of residential and employment population densities, lesser degree of mix of land use, and relatively greater level of median household income than the other four types of neighborhoods. Cluster 3 (“urban”) and Cluster 4 (“aging suburb”) had moderate levels of almost all neighborhood features, except for a greater degree of mix of land use and comparatively higher percent population aged 65 or above than other clusters, respectively.

Figure 1 shows that the high-density urban core (abbreviated as urban core) and low-income, non-white inner city (abbreviated as inner city) neighborhoods were tightly clustered in a small segment within the municipal boundaries of the Twin Cities. Urban and aging suburb neighborhoods comprised those transitional areas located between the urban core or inner city neighborhoods and the suburban areas. Another small grouping of aging suburb and high-income extended into the counties of Carver and Scott and the county of Washington, respectively. The generated clusters reflected comprehensive but distinguishable physical and sociodemographic environments.

Figure 1 Neighborhood types in 1993 in the Twin Cities Region of Minnesota

## 1.3 Relationship between neighborhood type and relative availability of sit-down restaurants and supermarkets”

Table 2 shows the post-estimated linear contrasts of percent of sit-down restaurants and percent of supermarkets in the neighborhood by year and for each neighborhood type pair from the multivariable linear mixed effects regression models. Urban core neighborhoods had a higher percent of sit-down restaurants (by 22.78-27.95 percentage points) compared with the other five types of neighborhoods in

1993; we did not observe any differences in the percent of supermarkets in 1993. In 2001, we observed more differences in percent of sit-down restaurants and supermarkets by neighborhood type. Inner city neighborhoods had a higher percent of sit-down restaurants (by 8.19 percentage points) than did suburban edge neighborhoods; aging suburb neighborhoods had slightly more supermarkets (1.52-1.78 percentage points) compared with the urban, high-income suburb, and suburban edge neighborhoods. In 2011, inner city neighborhoods had more sit-down restaurants (8.57-12.27 percentage points) than the urban, aging suburb, and high-income suburb neighborhoods. Figures 2 and 3 show the estimated mean of percent of sit-down restaurants and supermarkets over time for each neighborhood type from the same models. Although urban core neighborhoods had a consistently greater percent of sit-down restaurants compared with other neighborhoods in all (three) observational years (Figure 2), the differences between urban core and the other three types of neighborhoods (inner city, high-income suburb, and suburban edge) decreased in 2011 compared with 1993 and 2001. Table S5 in Additional File 1 shows the p values for the changes of differences in estimated mean of percent of sit-down restaurants/supermarkets for each neighborhood type pair between two observation years from the same models.

**Table 2 Contrasts<sup>a</sup> of percent of sit-down restaurants<sup>b</sup> and percent of supermarkets<sup>c</sup> for each neighborhood type<sup>d</sup> pair**

	<b>Sit-down restaurants <sup>c</sup></b>	<b>Supermarkets <sup>d</sup></b>
	Estimated beta (95% confidence interval)	Estimated beta (95% confidence interval)
<b>1993</b>		
Urban core vs. inner city	23.02 (13.18, 32.85)	1.87 (-2.50, 6.24)
Urban core vs. urban	22.78 (13.97, 31.60)	1.41 (-2.51, 5.33)
Urban core vs. aging suburb	23.75 (14.91, 32.59)	0.18 (-3.75, 4.11)
Urban core vs. high-income suburb	24.93 (15.47, 34.39)	0.58 (-3.63, 4.78)
Urban core vs. suburban edge	27.95 (18.61, 37.29)	1.68 (-2.46, 5.83)
Inner city vs. urban	-0.23 (-7.27, 6.80)	-0.46 (-3.59, 2.67)
Inner city vs. aging suburb	0.73 (-6.19, 7.66)	-1.69 (-4.77, 1.39)
Inner city vs. high-income suburb	1.91 (-5.65, 9.48)	-1.30 (-4.66, 2.07)
Inner city vs. suburban edge	4.94 (-2.41, 12.28)	-0.19 (-3.46, 3.08)
Urban vs. aging suburb	0.967 (-3.29, 5.23)	-1.23 (-3.12, 0.66)
Urban vs. high-income suburb	2.15 (-2.85, 7.14)	-0.84 (-3.06, 1.38)
Urban vs. suburban edge	5.17 (0.63, 9.71)	0.27 (-1.75, 2.29)
Aging suburb vs. high-income suburb	1.18 (-3.11, 5.47)	0.39 (-1.51, 2.30)
Aging suburb vs. suburban edge	4.20 (0.55, 7.86)	1.50 (-0.13, 3.13)
High-income suburb vs. suburban edge	3.02 (-1.10, 7.14)	1.11 (-0.73, 2.94)
<b>2001</b>		
Urban core vs. inner city	13.94 (6.04, 21.84)	2.02 (-1.48, 5.51)
Urban core vs. urban	18.14 (10.80, 25.48)	2.09 (-1.15, 5.34)
Urban core vs. aging suburb	19.51 (11.96, 27.06)	0.32 (-3.03, 3.66)
Urban core vs. high-income suburb	18.81 (10.65, 26.96)	1.91 (-1.70, 5.52)
Urban core vs. suburban edge	22.13 (14.04, 30.22)	1.84 (-1.74, 5.41)
Inner city vs. urban	4.20 (-1.44, 9.85)	0.78 (-2.42, 2.58)
Inner city vs. aging suburb	5.57 (-0.11, 11.26)	-1.70 (-4.22, 0.82)
Inner city vs. high-income suburb	4.87 (-1.38, 11.13)	-0.11 (-2.88, 2.66)

<b>Inner city vs. suburban edge</b>	8.19 (2.10, 14.28)	-0.18 (-2.88, 2.52)
<b>Urban vs. aging suburb</b>	1.37 (-2.06, 4.79)	-1.78 (-3.29, -0.26)
<b>Urban vs. high-income suburb</b>	0.67 (-3.44, 4.78)	-0.19 (-2.00, 1.63)
<b>Urban vs. suburban edge</b>	3.99 (0.24, 7.74)	-0.25 (-1.91, 1.40)
<b>Aging suburb vs. high-income suburb</b>	-0.70 (-4.18, 2.78)	1.59 (0.05, 3.13)
<b>Aging suburb vs. suburban edge</b>	2.62 (-0.34, 5.58)	1.52 (0.21, 2.84)
<b>High-income suburb vs. suburban edge</b>	3.32 (0.03, 6.61)	-0.07 (-1.53, 1.39)
<b>2011</b>		
<b>Urban core vs. inner city</b>	2.59 (-7.69, 12.86)	2.19 (-2.37, 6.76)
<b>Urban core vs. urban</b>	12.33 (2.93, 21.74)	2.95 (-1.24, 7.13)
<b>Urban core vs. aging suburb</b>	14.21 (4.67, 23.74)	0.48 (-3.76, 4.72)
<b>Urban core vs. high-income suburb</b>	11.15 (1.09, 21.21)	3.57 (-0.89, 8.04)
<b>Urban core vs. suburban edge</b>	14.85 (5.04, 24.67)	2.03 (-2.32, 6.39)
<b>Inner city vs. urban</b>	9.75 (2.49, 17.01)	0.75 (-2.48, 3.98)
<b>Inner city vs. aging suburb</b>	11.62 (4.46, 18.79)	-1.71 (-4.90, 1.47)
<b>Inner city vs. high-income suburb</b>	8.57 (0.87, 16.26)	1.38 (-2.04, 4.80)
<b>Inner city vs. suburban edge</b>	12.27 (4.95, 19.57)	-0.16 (-3.42, 3.10)
<b>Urban vs. aging suburb</b>	1.87 (-2.56, 6.30)	-2.46 (-4.43, -0.50)
<b>Urban vs. high-income suburb</b>	-1.18 (-6.47, 4.11)	0.63 (-1.72, 2.98)
<b>Urban vs. suburban edge</b>	2.52 (-2.14, 7.17)	-0.91 (-2.98, 1.16)
<b>Aging suburb vs. high-income suburb</b>	-3.05 (-7.65, 1.54)	3.09 (1.05, 5.14)
<b>Aging suburb vs. suburban edge</b>	0.65 (-3.18, 4.47)	1.55 (-0.15, 3.26)
<b>High-income suburb vs. suburban edge</b>	3.70 (-0.60, 8.00)	-1.54 (-3.46, 0.38)

<sup>a</sup> Multivariable linear mixed effects regressions modeling the percent of sit-down restaurants relative to total sit-down restaurants and fast food restaurants and percent of supermarkets relative to total supermarkets, grocery stores and convenience stores as functions of neighborhood type in 1993, time elapsed since 1993, interaction between neighborhood type in 1993 and time elapsed, changes in residential population density, median household income, percent of white race and percent of single-family housing since 1993, total sit-down restaurants and fast food restaurants (sit-down restaurant

model only), and total supermarkets, grocery stores and convenience stores (supermarket model only) and a random intercept for each neighborhood.

<sup>b</sup> Percent of sit-down restaurants relative to total sit-down restaurants and fast food restaurants in the neighborhood.

<sup>c</sup> Percent of supermarkets relative to total supermarkets, grocery stores and convenience stores in the neighborhood.

<sup>d</sup> Derived from cluster analysis of block-group level data from 1993: percent of population aged under 14, aged between 15 and 29, aged between 30 and 44, aged between 45 and 64, aged above 65, percent of education of college or above, percent of white race, percent of black race, median household income, residential population density, employment population density, mix of land use and percent of single-family housing.

## Discussion

We identified six types of neighborhoods in the Twin Cities Region of Minnesota that were characterized by clusters reflecting distinct combinations of built environment with sociodemographic and economic features. Our results indicate an increasingly varied distribution of restaurants and food stores by neighborhood type over time. Our results also hint at the complexity of the relationship between the neighborhood built environment and sociodemographic characteristics and the presence of a certain type of food outlet in the neighborhood.

Our findings contribute to a growing literature on the associations between the multifaceted composition of the built environment, sociodemographic features, and the distribution of food resources. In previous work, researchers investigating the association between neighborhood characteristics and neighborhood food availability have generally characterized neighborhood features more narrowly, focusing on a single construct such as income or race [1]. These studies have produced inconclusive results. Recognizing that analyses may be confounded by correlations among neighborhood features, we included a broad set of neighborhood resource variables to more fully represent neighborhood-defining patterns based on many interrelated built environment and sociodemographic characteristics.

We found that our neighborhood types were not spatially clustered into homogeneous regions but, instead, were distributed across the Twin Cities Region. For example, the municipal boundaries of the Twin Cities did not contain only urban core and inner city neighborhoods but also included urban and aging suburbs. Similarly, aging suburbs and high-income neighborhoods extended to the boundaries of the region, thus they were atypically closer to the city center. Therefore, our results support the work of others who have noted a recent blending of built environment and sociodemographic characteristics, resulting in reduced demarcation between the central city and its outlying suburban areas [19, 20].

Because both the central cities and the outlying areas in metropolitan U.S. are becoming more diverse in form and social composition [20, 21], reliance on single constructs of neighborhoods, such as population density or distance to central business district, may not adequately capture the complexity of neighborhood types.

The distributions of restaurants across neighborhoods in 2001 and 2011 were more varied than in 1993, suggesting that some neighborhoods became relatively more appealing to sit-down restaurants and perhaps less appealing to fast food restaurants. Specifically, we found only suburban edge neighborhoods had a lower percent of sit-down restaurants than did the inner city neighborhoods in 2001; however, the urban, aging suburb, and high-income suburb neighborhoods, similar to the suburban edge, also had a lower percent of sit-down restaurants than did the inner city in 2011. We observed two facts about 2011 that we did not observe for 1993—inner city neighborhoods had greater relative availability of sit-down restaurants than other neighborhoods (except for urban core) and inner city neighborhoods had greater absolute numbers of sit-down restaurants than other neighborhoods (except for urban core and older suburb, data not shown). These two observations were noteworthy. Although inner city neighborhoods consistently had the lowest household income during the observational period (data not shown), inner city neighborhoods had greater spatial access to sit-down restaurants than other neighborhoods in 2011. Residents in inner cities may therefore use sit-down restaurants more frequently than residents in other neighborhoods.

We found that, between 1993 and 2011, inner city neighborhoods experienced a greater increase in percent of sit-down restaurants compared with urban core, urban, and aging suburb neighborhoods (See Table S3 in Additional File 1). It is possible that the desire for cultural amenities, entertainment and other facilities in central cities is an important factor in the inner city population increases, as seen in evidence from New York, NY [22], Houston, TX [23], Washington, DC [24], and other cities or metropolitan areas [25]. There is some evidence that as residential population increases, the demand for sit-down restaurants also increases [3, 26]. In addition, during our study period, U.S. inner cities transitioned from goods production sectors toward relatively place-bound service sector industries [20, 27], which includes restaurants [28, 29]. Similarly, we found that the numbers of sit-down restaurants and fast food restaurants in inner city neighborhoods in the Twin Cities Region increased greatly (by approximately 200 percent) between 1993 and 2011. Lester et al. [29] observed that, in twenty U.S. inner cities between 1990 and 2000, jobs in retail services replaced jobs lost in goods-producing industries. Retail- and service-dominated neighborhoods may provide a complementary environment for clustering of restaurants, food stores and other retail options [27]. Similarly, improvements in transportation and landscaping may create a more spatially accessible and/or walkable features that attract service and retail options [30, 31]. During the study period, the Twin Cities experienced improvements in light rail, the park systems and new sports stadiums [32].

We also found a more varied distribution of food stores across neighborhoods in 2001 and 2011 that we did not see in 1993. Specifically, we found that aging suburb neighborhoods had a greater percent of supermarkets (i.e., fewer percent of grocery stores and convenience stores) than did the urban and high-

income suburb neighborhoods in 2001 and 2011, but not in 1993. Such differences were driven largely by the great increase in the number of grocery stores and convenience stores in the high-income and suburban edge neighborhoods in comparison with increases in numbers of supermarkets in aging suburbs (data not shown). The higher percent of grocery and convenience stores in urban and high-income neighborhoods may compound barriers to accessing healthful foods if such foods are less available in grocery and convenience stores [33].

The percent of sit-down restaurants in urban core neighborhoods was stable during the observational period. This constant percent implies a “saturated” urban core with respect to the relative availability of sit-down restaurants. The unchanged relative availability of sit-down restaurants paralleled an increase in the well-educated population that predominately lived in urban core neighborhoods. This finding was similar to observation for Houston, TX [23], which also showed an increase in the well-educated population in urban core neighborhoods.

None of the time-varying covariates (i.e., changes in residential population density, median household income, percent of white and percent of single-family housing units) was associated with the change in percent of sit-down restaurants over time. For example, although the percent of sit-down restaurants in urban core changed little, residential population density in urban core increased by 12.6% in the years between 1993 and 2011 (data not shown); in contrast, residential population density in the high-income suburb increased little between 1993 and 2011 (data not shown), unlike the significant increase in the percent of sit-down restaurants in high-income suburb in the same period (data not shown). Thus, still unclear are the reasons for a continual increase in sit-down restaurants, instead of fast food restaurants, to locate in all neighborhoods except for urban core. This question should be examined in future research.

In the supermarket model, however, we found that an increased percent of supermarkets was associated with a smaller increase (or more rarely a decrease) in the percent of single-family housing units (See Table S4 in Additional File 1). These largely incompatible land uses—single-family housing and supermarkets – may have opened opportunities for urban planners to use regulatory tools (e.g., zoning) to introduce targeted food stores into the neighborhoods. These regulatory tools could side-step concerns/requirements such as intrusive light [34], sufficient parking [35], or increased traffic, thereby avoiding resistance to introducing a supermarket into neighborhoods with large increases of single-family housing.

Although we did not intend to examine the association between the individual neighborhood characteristics and relative availability of sit-down restaurants and supermarkets, we noticed that some individual neighborhood characteristics may co-vary with each other and jointly affect the distribution of food resources. For example, the urban core had the greatest residential and employment population densities and the greatest percentage of population aged between 15 and 29 years, factors that may jointly contribute to the fact that the highest percentage of sit-down restaurants was in the urban core. To disentangle the complexity undergirding the relationships among neighborhood built environment and

sociodemographic characteristics, future examination of these associations should use individual-level data that target restaurant users.

The Twin Cities Region experienced multiple different economic conditions during the period of our study: economic expansion (1993–2007), economic recession (2007–2009), and economic recovery (2009–2011) [36]. Nevertheless, we observed a steady increase in numbers of sit-down restaurants, fast food restaurants, supermarkets, grocery stores and convenience stores across all neighborhood types (data not shown). These increases were consistent with national reports, and they reflected the macroeconomic shifts in the retail food industry [37]. Thus, neighborhoods had increasingly easy access to all foods regardless of neighborhood type.

Our analysis is novel because, unlike earlier related studies, we used a large and comprehensive set of variables to define neighborhoods, e.g., population and employment density, land use mix, population age, education level, race, and household income. In addition, although we examined only one large metropolitan (geographical) region, our method to assess associations between this complex group of neighborhood characteristics and food availability is generalizable. Our study has several caveats. First, the Twin Cities Region was notably more affordable for housing and transportation and offered more diverse housing choices compared with similar metropolitan areas [11]. Those features may have fostered more convenient access to restaurants and small food stores. Second, the multidimensional class structure we identified by our data-driven approach is difficult to compare with class structure based on single features that other researchers have used. However, because of a lack of consistent association between individual neighborhood characteristics and specific food resource types [38], we elected to use our data-driven approach to characterize the neighborhood environment. Third, the marked undercount of food outlets in the D&B data may have introduced bias [39]. We used the relative number (expressed as a percent) of sit-down restaurants and supermarkets to determine whether different neighborhood types had different relative numbers of these food resources. For example, if sit-down restaurants had a higher matched rate compared with fast food restaurants in urban core neighborhoods versus high-income suburb neighborhoods in the D&B data, we risked exaggerating the gap in the numbers of sit-down restaurants relative to total sit-down restaurants and fast food restaurants between urban core and high-income suburbs. Indeed, using direct field observation in the Chicago Metropolitan Statistical Area, Powell and colleagues validated the D&B food resource data and found that the matched rate of fast food restaurants differed by various neighborhood characteristics such as income, race, and location (urbanized area, urban cluster and non-urban area as defined by the US Census Bureau) [40]. Because we used 13 built environment and sociodemographic characteristics to classify neighborhoods, future researchers should explore whether the matched rate of food outlets varies by the overall characteristics of the neighborhood. Fourth, the block group is probably too small to reflect the service area of restaurants and food stores, especially in suburban areas. However, census block group level data yield better estimates of the locations of food resources and households [41], compared with data from larger geographic units such as census tracts and zip codes. In addition, we could not obtain some retrospective built environment and sociodemographic data, such as traffic and crime, for the whole region, which have been suggested as relevant factors [42, 43].

## Conclusion

Using the Twin Cities Region as a case study, we examined the relationships between neighborhood type and relative availability of sit-down restaurants and supermarkets. We observed a complex and increasingly varied distribution of restaurants and food stores across six types of neighborhoods with distinctive built environment and sociodemographic characteristics during the past two decades. For the year 2011, we observed a higher relative availability of sit-down restaurants in inner cities compared with urban, aging suburbs, high-income suburbs, or suburban edge neighborhoods; we observed a lower relative availability of inner city sit-down restaurants in 1993 and 2001. Although our research focused on the Twin Cities region, more research across more diverse regions and areas to confirm our findings is needed. A more thorough examination of the co-varying relationship among neighborhood built environment characteristics and sociodemographic characteristics will help urban planners to identify the types of neighborhoods most likely to be successful for restaurant and food store siting.

## Abbreviations

Twin Cities Region of Minnesota    Twin Cities Region

## Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and material

The data that support the findings of this study are available from Carolina Population Center but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available.

Competing interests

The authors have no financial or other conflicts of interest to disclose.

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#### Authors' contributions

Ke Peng, Ph.D had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Peng, Rodriguez, Gordon-Larsen. Acquisition of data: Peng, Gordon-Larsen. Analysis and interpretation of data: Peng, Rodriguez, Hirsch, Gordon-Larsen. Drafting of the manuscript: Peng, Rodriguez, Hirsch, Gordon-Larsen. Critical revision of the manuscript for important intellectual content: Rodriguez, Gordon-Larsen. Statistical analysis: Peng, Hirsch, Rodriguez, Gordon-Larsen. Obtained funding: Gordon-Larsen. Final approval of the version to be published: Rodriguez, Gordon-Larsen. Study supervision: Rodriguez, Gordon-Larsen. All authors have read and approved the manuscript.

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#### Authors' information (optional)

Not applicable

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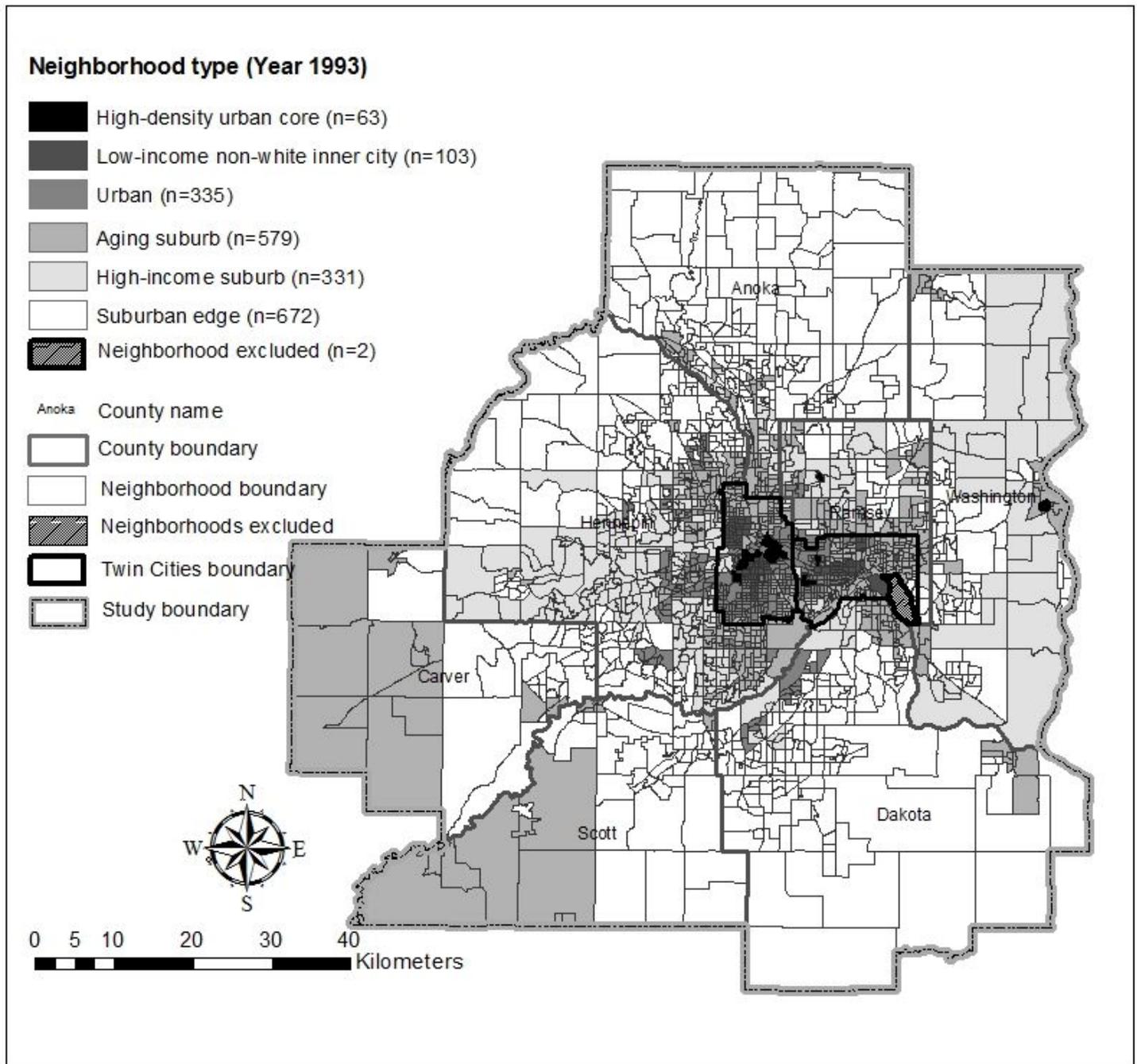
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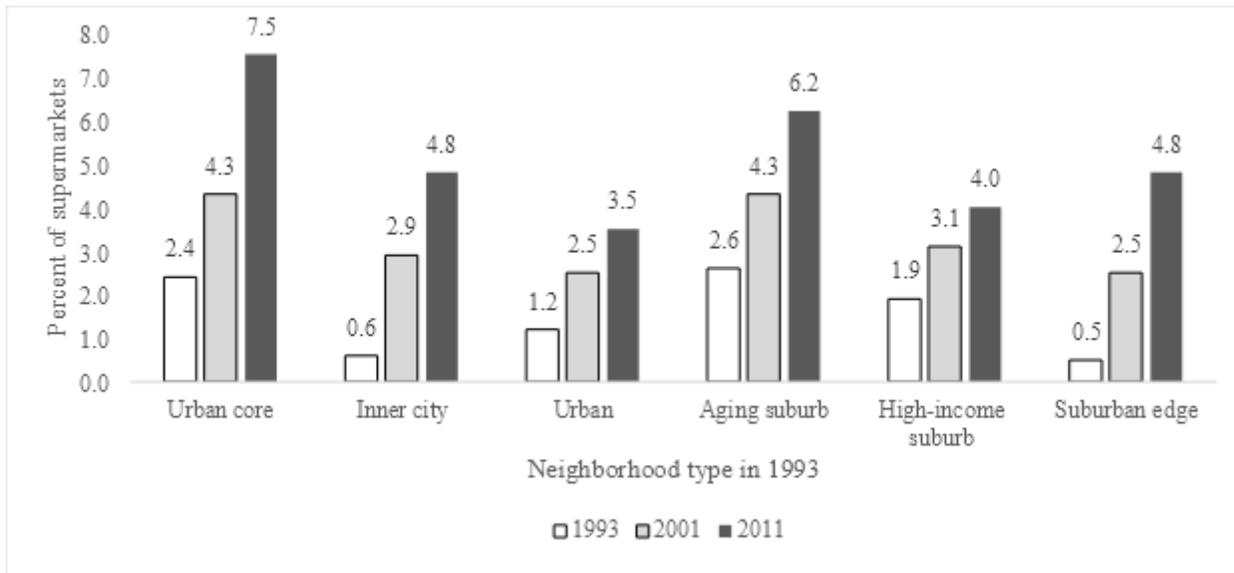
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## Figures



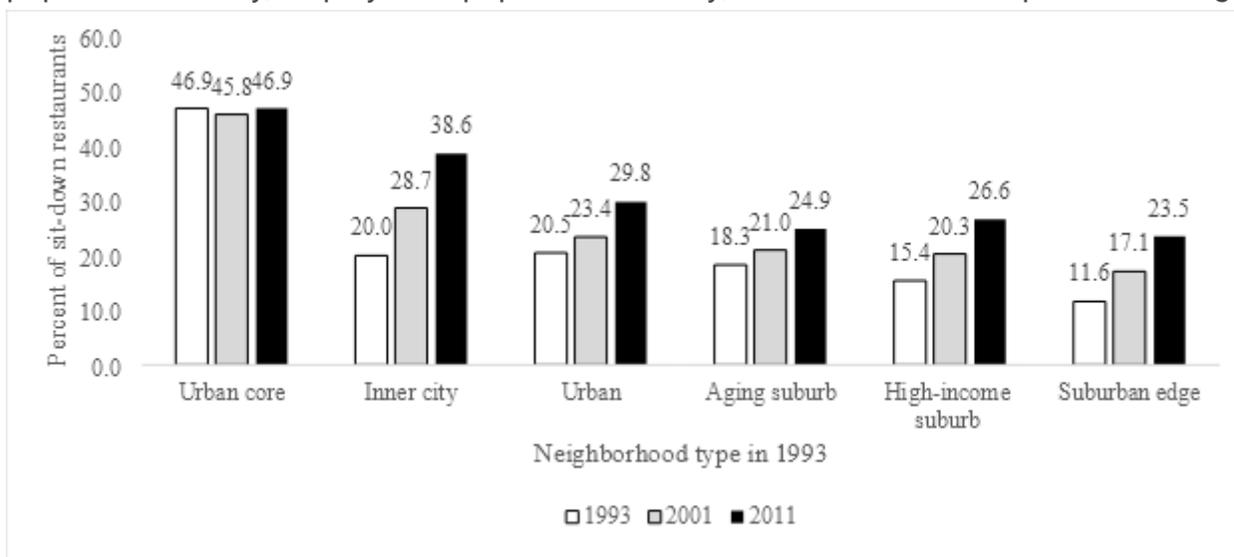
**Figure 1**

Neighborhood types in 1993 in the Twin Cities Region of Minnesota



**Figure 2**

Estimated mean a of percent of sit-down restaurants by six types of neighborhoods b a Multivariable mixed effects regression modeling percent of sit-down restaurants relative to total sit-down restaurants and fast food restaurants in each neighborhood as a function of neighborhood type in 1993, time elapsed since 1993, interaction between neighborhood type in 1993 and time elapsed, changes in residential population density, median household income, percent of white and percent of single-family housing since 1993, total sit-down restaurants and fast food restaurants and a random intercept for each neighborhood. b Derived from cluster analysis of block-group level data in 1993: percent of age under 14, age between 15 and 29, age between 30 and 44, age between 45 and 64, age 65 or above, percent of education of college and above, percent of white, percent of black, median household income, residential population density, employment population density, mix of land use and percent of single-family housing.



**Figure 3**

Estimated mean a of percent of supermarkets relative to total supermarkets, grocery stores and convenience stores by six types of neighborhoods b: Twin Cities Region, 1993-2011. a Multivariable mixed effects regression modeling percent of supermarkets relative to total supermarkets, grocery stores and convenience stores in each neighborhood as a function of neighborhood type in 1993, time elapsed since 1993, interaction between neighborhood type in 1993 and time elapsed, changes in residential population density, median household income, percent of white and percent of single-family housing since 1993, total supermarkets, grocery stores and convenience stores and a random intercept for each neighborhood. b Derived from cluster analysis of block-group level data in 1993: percent of age under 14, age between 15 and 29, age between 30 and 44, age between 45 and 64, age 65 or above, percent of education of college or above, percent of white, percent of black, median household income, residential population density, employment population density, mix of land use and percent of single-family housing.

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