Obesity and Diabetes, the Built Environment, and the 'Local' Food Economy

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Abstract

Obesity and diabetes are increasingly attributed to environmental factors, however, little attention has been paid to the influence of the 'local' food economy. This paper examines the association of measures relating to the built environment and ‘local’ agriculture with U.S. county-level prevalence of obesity and diabetes. Key indicators of the ‘local’ food economy include the density of farmers’ markets, volume of direct farm sales, and presence of farm-to-school programs. This paper employs a robust regression estimator to account for non-normality of the data and to accommodate outliers. Overall, the built environment is associated with the prevalence of obesity and diabetes and a strong 'local' food economy may play an important role in prevention. Results imply considerable scope for community-level interventions.

Keywords: community, diabetes, food environment, famers’ market, intervention, leverage points, local food, robust regression, obesity, outliers.

1. Introduction

Poor dietary choices are associated with obesity, diabetes, and other chronic diseases that are leading causes of death such as heart disease, stroke, and cancer (McGinnis and Nestle 1989). Much of the existing research focuses on the role of individual-level factors and examines how dietary choices and health are affected by demographic and socioeconomic characteristics such as education, employment, ethnicity, and income (Dowler 2001; Davey Smith and Brunner 1997). While research into individual-level factors is important, interventions supported by this research have had limited success (Elinder and Jansson 2008; Egger and Swinburn 1997). More recently, the influence of the built environment has received considerable attention, particularly in the United States.

The literature highlights the importance of community-level factors as explanations of dietary choices (Morland et al 2002) and diet-related health outcomes, such as obesity and diabetes (Morland et al. 2006; Mobley et al. 2006). Evidence suggests the built environment, and the food environment especially, plays a strong role in influencing obesity (Feng et al. 2010). Food environmental factors shown to be important include the density of restaurants, including fast-food outlets and full-service venues, as well as the density of retail food stores, including supermarkets and convenience stores. Reviews of the existing literature suggest more research on the influence of the built environment on health is needed, particularly research emphasizing the potential of broad-based community-level interventions (Holsten 2008; Papas et al. 2007). Success of community-level interventions depends on the extent that the built environment is associated with obesity and diabetes. An association suggests a role for local and regional governments in addressing important health issues (WHO 2010).

While many features of the built environment have been examined, little attention in the literature has been given to the possible influence of the 'local' food economy. The term 'local' means foods that have been sourced locally from farms and usually refers to a distance (e.g. within 50 miles) or a political boundary (e.g., within county borders). The hallmark of the local food economy is the farmers' market, although Community Supported Agriculture programs, and other outlets like roadside stands, small and independent grocers, and direct farm sales are also examples (Adams and Salois 2010). In a recent report from the Centers for Disease Control (CDC) on recommended strategies to prevent obesity, one suggestion was that communities should improve ways to bring food from "farm to fork" more directly and effortlessly, namely through increased density of farmers' markets (Kettle Kahn et al. 2009). The key reasoning is that local food outlets, like farmers' markets, serve as an important additional source of healthy food options, especially fresh fruits and vegetables. From a health perspective, a community that has a strong local food economy has a greater availability of affordable healthy food options, which can promote better dietary decision-making and health. To date, only a handful of studies examine the presence of 'local' foods on dietary outcomes (Anliker 1992; Balsam 1994; Herman et al 2008), and none directly on health outcomes. Prior findings support the idea that farmers' markets improve dietary choices by enhancing the availability of affordable healthy foods, such as fresh fruits and vegetables (Larsen and Gilliland 2009). There is a clear need, however, for research into how 'local' foods may influence dietary health outcomes, such as obesity and diabetes.

The objective of this study is to examine how the built environment affects the prevalence of obesity and diabetes in the U.S., paying special attention to the impact of the 'local' food economy. Including an extensive set of environmental indicators is essential for assessing simultaneous effects of different indicators on both obesity and diabetes. Focusing on particular indicators in isolation, such as fast food restaurants, can yield misleading results and incorrect policy conclusions. The general built environmental is indicated by measures relating to geography, physical activity availability, and the food environment. Indicators on the strength of the 'local' food economy include the density of farmers' markets, volume of direct farm sales, and farm-to-school programs. Robust regression is used to account for non-normality of the data and to accommodate outliers in the dependent and independent variables. This paper is organized as follows. Section 2 introduces the economic model and describes the data. Section 3 reviews the robust regression estimator. The results of the paper are discussed in Section 4. The final section reviews the policy implications and concludes.

3. Economic Model and Data

Building on the previous literature, a simple and general empirical model describes the relationship between a particular health outcome and the built environment,

$$H = f\left(S, B \mid \Omega\right)$$

where H is specific health outcome (e.g., being obese, or having diabetes), S is a vector of socioeconomic variables (e.g., race, or income) and B is a vector of community-level variables representing the built environment and other geographic factors. The built environment can be described by availability of different types of food outlets (e.g., fast-food restaurants, grocery stores, farmers markets) or other environmental features (e.g., recreational facilities, natural amenities). The vector Ω represents unobservable health attributes and taste parameters that affect the health outcome. While many studies tends to focus on socioeconomic variables as explanatory factors for obesity or diabetes (and others on certain health factors), recent evidence suggests the built environment plays a strong role.

Primary county-level data are obtained from the Food Environment Atlas published by the Economic Research Service (ERS) of the U.S. Department of Agriculture (USDA). The Atlas provides statistics on three main categories: health, food environment, and community characteristics. Health variables include the prevalence of adult obesity and diabetes. The food environment variables describe the different types of food outlets, and include measures such as the number of grocery stores, supercenters, and convenience stores. Community characteristics include measures such as race/ethnicity, income, and poverty, among others.

The data in the Atlas are sourced from different government entities for all 3,141 U.S. counties. This study only includes counties in the continental U.S. and omits counties with missing information ($n = 3{,}051$). Table 1 lists all the variables used along with the year, original data source, and descriptive statistics. Two health outcome measures are investigated: county rates of obesity and diabetes. The obesity rate is the age-adjusted percentage of adults (age $\geq$ 20) with body mass index (BMI) greater than or equal to 30. Body mass index is computed by dividing weight in kilograms by height in meters squared. The diabetes rate is the age-adjusted percentage of adults with diabetes, excluding gestational diabetes. The rates of obesity and diabetes are based on estimates from the CDC, obtained from the Behavioral Risk Factor Surveillance System (BRFSS). A potential limitation of the BRFSS data is that they are self-reported measures. Since respondents tend to underestimate body weight and overestimate height the obesity rate may be underestimated.

Variables describing the food environment can be partitioned into three categories: eating-out food environment, retail food environment, and the 'local' food environment. The eating-out environment is indicated by the number of full-service and fast-food (or limited-service) restaurants per 1,000 persons. Full-service restaurants are defined as establishments that provide food services to customers on the basis of a waiter/waitress service (i.e., customers are seated while ordering and being served food and then pay after eating). Fast-food restaurants are defined as establishments that provide food services to customers on the basis that food is ordered and paid for before eating.

The retail food environment is indicated by the number of supermarkets and grocery stores, gas-based convenience stores, no-gas convenience stores, and supercenter/warehouse club stores per 1,000 persons. Supermarkets and grocery stores are defined as establishments typically referred to as medium-sized supermarkets and also include small-end grocery stores that retail food as their primary business function (this includes delicatessen-type outlets).

Gas-based convenience stores are defined as establishments engaged in selling fuel or gasoline but also sell a selection of limited food items. No-gas convenience stores are defined as establishments that retail a limited selection of food items but do not sell fuel or gasoline. Supercenters and warehouse clubs are defined as establishments that in addition to retailing food and groceries, also sell merchandise including clothing, furniture, and electronics.

The 'local' food environment is indicated by the percent of farms with direct-sales, the value of direct farm sales per capita, the number of farmers' markets, and the presence of farm-to-school programs. The percent of farms with direct sales is defined as the percent of farms in the county that sell directly to final consumers. The value of direct farm sales per capita is defined as the dollar value of direct farm sales in the county divided by the population of the county. Both variables are sourced from the U.S. Agricultural Census. Farmers' markets are defined as the number in the county per 1,000 residents. A farmers' market is defined as an establishment in which at least two vendors retail food products directly to the consumer through the same venue. In order to count as a farmers' market, more than half of total retail sales must be obtained from the consumer directly. This variable is sourced from the USDA Agricultural Marketing Service.

Lastly, the farm-to-school program variable is an indicator if the county has one or more a farm-to-school programs (=1) or none (=0). The data are maintained by the National Farm to School Network. Farm-to-school programs consist of special programs designed to bring agricultural products directly from the farm to local schools for consumption. Such programs include direct sourcing from local producers, local sourcing through the Department of Defense procurement system (known as "DOD Fresh"), school gardens, farm tours, farm-related nutrition education or other classroom activities, and school menus highlighting locally-sourced foods. A county is counted as having a farm-to-school program whether the program covers the whole county or whether the program operates only in a school or school district within the county. The farm-to-school measure is limited in scope since there is no way of knowing if such a program covers just one school district in a portion of the county or all school districts over the whole county. Despite this weakness, the variable represents the best available information at the county-level regarding farm-to-school programs. Moreover, there is valuable information in assessing if the actual presence of farm-to-school programs is associated with obesity and diabetes. While there is research that looks at how farm-to-school programs, and similar programs, improve dietary choices (Knai et al. 2006; Joshi et al. 2008), there are no studies on health outcomes. Food choices and habits tend to be formed early in life (Briefel et al. 2009). Thus, developing patterns of healthy eating and consumption of fruit and vegetables in childhood is indicative of healthy eating patterns in adulthood.

Other variables capture aspects of the built environment relating to food accessibility, physical activity outlets, and geography. Food accessibility is indicated by the percentage of housing units in a county that are more than one mile from a supermarket or large grocery store and have no car, and also by the percentage of the total population in a county that are low income and live more than one mile from a supermarket or large grocery store. Availability of physical activity outlets is indicated by the density of recreational & fitness facilities, measured as the number of fitness and recreation centers in a county divided by the number of residents. Fitness and recreation centers are defined as facilities primarily engaged in activities such as exercise or recreational sports activities. The geographic environment is indicated by a natural amenity index based on topographical variation (e.g., water, mountains, sunny weather patterns, etc.). The index measures a county's natural amenities score as a standard deviation from the all-county average value. An index with a large negative value indicates a county that has a much lower score than the all-county average, while a large positive value indicates a county with natural amenities higher than the all-county average. An indicator is also included if the county is a metropolitan (=1) or non-metropolitan county

(=0). Under the 2003 Office of Management and Budget (OMB) classification, nearby counties are classified as metropolitan if they are economically tied to the central (i.e., metro) county, as measured by the share of workers commuting on a daily basis. Counties are classified as non-metropolitan if they are outside the boundaries of metropolitan areas and have no cities with 50,000 residents or more.

Socioeconomic variables indicate the racial/ethnic composition of the county, including the percent of county residents that are white, that are black or African-American, and that are Asian (percent of county residents Hispanic is omitted). Economic well-being is measured by median household income (in thousands of U.S. dollars). Lastly, the poverty rate indicates the percent of county residents with household income below the poverty threshold. A complete description of all variables can be obtained from www.ers.usda.gov/FoodAtlas/.

3. Estimation Strategy

Ordinary least squares (OLS) estimates are driven by the assumption of normally distributed residual error terms. If the residuals are characterized by a fat-tailed non-normal distribution, then OLS estimates are inefficient. Fat-tailed residual distributions can arise when outliers are present in the data. In general, two types of outliers may occur, which in general involves a data point that substantially deviates from the expected value (Rousseeuw and Leroy 1987). The first type occurs on the dependent variable and is referred to as a vertical outlier. The second type occurs on the explanatory variable and is called a leverage point. Either type falls under the umbrella of being an influential observation and can strongly impact OLS estimates. Since the undue influence of select data points may not be desirable, alterative estimation strategies should be sought (Dehon et al. 2009). Although common practice, throwing away outlying observations is a mistake since these observations are often the most important (Zaman et al. 2001). Influential data points should be appropriately handled in the econometric model rather than tossed out.

Robust regression estimators accommodate fat-tailed error distributions and provide parameter estimates resistant to influential observations (Huber 1973, 1981). Ideally, they also maintain efficiency in the presence of non-normality, though not all have this desirable property. There are several types of robust estimators which operate by giving less weight to observations further from the expected value. Consider the following linear regression model

$$y_i = X_i^{'}\beta + \varepsilon_i , \tag{1}$$

for the i^{th} observation where $i = 1,\ldots,n$. y is the $n\times1$ dependent variable vector, X is the $n\times m$ independent variable matrix, β is the $m\times1$ vector of parameters to be estimated, m is the number of independent variables where $m = 1,\ldots,M$, and ε is the $n\times1$ residuals vector. When the residuals are very large, the OLS error variance is inflated causing inflated standard errors, which also negatively affects the efficiency of the estimator. To handle the dual problem of both vertical outliers and leverage points, the class of MM-estimators was developed (Yohai 1987). MM-estimators combine high breakdown value estimation and efficient estimation. MM-estimators build upon the class of S-estimators proposed by Rousseeuw and Yohai (1984). Unlike S-estimators, however, MM-estimators maintain high efficiency when the residuals are normally distributed.

The MM-estimator is given by

$$Min\sum_{i=1}^{n}\rho\left(\frac{e_i}{\hat{s}}\right) \tag{2}$$

where $\hat{s}$ is a robust scale estimate used to standardize the residuals. The function ρ is typically convex and provides the contribution or weight of the i^{th} residual to the minimization problem. A valid ρ is symmetric, $\rho(e) = \rho(-e)$, and positive, $\rho(e) \geq 0$, with a unique minimum at zero, $\rho(0) = 0$. Differentiating with respect to the coefficients and setting partial derivatives to zero yields the $M+1$ system of equations

$$\sum_{i=1}^{n}\varphi\left(\frac{y_i - X_i^{'}\beta}{\hat{s}}\right)X_i = \sum_{i=1}^{n} w_i\left(\frac{y_i - X_i^{'}\beta}{\hat{s}}\right)X_i = 0\,. \tag{3}$$

where φ is the derivative of ρ. The weighting function is defined as $w(e,\hat{s}) = \varphi(e,\hat{s})/e$ so that $w_i = w(e_i,\hat{s})$. The derivative, φ, measures the influence of each observation on the value of the parameter estimate and is called the influence function (Hampel 1974). The bisquare ρ -function is used in the MM-estimator

$$\rho(e) = \begin{cases} \dfrac{k^2}{6}\left\{1-\left[1-\left(\dfrac{e}{k}\right)^2\right]^3\right\} & for\ |e| \le k \\ \dfrac{k^2}{6} & for\ |e| > k \end{cases}, \tag{4}$$

which yields the weighting function

$$w(e) = \begin{cases} \left[1-\left(\dfrac{e}{k}\right)^2\right]^2 & for\ |e| \le k \\ 0 & for\ |e| > k \end{cases}. \tag{5}$$

The weights decline as e moves away from zero. The tuning constant for the bisquare is $k = 4.685\sigma$ which produces 95% efficiency at the normal. The MM-estimator achieves both a high breakdown point (50%) and high efficiency (95%). In other words, the MM-estimator can cope with data contamination up to 50% of the sample but still achieve asymptotic efficiency of 95% even if the errors follow a normal distribution (Hampel 1971). Although more computationally intensive, MM-estimators provide the best level of protection against influential data points in terms of efficiency. Under the usual regularity conditions, MM-estimators are strongly consistent and asymptotically normal, with variance depending only on the limiting value of the scale estimator ($\hat{s}$).

4. Results

The data are first investigated for normality. Several test statistics substantiate rejection of normality, which are summarized in table 2. Each test has its own advantages and disadvantages. For example, the Jarque-Bera test and the Lilliefors test are sensitive to small samples. The Shapiro-Wilks test and the Anderson-Darling test are considered best, in terms of power, for detecting departures from normality. Regardless of the test statistic, each rejects the normality hypothesis (although rejection of normality is stronger in the obesity model). Therefore, OLS is unsuitable and robust regression is more appropriate. The MM-estimator is applied next to assess the impact of the built environment on the prevalence of obesity and diabetes. Parameter estimates are given in table 3. Figure 1 and Figure 2 display the final weights used for each observation in the MM-estimator regression for obesity and diabetes, respectively, indicating a non-trivial number of observations are down-weighted.

4.1 'Local' Food Results

Measures describing the 'local' food economy are noteworthy. The percentage of farms in the county that engage in direct sales has a significant and negative association with the obesity rate. Moreover, as the total per capita dollar volume of direct farm sales increases, both the rate of obesity and diabetes falls. A $100 increase in per capita direct farm sales is associated with 0.80% lower obesity rate and a 1.2% lower diabetes rate. The density of farmers' markets is also important. An additional farmers' market per 1,000 people is associated with a 0.78% lower diabetes rate. Farm-to-school programs are also negatively associated with obesity and diabetes. Counties that have at least one farm-to-school program have on average a 1.06% lower obesity rate and 0.29% lower diabetes rate.

Overall, while the magnitude of the estimates are small, results suggest the 'local' food economy is negatively associated with obesity and diabetes. Although no previous study looks at the impact of alternative food systems (such as farmers markets) on health outcomes, existing research finds improved access to farmers' markets is associated with increased availability of healthy food at lower costs (Larsen and Gilliland 2009) and increased consumption of fresh fruits and vegetables among low-income people (Conrey et al. 2003). The finding that counties with farm-to-school programs have lower prevalence of obesity and diabetes is also consistent with the results in Briefel et al. (2009) in which children attending schools with such programs tend to drink less sugary beverages and eat less energy-dense, low-nutrient foods. Although the results do not specify the causal mechanisms in which a strong 'local' food economy is associated with lower prevalence of obesity and diabetes, one likely mechanism is the increase in supply of healthy food options. Farmers' markets, farm-to-school programs, and direct farm sales improve not only the supply and options of fresh fruit and vegetables, but they also make them easier to obtain and encourage better dietary choices.

The importance of the 'local' food economy to health is highlighted when taken into further context. Local agriculture is the fastest growing segment of the retail food market. The 'local' food economy jumped from an estimated value of about $4 billion in 2002 to about $5 billion in 2007, and is expected to increase to roughly $7 billion by 2012 (Tropp, 2008). The number of officially registered farmers markets in the U.S. grew from 1,755 in 1994 to 4,685 in 2008 (USDA-AMS, 2008). In 1992, the total value of sales at farmers markets was about $400 million, which has grown to $1.2 billion as of 2007 (Crossroads Resource Center, 2009). Given this tremendous growth, local agriculture has the capacity to change the structure of the food system, which may lead to enhanced community food security, fewer food deserts, and improvements in consumer health that are linked to eating more fresh and unprocessed foods (Adams and Salois 2010).

The extent this is true, rather than responding to a growing obesity epidemic and an alarming diabetes rate with narrowly focused attempts to reduce access to unhealthy foods, effective community-level interventions may also involve strengthening the 'local' food economy. This requires urban and rural planners to incorporate the 'local' food market in community design policies, which will help public health practitioners to utilize 'local' foods to influence dietary health. The planning and building of a local food system infrastructure has been largely ignored by urban planners as well as public health managers (Nichol, 2003). Action towards facilitating growth and expansion of the 'local' food market is warranted given the potential for improving dietary choices. Specific strategies involve increasing the availability and accessibility of farmers' markets, augmenting direct farm sales through marketing campaigns, and enhancing farm-to-school programs. Such strategies may bring healthy food options not just to the community-at-large, but also to low-income and high-risk individuals (Black and Macinko 2008).

Caution is warranted in the interpretation of the results, however, given the cross-sectional nature of the data. The possibility remains that healthier communities support alternative food systems which encourage a stronger 'local' food economy rather than the other direction. Healthier people may also choose to live in environments with better access to healthy and nutritious food. Therefore, estimated associations do not imply causality and could represent self-selection. This is a limitation shared by most studies on the built environment, thus future research should examine emphasize longitudinal studies.

4.2 Other Built Environment Results

Socioeconomic indicators perform as expected and are similar to other studies on obesity, though fewer comparisons for diabetes are available (Boardman et al. 2005; Lopez 2007; Vandegrift and Yoked 2004). The percentage of the population white or black has a positive association with both obesity and diabetes, while the percentage Asian has a negative association (the percent Asian is insignificant for diabetes). Rising median household income is associated with reduced rates of obesity and diabetes. A negative association between income and obesity is also a common finding (Lopez 2007; Vandegrift and Yoked 2004).

While most studies in the literature do not decompose impacts of income and poverty, results imply an increase in the poverty rate is associated with higher obesity but not diabetes.

Results indicate that distance and availability play important roles in both obesity and diabetes, particularly for low-income households. An increase in the percent of low-income households greater than one mile to a supermarket or grocery store has a positive association with both obesity and diabetes. Results highlight the problem of so-called food deserts, areas with limited access to affordable and nutritious food (Black and Mancinko). Limited accessibility to food outlets can be the result of transportation difficulties, such as not owning a car or poor access to public transportation, but can also be the result of an inadequate supply of food outlets selling nutritious food. Many studies find that low-income households live further away from healthy food outlets and closer to unhealthy places, like fast-food restaurants (Block et al. 2004; Moore and Diez Roux 2006; Powell et al. 2007). Lack of access to healthier foods and easier accessibility of processed and unhealthy foods can cause decreased consumption of fresh fruits and vegetables among the poor (Morland et al. 2002).

Density of recreational and fitness facilities have a negative association with obesity and diabetes. Studies find the availability of such facilities is associated with greater physical activity (Brownson 2001; Poortinga 2006) and better health (Mobley et al. 2006). In addition, natural amenities are found to have a negative association with obesity and diabetes. The amenity index is a likely proxy for the extent of outdoor recreational activities available and may reflect the availability of physical activity options for residents. Other studies find that more open space can lead to lower rates of obesity and diabetes (Ellaway et al. 2005; Giles-Corti 2005). Lin et al. (2007) find that less amenable climates are associated with increased overweight and obesity.

While the density of fast-food restaurants has a positive association with diabetes, the effect on obesity is not significant. Although there is evidence that consumption of fast-food is associated with obesity and insulin resistance (Jeffrey and French 1998; Pereira et al. 2005), there is conflicting evidence that the actual density of fast-food outlets is positively correlated with obesity (Feng et al. 2010). For example, Maddock (2004) finds a positive correlation between prevalence of fast-food outlets and obesity using state-level data, a finding confirmed by Mehta and Chang (2008) and Chou et al. (2004) using individual-level data. Jeffery et al. (2006), however, find that while eating at fast-food restaurants is positively associated with obesity, the actual density of fast-food outlets is not. Full-service restaurants have a significant and negative association with both obesity and diabetes. The density of full-service restaurants may indicate an eating environment with better food options or may proxy attitudes of residents with preferences for healthier foods. On the other hand, restaurants have been the target of local and regional government initiatives aimed at improving food choices (e.g., the New York City-sponsored National Sodium Reduction Initiative led by the health department aimed at reducing the amount of salt in restaurant foods). Such initiatives are common as it is increasingly recognized that more food is eaten away from home, which tends to be higher in fats and calories than food prepared at home (Mehta and Chang 2008).

The density of grocery and supermarket stores is not significantly associated with obesity or diabetes. The insignificant effect obtained here may be the result of combining supermarkets and small-end grocery stores in the same measure which can have opposing effects. Morland and Evenson (2009) find that areas with more small grocery stores had higher obesity rates. While Morland et al. (2006) find a negative association for supermarkets and a positive association for grocery stores, once the model included socioeconomic variables the positive effect became insignificant. The insignificant estimate could also be the result of including such a complete set of environmental measures. For example, Mobley et al. (2006) find that grocery stores are unrelated to obesity once they include a full set of indicators in the model.

The density of gas-based and no-gas convenience stores is not associated with higher rates of obesity and but is associated with greater prevalence of diabetes. Other studies find a positive association between convenience stores and obesity, however, these studies tend not to include distinct measures of convenience stores based on the availability of gas (Morland and Evenson (2009) is one exception). Results suggest that no-gas convenience stores have a greater negative impact on health. While selling food is not the only business of gas-based convenience stores, the business of no-gas convenience stores usually depends solely on selling food items which tend to be unhealthy processed foods.

Supercenter and warehouse club store density has a positive association with obesity. Supercenters and club stores advertise on the basis of substantial savings, often using quantity discounts to promote bulk purchasing. Supercenters tend not to offer fresh fruits and vegetables but primarily sell processed foods that have longer shelf-life (Bustillos et al. 2009). While none of the existing studies on the built environment and obesity examine the differential impact of supercenters from other retail food outlets, results here support the finding in Courtemanche and Carden (2010) that the density of Wal-Mart supercenters is positively associated with obesity.

5. Conclusion

This study investigates the influence of the built environment on obesity and diabetes in the U.S. with a full range of environmental measures, including measures relating to the 'local' food economy. A robust regression estimator is used to account for non-normality of the data and to accommodate outliers. Two limitations are of note. One limitation, shared by most studies on this topic, is the cross-sectional nature of the data. Estimated associations do not imply causality. Future research should examine the impact of environmental factors in a longitudinal manner. A second potential limitation involves the use of county-level data. Ecological or aggregate level studies are, however, not uncommon in the built environment literature (Chou et al. 2004; Lopez et al. 2006; Maddock 2004; Mehta and Chang 2008; Pickett et al. 2005; Vandegrift and Yoked 2004), with data at the county, state, and even country level. More importantly, as pointed out earlier, interventions recommended by individual-level studies have been largely unsuccessful at altering dietary behavior. As discussed by Sallis et al. (1998, p.379): "environmental and policy interventions based on ecological models of behavior have the potential to influence entire populations."

Despite these limitations, several benefits emerge from the analysis. First, few studies include a complete set of environmental factors, focusing instead on certain factors in isolation, such as fast-food restaurants or grocery stores. Estimated effects of environmental indicators on health outcomes obtained in isolation can result in under- or over-estimated relationships (Black and Macinko 2008), emphasizing the importance of comprehensive studies. Second, the current literature largely ignores the role of the 'local' food economy. Key indicators of the ‘local’ food economy (including the percent of farms with direct-sales, the value of direct farm sales per capita, the number of farmers’ markets, and the presence of farm-to-school programs) are found to be related to both obesity and diabetes. Third, the literature overlooks how the built environment impacts diabetes, focusing on obesity only. Results suggest that environmental features, in addition to socioeconomic characteristics, are key explanatory factors of both obesity and diabetes.

Although the findings in this paper do not assess causality, policy implications surface nonetheless which emphasize involvement of local and regional authorities. First, while few studies include a measure of both poverty and income, the positive association found here confirms the conclusion in Drewnowkski (2004) that obesity follows a socioeconomic gradient, with higher rates found among the poor. This suggests that although community-level interventions should aim to benefit all members, special attention should be given to the poor, who are at greater risk. Second, not only do results on the access measures emphasize that community-level interventions should target low-income households, but also that effective interventions may involve improving accessibility of healthy food. Better access can be achieved by improving the density of food outlets through targeted urbanization and zoning policies that minimize the existence of food deserts. Alternatively, enhanced access can be achieved through transportation strategies, which may include better public transit programs with access to food retailers, enhanced food delivery services by supermarkets, or even pick-up and drop-off services for customers offered by the stores themselves (Mikkelsen and Chehimi 2007). Third, since environmental amenities and physical activity outlets are negatively associated with obesity, community-level interventions could include efforts to expand the availability of community services that promote physical activity. Such options may involve the creation of more parks and open space or recreational centers. Actions towards this end should be mindful of the ability of low-income households to pay to use such facilities as well as the need to fund such projects from public taxes.

Lastly, this paper suggests another aspect of the built environment related to obesity and diabetes: the 'local' food economy. Specifically, results find a negative association between 'local' food indicators (farmers' markets, direct farm sales, and farm-to-school programs) and county prevalence rates of obesity and diabetes. Research suggests that 'local' food outlets encourage better dietary choices and healthier eating. To the extent this is true, efforts to curb obesity and diabetes could involve interventions based on community-wide programs to develop a strong 'local' food economy through creation of farmers' markets, farm-to-school-programs, and enhanced direct farm sales. Since very few studies investigate 'local' food indicators on health outcomes additional research is needed. In particular, future research needs to develop theoretical and empirical models that explain why this relationship exists, specifically attempting to uncover the causal mechanisms.

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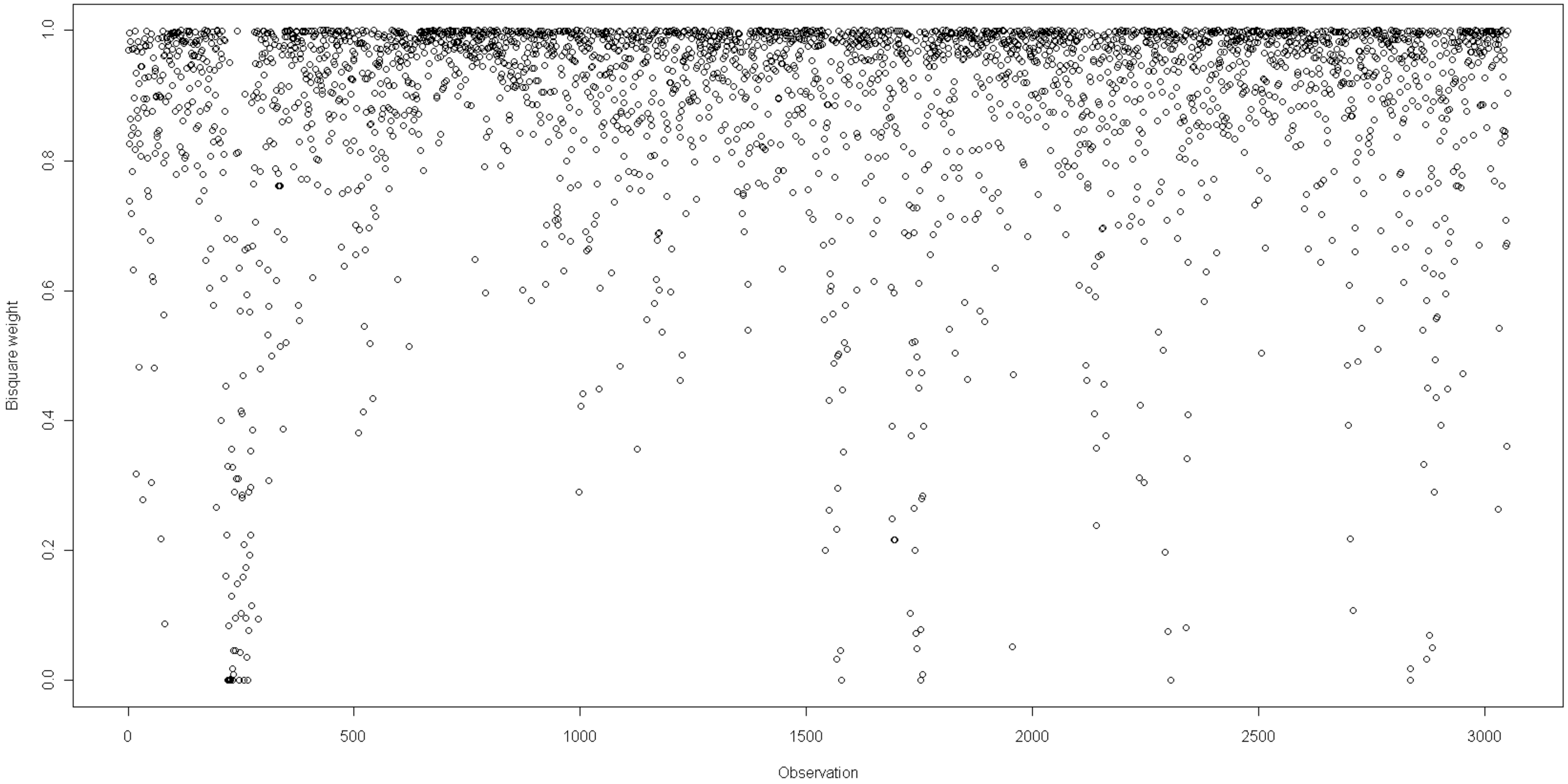

Figure 1. Final weights from obesity MM-estimator

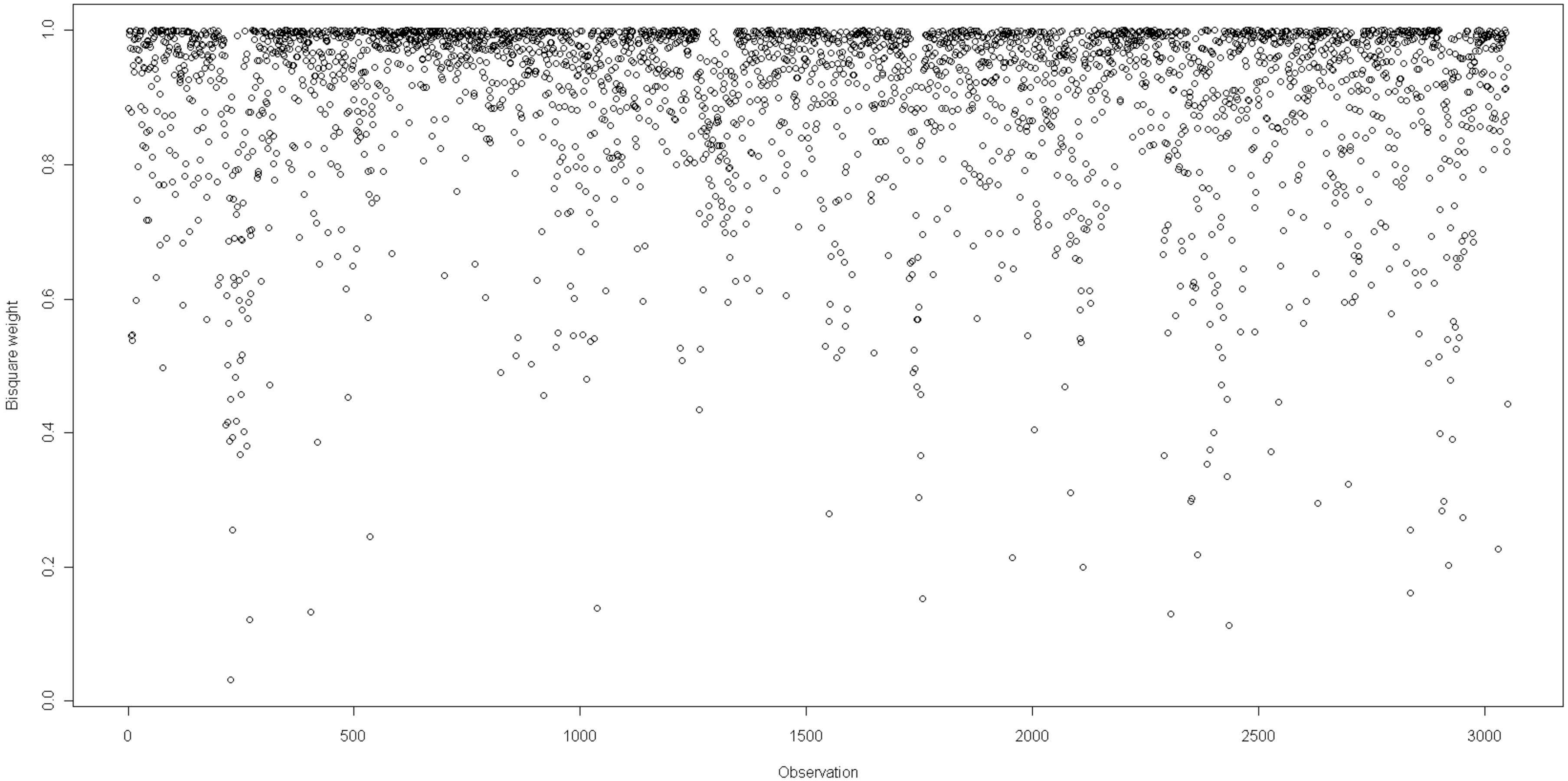

Figure 2. Final weights from diabetes MM-estimator

Table 1. Data Description

Variable	Year	Source	Mean	SD	Min	Max
Adult obesity rate	2007	CDC/BRFSS	28.28	3.61	12.5	43.50
Adult diabetes rate	2007	CDC/BRFSS	9.65	2.01	3.20	17.40
Fast-food restaurants density	2007	Census Bureau	0.59	0.32	0	7.12
Full-service restaurants density	2007	Census Bureau	0.81	0.59	0	14.24
Supermarkets-Grocery store density	2007	Census Bureau	0.28	0.22	0	3.27
Convenience stores no gas density	2007	Census Bureau	0.08	0.10	0	1.71
Convenience stores with gas density	2007	Census Bureau	0.56	0.31	0	4.78
Supercenters and club stores density	2007	Census Bureau	0.01	0.02	0	0.26
Percent of farms with direct sales	2007	Agricultural Census	6.34	5.96	0	100
Direct farm sales per-capita (dollars)	2007	Agricultural Census & Census Bureau	7.30	12.69	0	274.51
Farmers' market density	2008	ERS & Census Bureau	0.04	0.07	0	1.01
Farm-to-school program	2009	Farm-to-school Network	0.06	0.24	0	1
Percent residents no car and >1 mile to store	2006	Multiple sources*	3.98	2.60	0	27.91
Percent low income and >1 mile to store	2006	Multiple sources*	22.81	11.37	0	79.49
Recreational/fitness facilities density	2007	Census Bureau	0.09	0.09	0	1.19
Natural amenity index	1999	ERS	3.49	1.04	1	7.00
Metropolitan/non-metropolitan county	2000	ERS	0.35	0.48	0	1.00
Percentage white	2008	Census Bureau	79.54	19.04	2	99.40
Percentage black	2008	Census Bureau	9.00	14.32	0	85.50
Percentage Asian	2008	Census Bureau	0.98	1.89	0	30.90
Median household income (dollars)	2008	Census Bureau	44034	11376	19182	111582
Poverty rate	2008	Census Bureau	15.27	6.05	3.10	54.40

* Data are sourced from "Access to Affordable and Nutritious Food -- Measuring and Understanding Food Deserts and Their Consequences: Report to Congress." See the ERS Food Atlas documentation for more information (http://www.ers.usda.gov/foodatlas/).

Table 2. Normality test statistics (p-value in parentheses)

Test name	Critical value[1]	Obesity model	Diabetes model
Anderson-Darling	0.751	9.135	1.953
Cramer-von Mises	0.220	1.281	0.322
Lilliefors	0.016	0.042	0.021
Jarque-Bera	5.99	364.002	22.565
Shapiro-Wilks[2]	1.00	0.983	0.998

[1] The critical value is based on a 5% significance level.
[2] Rejection occurs if the test statistic is less than the critical value.

Table 3. Robust regression estimates (t-statistics in parentheses)

Variable	Obesity	Diabetes
Intercept	30.189***	9.468***
	(34.846)	(17.348)
Percentage white	0.024***	0.017***
	(5.402)	(5.983)
Percentage black	0.093***	0.064***
	(16.078)	(20.865)
Percentage Asian	-0.174***	-0.016
	(-5.339)	(-0.668)
Median household income (thousands of dollars)	-0.440***	-0.525***
	(4.540)	(-9.318)
Poverty rate	0.060***	-0.011
	(3.225)	(-0.955)
Percent of households no car and >1 mile to store	0.026	0.101***
	(0.786)	(3.936)
Percent low income and >1 mile to store	0.025***	0.027***
	(2.975)	(4.650)
Recreational and fitness facilities density	-3.062***	-0.565
	(-5.050)	(-1.629)
ERS natural amenity index	-0.752***	-0.054*
	(-12.433)	(-1.795)
Metropolitan/non-metropolitan counties	0.289***	0.245***
	(2.641)	(3.796)
Fast-food restaurants density	-0.304	0.323***
	(-1.500)	(2.676)
Full-service restaurants density	-1.222***	-0.578***
	(-9.643)	(-8.394)
Supermarkets-Grocery store density	-0.226	0.029
	(-1.016)	(0.243)
Convenience stores no gas density	0.124	2.037***
	(0.276)	(6.342)
Convenience stores with gas density	0.257	0.239**
	(1.448)	(2.202)
Supercenters and club stores density	8.948***	1.700
	(3.321)	(1.348)
Percent of farms with direct sales	-0.027***	-0.007
	(-3.430)	(-1.388)
Direct farm sales per capita (dollars)	-0.009***	-0.012***
	(-2.656)	(-5.238)
Farmers' market density	0.143	-0.729**
	(0.245)	(-1.986)
Farm-to-school program	-1.093***	-0.266***
	(-5.913)	(-2.640)

*** indicates two-tailed significance at the 0.99 level, ** at 0.95 level, * at 0.90 level.