Body Mass Index and Neighborhood Characteristics:

Assessing Selection and Causation Mechanisms Using Mover-Stayer Models

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Introduction

Obesity and overweight are major public health problems. An estimated 65% of US adults are overweight or obese [1] with up to 280,000 annual deaths attributable to obesity [2, 3]. In an effort to understand factors associated with adult obesity/overweight, attention has recently focused on the potential effects of environmental influences. Yet, studies linking the physical environment to the risk of being overweight or obese are limited by the fact that residents are not randomly distributed by neighborhood. If significant associations are found between neighborhood characteristics and individuals' body mass indices (BMI) in observational studies, one cannot confidently draw conclusions about causality. Neighborhood features may cause people to be more physically active, or physically active individuals with low BMI's may be more likely than overweight, sedentary individuals to choose neighborhoods that support their pre-existing healthy lifestyle.

If non-random selection into neighborhoods exists, then the observed association between individual BMI and neighborhood features arises from two sources: (a) physical or socio-cultural features of the built environment give rise to variation in individual BMI (i.e., a causal mechanism), and (b) unobserved characteristics that affect both residential location and individual BMI (i.e., a non-random selection mechanism). If non-random selection occurs, estimates that do not correct for its effects will misstate the strength of the causal relationship.

In this analysis, our aim is to characterize the relative contributions of the causal and selection explanations with non-experimental data by testing three hypotheses:

1. Walkable neighborhoods, as measured by population density, pedestrian-friendly design, and land-use diversity (e.g., mixed use, proximity to open space, access to grocery stores) are associated with lower levels of individual BMI, *ceteris paribus*.
2. Individual characteristics (e.g., age, sex, race), familial characteristics (e.g., family history of obesity), and socio-cultural factors (e.g., neighborhood ethnic composition) influence individual BMI, *ceteris paribus*.
3. The size of the causal effects identified in hypotheses 1 and 2 will be attenuated after adjusting for the effects of non-random selection into neighborhoods, *ceteris paribus*.

To test these hypotheses, we assess the influence of causal effects in the presence of non-random residential selection using longitudinal mover-stayer models. There is no definitive statistical test of the relative contributions of causation and selection that can be used when dealing with non-experimental data. Accordingly, we consider mover-stayer models to assess the causal relationships between neighborhood characteristics and individual BMI in the presence of neighborhood selection effects.

This study relies on a world-class population-based data source, the Utah Population Database (UPDB). The vast genealogical records in the UPDB are linked to state-wide vital records (pre-pregnancy weights on birth certificates) that contain longitudinal data on height and weight (used to construct BMI) and residential location for individuals and their kin. The UPDB is also linked to U.S. Census, state, and county information on neighborhood characteristics using Geographic Information Systems (GIS) databases. The UPDB represents a unique and comprehensive database with which to address neighborhood effects on BMI; it encompasses the adult/adolescent population and represents the full range of neighborhood settings.

Literature Review

Over 65% of U.S. adults are considered overweight (BMI≥25) and 31% are obese (BMI≥30) [4]. Adult obesity is associated with shortened life expectancies and an excess risk of chronic diseases such as type 2 diabetes, heart disease, osteoarthritis, and some form of cancers, as well as social stigmas and substantial economic costs [4]. Childhood overweight levels have tripled since the 1970's [5] and obese youth born in the year 2000 are estimated to face a 30-40% chance of becoming diabetic [5].

Given rapid increases in obesity, researchers have begun to emphasize how obesogenic environments may account for this trend. In examining the relative influence of causal and selection forces on obesity patterns, our study addresses two of the four themes for research outlined in the Strategic Plan for NIH Obesity Research[4]. First, we propose to examine the role of the physical environment in supporting healthy physical activities and eating choices. Second, we address cross-cutting topics, such as the identification of at-risk groups using a multi-disciplinary approach.

Past research has found relationships among walkable neighborhood designs, support for physical activity and healthy eating, and obesity or overweight [6-8]. Walkable neighborhoods are those designed to include the "3Ds": population Density, Diversity of destinations, and pedestrian friendly Designs [9]. High densities and diverse land uses together mean that many people are within walking distance of multiple desirable destinations. Well-connected streets, a measure of pedestrian friendly design, further support walking by allowing walking trips to be relatively short, direct, and convenient. Research has demonstrated that greater density neighborhoods have lower BMIs [6, 10-14]. Density, although not always associated with lower BMI [8, 13, 15], provides a critical mass of individuals that may encourage the development of walking destinations and may discourage exclusive reliance on cars. More pedestrian friendly street connectivity [16, 17] or accessible and high quality sidewalks [16-18] have been associated with fewer weight problems (except see [10, 19]). Indicators of diverse and walkable destinations in a neighborhood are associated with lower weight [10, 19-21].

Many studies depend upon the Behavioral Risk Factor Surveillance System (BRFSS) or other national surveys [7, 22]. Although such surveys are useful, they do not provide extensive response rates in any one neighborhood. We propose to utilize birth certificate databases (using pre-pregnancy weights) because they provide extensive coverage of neighborhoods (i.e., very large numbers per neighborhood). If birth certificate databases prove useful in the present study, as we anticipate given our preliminary analyses, the results could encourage researchers from other states to consider using similar databases. Extensive local databases on the obesity problem may prove most relevant to policy makers and other local and state officials who will be needed as partners for neighborhood-based obesity prevention efforts.

All neighborhood studies of obesity and the environment are vulnerable to the selection threat to internal validity. To date, most studies of obesity and neighborhood environments have assumed that no selection effects exist. Yet, it is very likely that neighborhood characteristics are not exogenous with respect to an individual's BMI. Rather, unmeasured factors that influence an individual's choice of residential location may also influence that individual's energy balance (e.g., preferences for physical activity or types of eating establishments). Researchers must be able to answer the question: To what extent do residents with unhealthy (healthy) behavior patterns self select into unhealthy (healthy) neighborhoods? Efforts to redesign neighborhood environments will be misdirected if residents with unhealthy behaviors simply choose unhealthy neighborhoods. In order for neighborhood policy and design interventions to succeed, it is important to determine if neighborhood environments have an independent effect on the health behaviors of their residents.

Recent reviews from sociology, public health, epidemiology, and planning have summarized a variety of strategies to address selection threats in community studies [23-26]: These include statistical, sampling, and research design techniques to deal with the selection problem. **Drawing from these approaches, we consider here the mover-stayer model as a way to examine overweight/obesity in relationship to neighborhood environments.**

Cross-sectional neighborhood research has identified many neighborhood correlates of obesity, such as collective efficacy [27], safety [28],and socioeconomic status [29] . These studies are limited by the possibility that residents self-select into neighborhoods for reasons related to obesity. Longitudinal studies may overcome these limitations by allowing researchers to assess how residents sort into neighborhoods. Past research shows that movers who relocate to more walkable neighborhoods reported fewer vehicle miles traveled [30] and more walking than in their former neighborhoods [31]; these studies did not examine obesity. However, higher BMI individuals tend to move to more sprawling, less pedestrian friendly neighborhoods [14] and individuals who move to denser neighborhoods tend to lose weight [32].

Studies of migrants often have not considered BMI-related factors. Instead, life cycle factors, such as household size, resident ages, and socioeconomic status, have been identified as causes for moving [33]. Recent CPS data [34] indicated that residents move for reasons related to housing, family, and work. Few of these reasons directly relate to neighborhood food or physical activity qualities that might be related to BMI. In addition, only a few studies have assessed preferences for walkable neighborhoods directly; these studies showed that 33% to 49% of respondents might prefer more walkable neighborhoods [35].

Reasons for relocation also might indirectly relate to BMI. For example, moves for changes in family size might relate to less physical activity among new mothers[36]. Moves for preferred schools [37] may bring other physical activity amenities. Moves for job changes [38] might involve changes in work and/or physical activity time allocations; job changes that require longer commutes may also be associated with higher BMI [11]. Moves to higher density apartment living have been found to relate to a desire for accessibility and nearby recreational space, as well as work and accessibility reasons, which might predict lower BMI [39]. To the extent possible, it is important to control for these changes that accompany residential relocation.

In this analysis, a mover-stayer analysis will be used to assess selection effects. Mover–stayer models have been used successfully [40, 41] to compare individuals and places between three groups: those who remain in the place of origin, those already living in the place of destination, and migrants moving between the two places. This permits an assessment of differential selection into and out of specific types of neighborhoods.

Data

Utah Birth Certificates

A complete set of Utah birth certificates from 1947-2002 have been linked to the UPDB. The birth certificates contain information on complications, risks, abnormalities, method of delivery, birth weight, gestation, and number of previous live births and stillbirths to the mother. Using the parent-child information contained in these certificates, the UPDB links these records into parent-child dyads and sibships. This information allows the UPDB to be updated in terms of maternal and paternal reproductive histories and to identify a variety of kin in the UPDB. The PPR staff link these data with genealogy records. Birth certificates that do not merge into existing genealogy families have been linked together to create two and three generation families.

Starting in 1989, Utah birth certificates contain data on ***self-reported pre-pregnancy weight*** as well as weight gain associated with a given birth. These certificates also provide residence information at the time of each birth. Accordingly, for all women who bore children in 1989 or later, the UPDB contains longitudinal data on their residential location and pre-pregnancy weight. We find that there are 225,000 women who gave birth in Utah in the past 16 years. Women with two or more children (N=135,300) are the most informative because they provide longitudinal BMI and location data.

The use of linked birth certificates in Utah to assess the association between BMI and neighborhood qualities (for causal or selection reasons) offers distinct advantages. First, Utah has a fertility rate that is higher than the national average and thus there are large numbers of women with two or more children. This provides data for initial BMI (at first birth) and neighborhood and subsequent changes for both variables. Second, birth certificates provide an extensive body of data captured by the UPDB including educational level of parents, race/ethnicity, and health conditions. Third, parents' decisions about residential location are often driven by neighborhood, life-style and schooling considerations [34]. The choices parents make because of child-based factors may be a driving force in affecting location decisions that in turn affect maternal BMI. Fourth, if these data are found to be useful in assessing the association between BMI and neighborhood quality, it is feasible to export the approach to other states. Finally, the analysis plan is particularly cost-effective because the record linkage that created a birth certificate history for each mother has already been done but unanalyzed in the way proposed here.

Use of birth certificate data has two potential limitations – both of which are addressable. First, the sample is restricted to mothers of reproductive age. Second, bearing children may create a weight gain profile that will obfuscate the association between neighborhood characteristics and maternal BMI. While we do not have the same depth of information on men nor women with no children, we are able to compare mothers with each other in terms of neighborhood and familial characteristics so that these potential biases shortcomings will be netted out.

Environmental Data

To test our hypotheses, we have already assembled an extensive data set on neighborhood environments in Salt Lake County, including measures of population Density, land-use Diversity, and pedestrian-friendly Design (i.e., the 3D's) measured in the 2000 U.S. Census. During the grant period we will link this data set to U.S. Census data for 1990 and 2000 Census data from the rest of the state of Utah. For land use diversity we already have two census-based diversity measures (proportion of workers who walk to work and median age of housing in the neighborhood) that relate well to BMI [42]. Other researchers have used mixed land uses from parcel based land use typologies [43]; we have assembled parcel data from the Salt Lake County Surveyor's Office that could be used to test other diversity measures. We also have street connectivity measures of pedestrian friendly designs. We have measures of pedestrian friendly design in the form of intersection density from road networks (data for 1985, 1997, and 2000 from Utah's Automated Geographic Reference Center). Public transportation data including light rail transit and bus systems have been obtained from Utah Transit Authority (UTA); these data are not available for past decades.

Population health data stratified by socio-cultural position are critical for monitoring and analyzing health issues. In our past research we have found it useful to include census block group variables that tap aspects of the racial/ethnic composition of the neighborhood, specifically, the proportion of Hispanic, African-American, and Hawaiian/Pacific Islander populations in the block group. In addition, we have used Census data on the median family income and the median age of the block group [42].

Mover-Stayer Analysis

By moving between neighborhoods with a wide range of characteristics, migrants provide an excellent opportunity to examine the effects of selection on understanding variation in BMI. Numerous studies exist that assess how neighborhoods relate to diet, exercise, and obesity but they have generally excluded any examination of the neighborhoods from which people originated. For migrants, BMI levels may reflect their origin or destination neighborhood or they may reflect a select group with traits that increase or decrease the chances that they will be obese, irrespective of their origin or destination.

We propose a modified method that has been applied successfully by Smith with respect to international migration and cancer mortality rates [40, 41]. The first step is to identify four groups that form the basis for comparison: long-time residents of neighborhood A (A-stayers), long-time residents of neighborhood B (B-stayers), migrants from A to B (AB movers), and migrants from B to A (BA movers). Given that there are nearly 2000 Census block groups in Utah, the strategy is to reduce the block groups into types. Persons identified as long-term residents comprise those who have lived in the same block type for ten or more years. Movers into a new neighborhood include persons who have lived there for five years or less. (The analysis will consider other duration cutoffs to assess the sensitivity of the results to this choice.) For movers to be of value, they must have moved between Utah neighborhoods categories. These analyses will be done using BMI information on multiparous mothers taken from Utah birth certificates.

Once the mover and stayer populations have been identified, age-standardized rates of overweight and obesity will then be calculated for all mover and stayer groups. *Age-*

standardized rate ratios (ASRRs) will be calculated as follows. (For the sake of illustration, we refer to obesity in our description here but this approach will also be applied to other BMI-based categories.) For every pair of origin/destination block groups (neighborhoods A and B, respectively) there are two obesity ASRRs:

- The *Destination vs. Origin ASRR* compares the age-standardized obesity rates between B-stayers to A-stayers. This comparison indicates the discrepancy between the two areas with respect to obesity, as represented by long-term residents.
- The *Movers vs. Origin ASRR* compares the obesity rate of AB movers to A-stayers. This comparison quantifies how different the migrant obesity rate is from the origin rate. (There will also be a parallel comparison for BA movers).

By comparing these two ASRRs, it is possible to make inferences about the role of selection and causation. For example, if the *Movers/Origin ASRR* is not statistically different from one, then this would indicate that the origin obesity risk persists in the mover group because movers have obesity rates similar to the community they departed. This suggests that a (causal) neighborhood effect (of the origin) with little non-random selection out of the neighborhood, at least with respect to obesity. If this happens jointly with an *Origin/Destination ASRR* that is significantly less than one (the destination neighborhood has lower obesity rates than the origin; i.e., migrants are moving to a healthier neighborhood), then this is also consistent with a causal explanation since recent migrants retain their obesity rates and are little affected by their new neighborhood. The assumption here is that destination neighborhoods, in the short run, would not be able to impart any substantial effect on obesity rates.

Alternatively, if the *Movers/Origin ASRR* and the *Destination/Origin ASRR* are both significantly less than one, then this suggests that the movers are a non-random subset of their origin (having lower obesity rates than their origin neighborhood) and they are electing to move to a destination area that conforms to their own obesity rates. This pattern is consistent with a selection process under the assumption that the new destination is unlikely to impart large effects quickly. In summary, ASRRs provide descriptive area-specific comparisons that show how migrants may be revealing causal or selection effects.

To get a global assessment of causation and selection, observed and expected changes in mover age-standardized rates will be calculated as follows:

(1) Observed Δ = (Δ in BMI for Migrants) – (Δ in BMI for Origin Stayers)

(2) Observed Δ = (Δ in BMI for Destination Stayers) – (Δ in BMI for Origin Stayers)

The measure of expected change is based on the expectation that the obesity rate of AB movers will look more like B-stayers. This expectation assumes that this happens because of selection (i.e., AB movers choose destination B for reasons associated with BMI). In a regression, these two change variables will be significantly and positively correlated if selection effects are present (migrants look like the stayers in the destination for reasons of selection under the assumption of weak short-term causal changes in obesity risk attributable to the destination). If causation effects prevail, then the association should be statistically insignificant since only the origin, and not the destination, has an influence on obesity risk. The analysis will also explore variations on this basic model in terms of age-specific groups, gender, and family history of obesity.

Preliminary Results

Our preliminary analysis focuses on new mothers in Salt Lake County between 1989 and 2007. In order to include the largest portion of the data, we analyze for this initial analysis pre-pregnancy weights for the first and second births for approximately 30,000 women who satisfy the inclusion criteria.

Table 1 provides descriptive statistics for the sample considered here. The two broad groups, "mover" and "stayers" are defined as women who move or stay within the boundaries of Salt Lake County at the time of their two births. All block-groups in Salt Lake County were categorized in terms of the average pre-pregnancy BMI for all births for all women for all the years covered in the data. At this stage we have placed each block group into one of four BMI quartiles: Q1 (lowest/leanest), Q2, Q3 and Q4 (highest/most overweight). If someone moves but remains within a BMI quartile then they are treated as movers but simply moving from, say, Q1 to Q1. Of course, women who remain at the same residence between the two births are stayers. Note that in Table 1 that movers (regardless of where they started and where they arrived) generally have lower BMI values, gain more weight as a percentage, and have longer birth intervals.

Figures 1, 2, and 3 show maps for block groups in Salt Lake County, for mean block-group BMI where each block-group is categorized into BMI quartiles. Figure 1 covers all births while Figures 2 and 3 describes the distribution of BMI for the first and third births, respectively. Note that the western half of the county shows much higher BMI levels than the eastern half, partly reflecting a sociodemographic divide with the eastern portion having generally higher more walkable neighborhoods and higher SES values.

Table 2A indicates that women from high BMI areas generally experience, at a personal level, more weight gain between their first two births. Moreover, movers who stay within a quartile tend to experience more weight gain than stayers within the same quartile.

Finally, women who move from a leaner quartile to a higher quartile (Q1 to Q4) experience more weight gain than if they mover from a heavier quartile to a leaner one (Q4 to Q1). At this preliminary descriptive level, this observation suggests that persons from the heavier quartile continue to experience the effects of having been from such a neighborhood while the large weight gains experienced by the Q1->Q4 migrants (which occur very quickly given the birth intervals) suggest a nonrandom selection by Q1 (at their first pregnancy) to the heavier neighborhoods. A similar trend is observed in Tables 3A and 3B where adjustments are made for age and birth interval effects.

In the final paper, we will be implementing the techniques described earlier to better disentangle selection and causal effects.

Conclusion

The full paper will address the general question regarding selection and causal using the techniques described and will extend the analysis to higher order births. At this stage, we have shown the value of using longitudinal data derived from vital records to examine weight change as a function of neighborhood characteristics – whether the mechanism is due to causal or selection forces.

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Table 1. Descriptive Statistics for Pre-Pregnancy Weights prior to First and Second Births Among Movers and Stayers in Salt Lake County, Utah, 1989-2007						
	Mover			Stayer		
Variable	**N**	**Mean**	**Std Dev**	**N**	**Mean**	**Std Dev**
Pre-Pregnancy BMI: 1st Pregnancy	19299	22.860	4.521	10380	23.320	4.742
Pre-Pregnancy BMI: 2nd Pregnancy	19299	24.383	5.506	10380	24.316	5.391
Pre-Pregnancy BMI Difference Between 1st & 2nd Pregnancy	19299	1.523	3.214	10380	0.996	2.699
Percent Change in Pre-Pregnancy BMI	19299	6.895	13.605	10380	4.453	11.074
Change in Pre-Pregnancy Weight (lbs) Between 1st & 2nd Pregnancy	19299	9.130	18.622	10380	6.019	15.903
Percent change in Pre-Pregnancy Weight	19299	6.869	12.990	10380	4.420	10.623
Number of Months Between 1st & 2nd Pregnancies	19299	36.956	20.572	10380	29.259	13.400

Table 2A. Average Change in Pre-Pregnancy Weight (lb) Between First and Second Birth

SL County Residents

			Second Pregnancy			
			Q1	**Q2**	**Q3**	**Q4**
First Pregnancy	**Mover**	**Q1**	3.68	6.51	8.17	9.69
		Q2	5.07	6.65	9.38	10.79
		Q3	8.11	8.76	9.39	11.72
		Q4	7.39	9.80	10.41	11.65
	Stayer		3.09	5.03	6.28	8.59

Table 2B. Sample Sizes Number of Women Used in the Analysis: Location ranked by average pre-pregnancy BMI from 1989 - 2007 Birth Certificates

SL County Residents

			Second Pregnancy			
			Q1	**Q2**	**Q3**	**Q4**
First Pregnancy	**Mover**	**Q1**	1477	735	619	353
		Q2	733	1545	1255	853
		Q3	398	963	2584	1654
		Q4	204	583	1507	3675
	Stayer		2070	2361	2896	2997

Residents are Ranked by Average Pre-Pregnancy BMI for 1989 - 2007 SL County Birth Certificates

Q1 = 21.48 to 23.21

Q2= 23.22 to 24.04

Q3 = 24.71 to 24.7078

Q4= 24.7084 to 26.34

Table 3A. Average Change in Pre-Pregnancy Weight (lb) Between First and Second Birth:
Controlling for Age and Birth Interval
SL County Residents

			Second Pregnancy			
			Q1	**Q2**	**Q3**	**Q4**
First Pregnancy	**Mover**	**Q1**	4.52	6.66	7.71	8.96
		Q2	5.19	6.40	8.37	9.67
		Q3	7.41	7.93	8.78	10.31
		Q4	5.87	8.64	8.85	10.34
	Stayer		5.41	6.72	7.59	9.35

Table 3B. Average Percent Change in Pre-Pregnancy Weight (lb) Between First and Second Birth:
Controlling for Age and Birth Interval
SL County Residents

			Second Pregnancy			
			Q1	**Q2**	**Q3**	**Q4**
First Pregnancy	**Mover**	**Q1**	3.51	5.04	5.81	6.36
		Q2	4.02	4.82	6.24	7.17
		Q3	5.58	5.84	6.51	7.65
		Q4	4.64	6.65	6.79	7.63
	Stayer		4.28	4.99	5.61	6.93

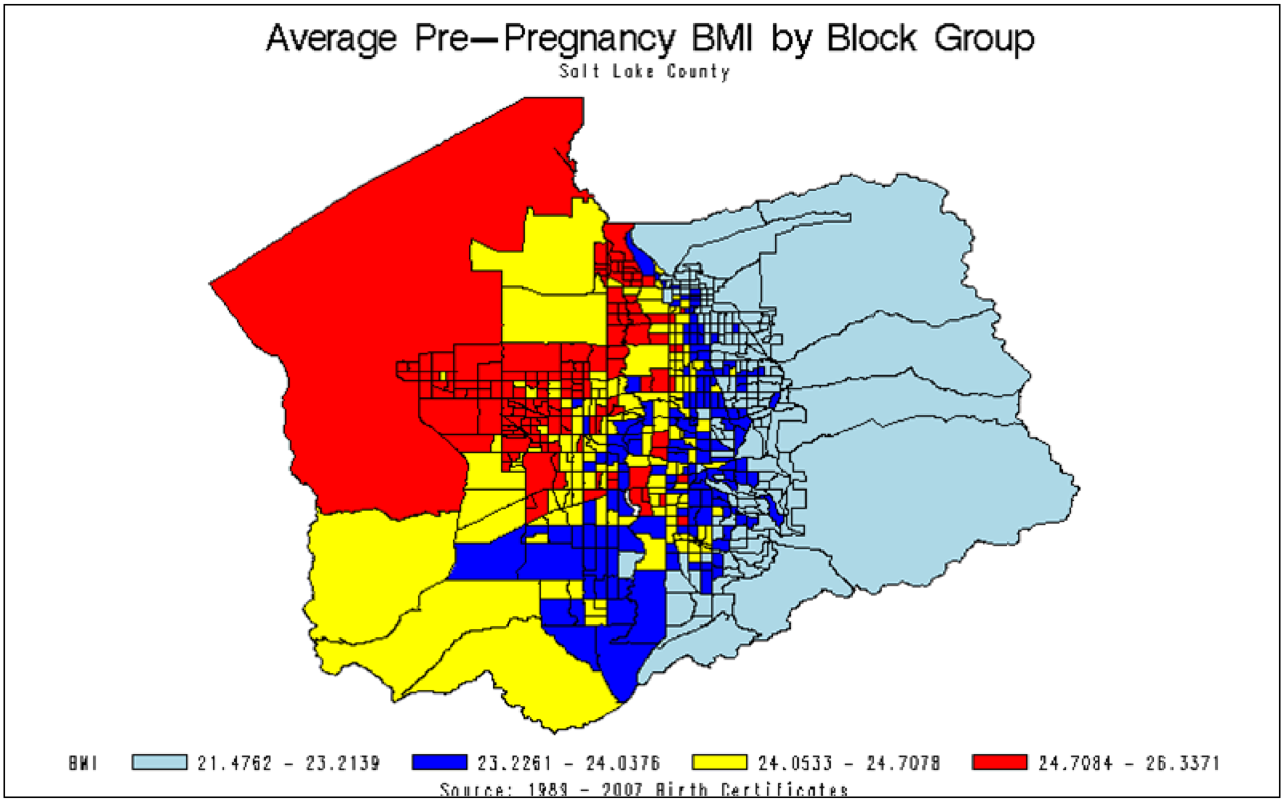

Figure 1. Pre-pregnancy BMI by Census Block Group. All Births, All Women, Salt Lake County, 1989-2007

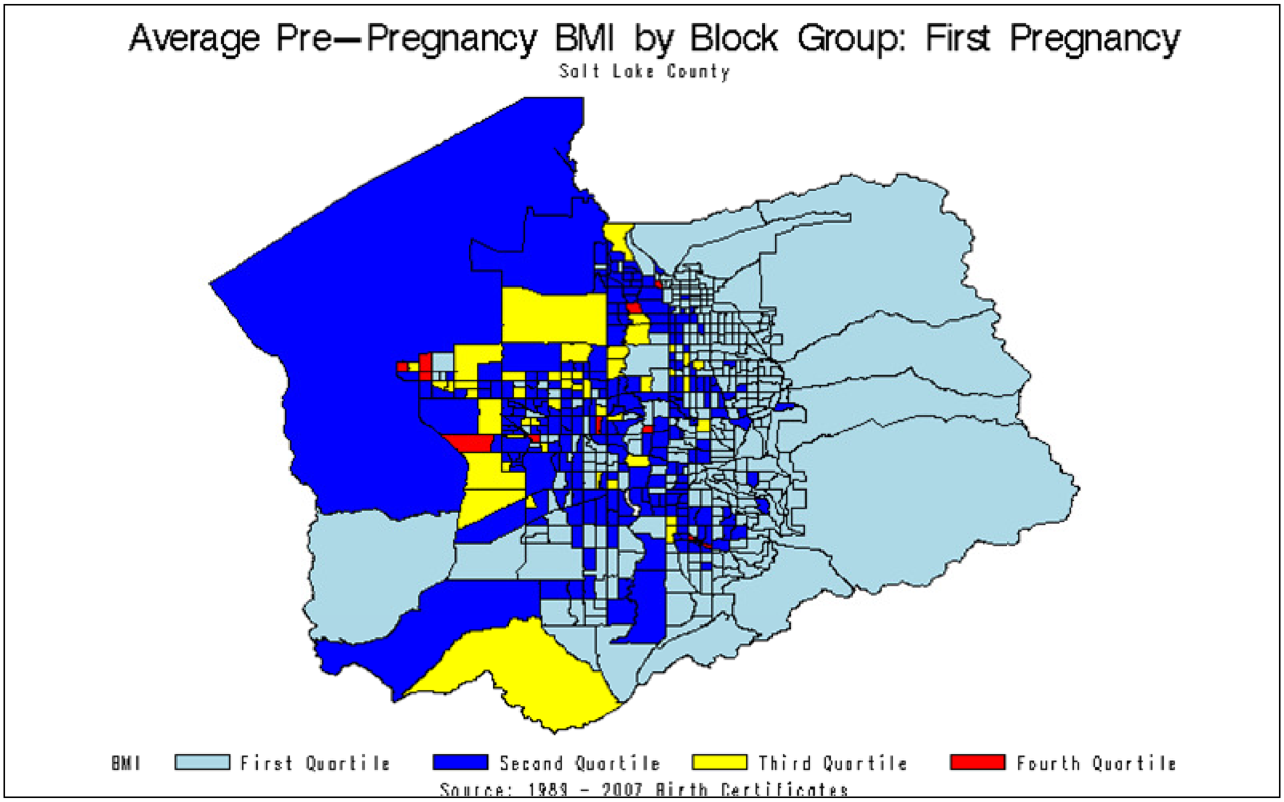

Figure 2. Pre-pregnancy BMI by Census Block Group. First Births, All Women, Salt Lake County, 1989-2007

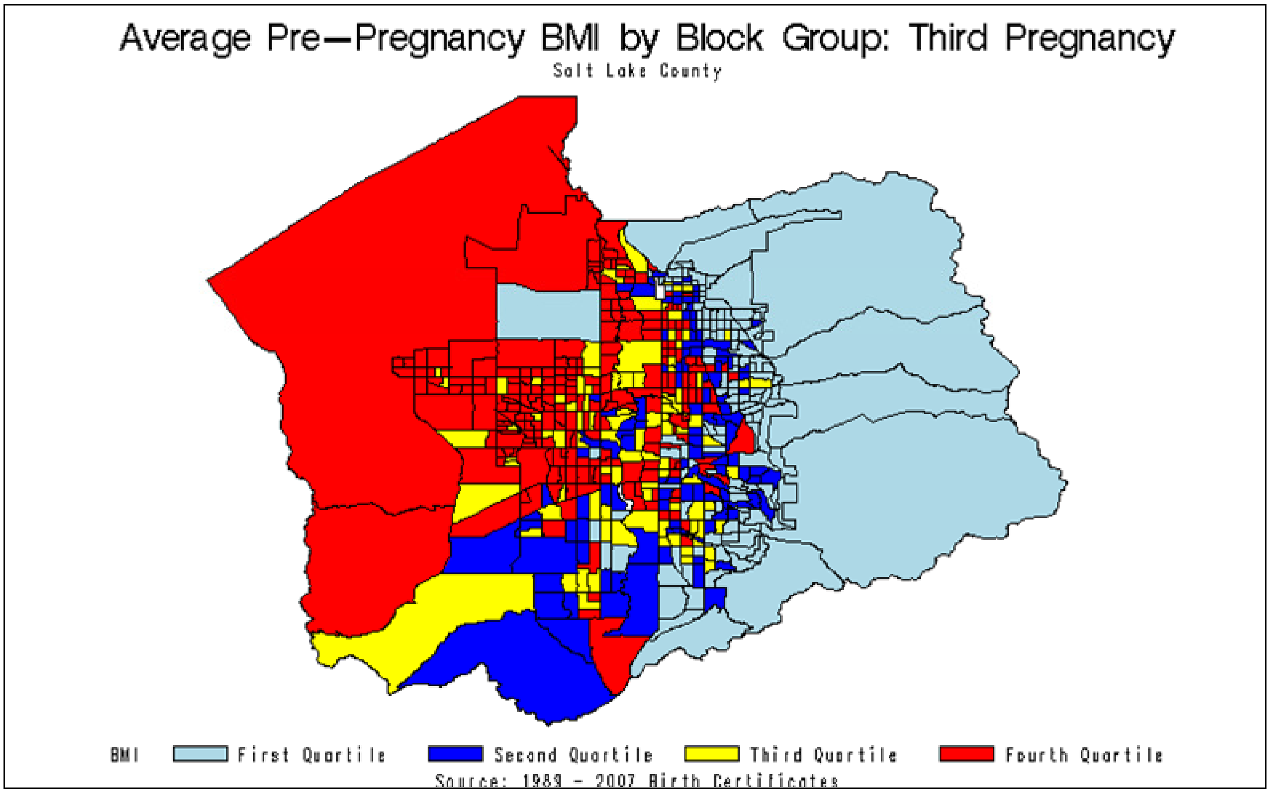

Figure 3. Pre-pregnancy BMI by Census Block Group. Third Births, All Women, Salt Lake County, 1989-2007