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Food Environment and Birth Outcomes In South Carolina

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FOOD ENVIRONMENT AND BIRTH OUTCOMES IN SOUTH CAROLINA

by

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Dedication

This dissertation is dedicated to my brilliant, loving, and supportive wife, to my exuberant, sweet, and smart little girl, and to my always encouraging and ever faithful parents and sister. Without your love and support, I could never have accomplished so much.

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Abstract

An increasing number of studies examined the association between neighborhood characteristics and birth outcomes. However, the results can be difficult to compare because of the variety of indicators used to characterize the neighborhood. As an important neighborhood characteristic, the food environment is associated with residents' nutrition status, diet quality, and related health outcomes. In addition, the food environment has been found to influence women's diet quality during pregnancy, which is a key factor in predicting birth outcomes. However to date, studies on food environment and birth outcomes are extremely limited.

This study examined the association between food environment (evaluated by both neighborhood- and individual-level indicators) and birth outcomes using data from all South Carolina births in 2008-2009. Birth outcomes were analyzed as continuous outcomes (birth weight and gestational age) and dichotomous outcomes (low birthweight (LBW) and preterm birth (PTB)). To facilitate comparison with other studies, a Neighborhood Deprivation Index (NDI) was used to identify the association between neighborhood characteristics and birth outcomes.

First, we identified those data associated with the food desert, a community food access measure developed by US Department of Agriculture

(USDA) characterizing neighborhood income and access to supermarkets, to evaluate the food environment and its relationship with the birth outcomes. We found that mothers living in food deserts did not have different birth outcomes compared to those living in areas with high neighborhood income and easy access to supermarkets. Neighborhood income is more important than food access in predicting birth outcomes.

Second, we estimated the association between mothers' accessibility (distance to the nearest store) and availability (count of stores within 1 mile around mothers' homes) to various types of food outlets and birth outcomes in an eight-county area in South Carolina. The results suggested that accessibility and availability of convenience stores were each associated with adverse birth outcomes. No significant associations were captured for healthy food outlets and limited service restaurants with birth outcomes.

In the end, we examined the relationship between NDI and adverse birth outcomes. Propensity score matching (PSM) analyses identified neighborhood deprivation as associated with increased risk of LBW among non-Hispanic whites, and with increased risk of PTB among non-Hispanic blacks. However, random effects logistic regression models identified the association between neighborhood deprivation and adverse birth outcomes only among non-Hispanic whites. PSM might be an appropriate approach to avoid off-support inferences.

Table of Contents

Dedication....................iii

Acknowledgements.................... iv

Abstract....................vii

List of Tables xiii

List of Figures xv

List of Abbreviations....................xvi

Chapter 1. Introduction 1

Rationale.. 1

Conceptual Framework 5

Specific Aims 6

Research Questions 7

Hypotheses.................... 8

Chapter 2. Literature Review 12

Birth Outcomes: Incidence, Definition and Consequences.................... 12

Individual-Level Risk Factors of Birth Outcomes 14

Neighborhood-Level Risk Factors of Adverse Birth Outcomes.................... 17

Neighborhood Deprivation Index and Birth Outcomes.................... 19

Food Environment and Dietary Intake 20

Measures of Food Environment 22

Community Food Access Measures.................... 24

Food Environment and Birth Outcomes 27
Racial Disparities on Adverse Birth Outcomes 29
Chapter 3. Methods 33
Study Area 33
Study Design 34
Food Outlet Data 34
South Carolina Birth Certificate Data 38
2000 US Census Data 41
USDA Food Desert 42
Accessibility and Availability of Food Outlets 43
Neighborhood Deprivation Index 44
Birth Outcomes 45
Confounders, Effect Modifiers, and Mediators 46
Edge Effects 48
Regression Models and Multilevel Analysis 48
Propensity Score Matching 50
Chapter 4. Food Desert and Birth Outcomes: Effects of Neighborhood Income and Community Food Access 62
Abstract 64
Introduction 66
Methods 69
Results 73
Discussion 75

Conclusion..81

Chapter 5. Built food Environment and Birth Outcomes in South Carolina 85

Abstract…...87

Introduction..89

Methods… 91

Results…..95

Discussion 97

Conclusion..102

Chapter 6. Neighborhood Deprivation and Adverse Birth Outcomes in South Carolina 108

Abstract…..110

Introduction...112

Methods… 114

Results…..118

Discussion 121

Conclusion...125

Chapter 7. Summary..135

Validity of Food Outlet Data...135

Quality of Birth Certificate Data 137

Food Environment Measures 138

PSM Method in Birth Outcome Research...139

Food Environment and Gestational Hypertension 140

Limitation and Strengths...145

Summary of the Findings 147
Racial Disparities 148
Implications and Future Directions 149
Bibliography 154
Appendix A. Sample of South Carolina Birth Certificate Questionnaire 180
Appendix B. Exemption Letter from the Institution Review Board at University of South Carolina 183
Appendix C. Birth Certificate Data Release Agreement from South Carolina Department of Health and Environmental Control 185

List of Tables

Table 2.1 Food environment measures by dimension of access 32

Table 3.1 Characteristics of live births in South Carolina (N=123,759)...............58

Table 3.2 Characteristics of live births in eight-county area (N=18,963)............59

Table 3.3 Summary of missing data in birth certificate data...............................60

Table 3.4 Number of various types of food outlets in eight-county area 61

Table 4.1 Maternal and offspring characteristics of live births in South Carolina (2008-2009), according to neighborhood income and food access 83

Table 4.2 The association between matrix of income and food access and birth outcomes in South Carolina...84

Table 5.1 Characteristics of sample in eight-county area in South Carolina.....104

Table 5.2 Summary of distance to the nearest food outlet and count of food outlet in 1 mile buffer by food outlet type in eight-county area in South Carolina 105

Table 5.3 The association between distance to the nearest food outlet (log-transformed) and birth outcomes in eight-county area in South Carolina 106

Table 5.4 The association between count of food outlets in 1-mile buffer (categorical) and birth outcomes in eight-county area in South Carolina.....107

Table 6.1 Loadings of variables of first principal component from PCA............129

Table 6.2 Characteristics of sample by quartiles of neighborhood deprivation index in South Carolina..130

Table 6.3 Covariates imbalance across Neighborhood Deprivation Index quartiles prior to and after matching by race in all births 2008-2009 in South Carolina 131

Table 6.3 Covariates imbalance across Neighborhood Deprivation Index quartiles prior to and after matching by race in all births 2008-2009 in South Carolina (cont.) 132

Table 6.4 Difference of prevalence of low birthweight and preterm birth between Neighborhood Deprivation Index quartiles after propensity score matching by race in all births 2008-2009 in South Carolina 133

Table 6.5 The association between Neighborhood Deprivation Index quartiles and low birthweight and preterm birth from random-effect logistic regressions by race in all births 2008-2009 in South Carolina 134

Table 7.1 The association between matrix of income and food access and gestational hypertension in South Carolina.. 152

Table 7.2 Distance to the nearest food outlet and number of food outlet in 1 mile buffer by gestational hypertension in eight-county area in South Carolina 153

List of Figures

Figure 1.1 Conceptual frameworks of neighborhood characteristics and birth outcomes in previous studies..10

Figure 1.2 Conceptual framework of food environment and birth outcomes.......11

Figure 3.1 Study area 53

Figure 3.2 Birth certificate data flow for birth in South Carolina 54

Figure 3.3 Birth certificate data flow for birth in eight-county in South Carolina..55

Figure 3.4 Diagram of data flow of USDA food desert designation.....................56

Figure 3.5 Directed Acyclic Graph in the study 57

Figure 4.1 Birth weight (top) and gestational age (bottom) distribution for categories of four-level food desert..82

Figure 5.1 Study area with 10-mile buffer zone and food outlets......................103

Figure 6.1 Distribution of neighborhood deprivation index by race in South Carolina 126

Figure 6.2 Distribution of Neighborhood Deprivation Index in South Carolina (Census tract level)..127

Figure 6.3 Propensity score overlap by level of neighborhood deprivation for non-Hispanic white (upper panel) and black (lower panel) 128

Figure 7.1 Logistic regression between distance to nearest food outlet or number of food outlet in 1 mile and gestational hypertension in eight-county area in South Carolina (N=15,171) 151

List of Abbreviations

AGA .... Appropriate Size for Gestational Age
BMI .... Body Mass Index
CDC .... Centers for Disease Control and Prevention
CI .... Confidence Interval
DAG .... Directed Acyclic Graph
D&B .... Dun & Bradstreet
DHEC .... Department of Health and Environmental Control
DHHS .... Department of Health and Human Services
ERS .... Economic Research Service
FD .... Food Desert
FFFI .... Fresh Food Financing Initiative
GIS .... Geographic Information System
GPS .... Global Positioning System
HA .... High Access
HFFI .... Healthy Food Financing Initiative
HI .... High Income
IUGR .... Intrauterine Growth Restriction
LA .... Low Access
LBW .... Low Birthweight
LFSFD .... Licensed Food Services Facilities Database
LI .... Low Income
LSA .... Limited Supermarket Access
MSA .... Metropolitan Statistical Areas
NAICS .... North American Industry Classification System
NDI .... Neighborhood Deprivation Index

OR .... Odds Ratio
PC .... Principal Component
PCA .... Principal Component Analysis
PRAMS .... Pregnancy Risk Assessment Monitoring System
PSM .... Propensity Score Matching
PTB .... Preterm Birth
Q .... Quartile
RUCA .... Rural Urban Commuting Area
SCAN .... South Carolina Community Assessment System
SD .... Standard Deviation
SEDAC .... Socioeconomic Data and Applications Center
SES .... Socioeconomic Status
SF3 .... Summary File 3
SGA .... Small for Gestational Age
Treasury .... Department of The Treasury
TRF .... The Reinvestment Fund
US .... The United States
USDA .... United States Department of Agriculture
WIC .... Special Supplemental Nutrition Program for Women, Infants, and Children

CHAPTER 1

Introduction

Rationale

Approximately 6 million pregnancies occur each year in the United States. While most women have a full term pregnancy and deliver a healthy infant, a safe and healthy pregnancy is not experienced by all women. Infant mortality is the most important indicator of birth outcomes. Infants with adverse birth outcomes such as low birthweight (LBW) and preterm birth (PTB), are at a greater risk of dying in infancy (McCormick, 1985; McIntire *et al.*, 1999). LBW occurs in approximately 1 of every 12 babies born each year in the United States (US), and it is an important predictor of future morbidity and mortality (JAMA, 2002). PTB affects more than 500,000, or 12.2% of live births in the United States annually (Martin *et al.*, 2012). In addition, PTB is a leading cause of infant mortality and morbidity. Surviving LBW and/or premature infants may face lifelong health problems (Behrman *et al.*, 2007).

At the individual-level, birth weight (or LBW) has been associated with risk factors including maternal age (Friede *et al.*, 1987; Valero De Bernabe *et al.*, 2004), marital status (Holt *et al.*, 1997), health behaviors such as smoking, alcohol use, substance use and sexual behaviors (Gluckman *et al.*, 2004), malnutrition (Mitchell *et al.*, 2004; Sram *et al.*, 2005; Wu *et al.*, 2004),

socioeconomic status (SES) (O'Campo *et al.*, 2008; Pearl *et al.*, 2001), and stress (Lesage *et al.*, 2004). While for PTB, known risk factors are multiple pregnancies, problems with the uterus or cervix (Flynn *et al.*, 1999), maternal health behaviors such as smoking, alcohol, substance use, and sexual behaviors (Nordentoft *et al.*, 1996; Peacock *et al.*, 1995; Windham *et al.*, 1995), maternal infections (Goldenberg *et al.*, 2000), maternal SES factors (Peacock *et al.*, 1995), and stress (Dole *et al.*, 2003; Nordentoft *et al.*, 1996; Peacock *et al.*, 1995).

Neighborhood-level factors may influence individual-level biological and behavior factors through a variety of mechanisms which may cause adverse birth outcomes such as LBW and PTB. In particular, the physical, social and economic conditions of the neighborhood may have effects on behaviors, stress, nutritional status, and physical health of the mothers living in the neighborhood which may result in adverse birth outcomes. Neighborhood factors including income/wealth (Farley *et al.*, 2006; Masi *et al.*, 2007; O'Campo *et al.*, 2008; Pearl *et al.*, 2001), employment (Masi *et al.*, 2007; O'Campo *et al.*, 2008; Pearl *et al.*, 2001), violence and crime (Masi *et al.*, 2007; Messer *et al.*, 2006b; Schempf *et al.*, 2009), and racial/ethnical composition (Masi *et al.*, 2007; Nkansah-Amankra *et al.*, 2010b; Reichman *et al.*, 2009; Schempf *et al.*, 2009), were found to be related to LBW and PTB (Metcalfe *et al.*, 2011). Living in a poor neighborhood has a negative impact on birth outcomes independent of individual risk factors. However, the results in these studies could be difficult to interpret and compare because of the variety of indicators used to characterize the neighborhood context. A comprehensive and standard indicator was needed to evaluate

neighborhood characteristics and allow being comparable among these studies. A standardized Neighborhood Deprivation Index (NDI) was developed according to Census sociodemographic factors and it may be an appropriate neighborhood indicator (Messer *et al.*, 2006c).

The built food environment is an important characteristic of the neighborhood environment. The built food environment has been associated with dietary intake and various health outcomes such as obesity and hypertension (Bodor *et al.*, 2008; Franco *et al.*, 2009; Jago *et al.*, 2007; Laraia *et al.*, 2004; Larson *et al.*, 2009a; Moore *et al.*, 2008b; Morland *et al.*, 2002; Pearce *et al.*, 2008, 2009). Research found that proximity of supermarkets is positively associated with diet quality among pregnant women (Laraia *et al.*, 2004). Nutritional intake during pregnancy is important for fetal growth and development, and poor nutrition before and during pregnancy has been associated with adverse birth outcomes (Mitchell *et al.*, 2004; Sram *et al.*, 2005; Wu *et al.*, 2004). Therefore, the built food environment may influence the dietary intake and nutritional status among pregnant women, and cause adverse birth outcomes. Moreover, food environment may be associated with health behaviors such as tobacco and alcohol use (Gruenewald *et al.*, 1993; Turner *et al.*, 2004), maternal stress (Laraia *et al.*, 2006), neighborhood and individual SES factors (income, poverty, employment, population composition etc.) (Hemphill *et al.*, 2008; Seliske *et al.*, 2009), maternal risk factors such as obesity, chronic and gestational hypertension and diabetes (Ahern *et al.*, 2011; Bodor *et al.*, 2010; Janevic *et al.*, 2010a), and all of these factors have been associated with birth outcomes.

However to date, the studies on food environment and birth outcomes were extremely limited and the results were inconsistent (Farley *et al.*, 2006; Lane *et al.*, 2008). Women living in proximity to a supermarket had significantly fewer LBW births than those living farther away (Lane *et al.*, 2008). While neither the gestational age nor birthweight-for-gestational-age was associated with density of alcohol outlets, tobacco outlets, fast-food restaurants or grocery supermarkets (Farley *et al.*, 2006). All these studies used Census tract-level measures to characterize the food environment, such as the density or presence of food outlets in a Census tract. These measures only captured the availability dimension of the food environment. Studies using the measures with more dimensions (e.g. accessibility and affordability) are needed. In addition, no studies examined the individual-level food access and birth outcomes to date.

One of the most well-known health disparities between non-Hispanic whites and blacks in the United States is that of pregnancy/birth outcomes. However, the causes of this disparity are unclear so far (Lu *et al.*, 2003). Previous discussions about individual-level risk factors for adverse birth outcomes, such as SES, risky behaviors, prenatal care, and stress, could not account for the racial disparities in pregnancy and birth outcomes (Goldenberg *et al.*, 1996; Lu *et al.*, 2003). Several studies indicated the racial differences in access to fast food (Dunn *et al.*, 2012) or healthy food (Bader *et al.*, 2010). The studies found that non-whites tended to exhibit greater access to fast food, higher consumption of fast food meals and worse access to healthy food (vegetables and fruits) compared to their white counterparts. Because of the racial difference

on food access, more and more studies investigated the effects of neighborhood factors on birth outcomes and tried to explain the racial disparities (Grady, 2006; Janevic *et al.*, 2010b; Love *et al.*, 2010; Messer *et al.*, 2008; Pearl *et al.*, 2001). However to date, no studies have examined the racial difference of the association between food environment and birth outcomes.

Conceptual Framework

Several conceptual frameworks on neighborhood characteristics and birth outcomes were established in previous studies (**Figure 1.1**) (Abu-Saad *et al.*, 2010; Culhane *et al.*, 2005; Masi *et al.*, 2007; Schempf *et al.*, 2009). Based on these models, our conceptual framework was drawn in **Figure 1.2**. The food environment, a dimension of the neighborhood context, is nested in the neighborhood with other neighborhood factors. Arrows indicate the connection from neighborhood environment to biological factors and following birth outcomes through different pathways. Neighborhood environment has been associated with health behaviors including dietary intake, smoking and alcohol use, and physical activity, which might affect biological factors directly or through nutrition and obesity. The neighborhood environment could also affect maternal risk factors such as stress, prenatal care, reproductive history, infection during pregnancy, chronic and gestational hypertension and diabetes. All these risk factors have been linked to birth outcomes (via biological factors). Demographic and individual SES factors are related to neighborhood characteristics, and influence health behaviors and maternal risk factors. Sociodemographic factors could also predict

birth outcomes through biological factors. Based on this conceptual framework, sociodemographic and neighborhood factors could be considered as the confounders between food environment and birth outcomes, whereas health behaviors and maternal risk factors are mediators in the pathway.

Specific Aims

Recent research has suggested that food availability and accessibility were associated with dietary intake and health outcomes (Bodor *et al.*, 2008; Franco *et al.*, 2009; Jago *et al.*, 2007; Laraia *et al.*, 2004; Larson *et al.*, 2009a; Moore *et al.*, 2008b; Morland *et al.*, 2002; Pearce *et al.*, 2009). Nutritional intake during pregnancy was important for fetal growth and development, and poor nutrition during pregnancy was associated with birth outcomes (Mitchell *et al.*, 2004; Sram *et al.*, 2005; Wu *et al.*, 2004). Therefore, deprived food environment may cause adverse birth outcomes by affecting dietary quality during pregnancy. Food environment may also be related to health behaviors, stress, SES factors, and maternal risk factors, which may cause adverse birth outcomes as well (Bader *et al.*, 2010; Farley *et al.*, 2006). According to the literature, the studies on food environment and adverse birth outcomes were extremely limited.

Based on US Census 2000 data, commercial and ground-truthed food outlet data, and birth certificate data covering all live births from 2008-2009 in South Carolina, this study was sought to examine the association of food environment and birth outcomes, and the association between neighborhood

deprivation and birth outcomes. Specifically, aims of the study could be described as below:

Specific Aim 1. To investigate the association between food desert dimensions (neighborhood income and food access) and birth outcomes in South Carolina, and to evaluate whether the associations vary by race.

Specific Aim 2. To examine the association between food access (accessibility and availability of food outlets) and birth outcomes in eight counties in South Carolina, and to identify whether the associations vary by race.

Specific Aim 3. To investigate the association between neighborhood deprivation (NDI) and adverse birth outcomes in South Carolina, and to evaluate whether the associations vary by race.

Research Questions

Research Question 1. Are the birth outcomes different among the areas defined by the two dimensions of food desert (high-income and high-access, low-income and high-access, high-income and low-access, and low-income and low-access (food desert))? Which dimension of food desert is more important in predicting birth outcomes, neighborhood income or community food access? Are the differences differentiated between non-Hispanic white and black mothers?

Research Question 2. Are increased distance to the nearest healthy food outlet and decreased distance to the nearest unhealthy food outlet associated with decreased birth weight and gestational age, and increased odds of LBW and PTB? Are increased number of healthy food outlets and decreased number of

unhealthy food outlets within 1 mile buffer associated with increased birth weight and gestational age, and decreased odds of LBW and PTB? Are the associations and differences differentiated among different race/ethnic groups?

Research Question 3. Is neighborhood deprivation (increased NDI) associated with increased odds of LBW and PTB in South Carolina? Are these associations different between non-Hispanic white and black women?

Hypotheses

The hypotheses were described below according to research questions:

Hypothesis 1. Births of mothers living in the areas considered to be food deserts are more likely to be classified as LBW (or decreased birth weight) and PTB (or decreased gestational age) independent of covariates than those of mothers living in areas with high neighborhood income and good food access. The low-income and low-access area (food desert) has the worst birth outcomes, following by low-income and high-access, and high-income and low-access area, whereas high-income and high-access area has the best birth outcomes. We hypothesize that low neighborhood income dimension of food desert plays a more important role on predicting adverse birth outcomes than low food access dimension. The associations are different between non-Hispanic white and black women.

Hypothesis 2. We hypothesize that mothers with longer distance to the nearest healthy food outlet (e.g. supermarkets, supercenters, grocery stores and warehouse clubs) and mothers with shorter distance to the nearest unhealthy

food outlet (e.g. convenience stores, limited service restaurants) are more likely to deliver a baby with LBW (or decreased birth weight) and PTB (or decreased gestational age). Mothers with more healthy food outlets (e.g. supermarkets, supercenters, grocery stores and warehouse clubs) and mothers with less unhealthy food outlets (e.g. convenience stores, limited service restaurants) in their neighborhoods are less likely to deliver a baby with LBW (or decreased birth weight) and PTB (or decreased gestational age). The associations are different between non-Hispanic white and black women.

Hypothesis 3. The neighborhood deprivation score was higher in non-Hispanic black women than in non-Hispanic white women. Mothers living in deprived areas are more likely to have LBW and PTB births. Different associations are found between non-Hispanic white and black mothers.

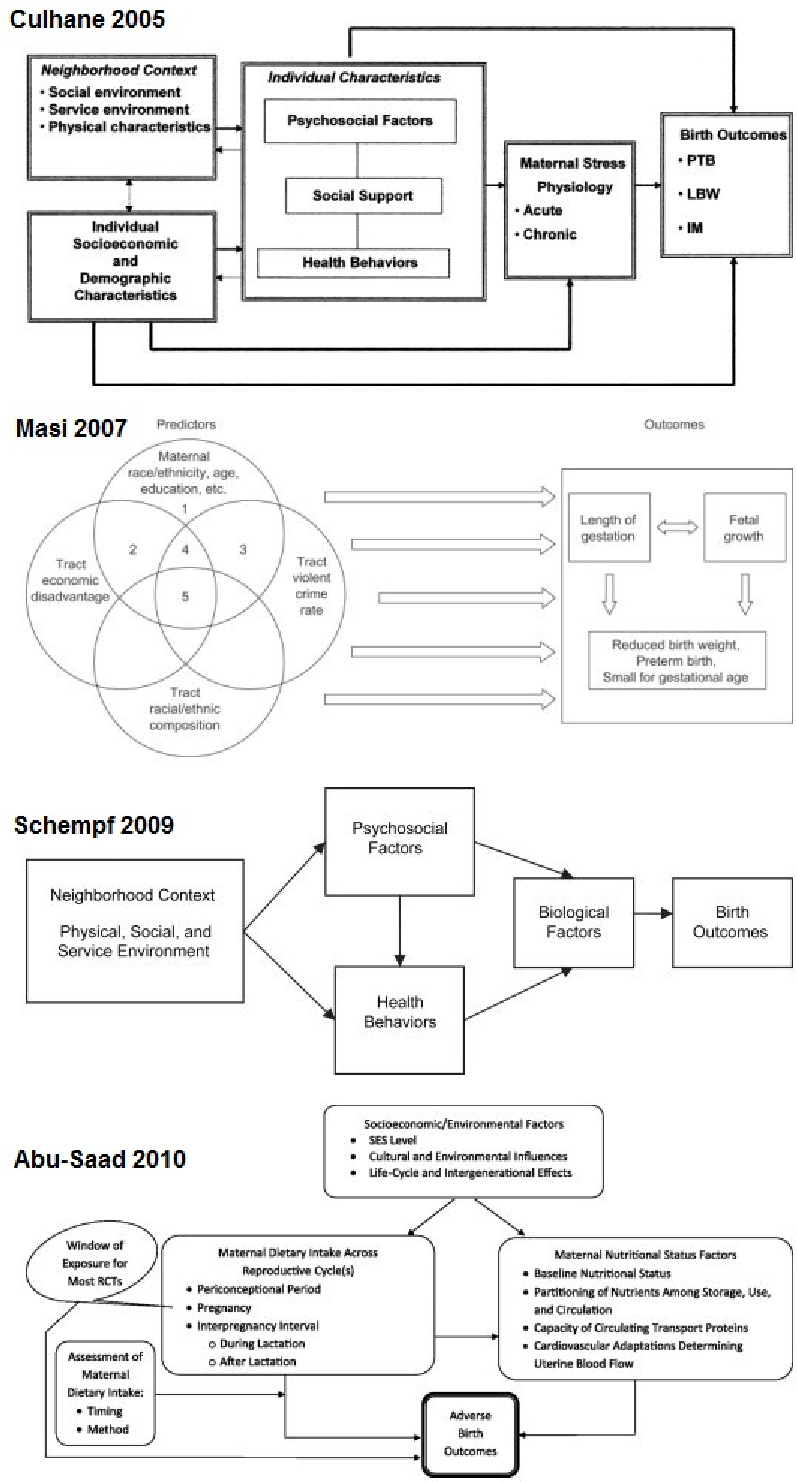

Figure 1.1 Conceptual frameworks of neighborhood characteristics and birth outcomes in previous studies

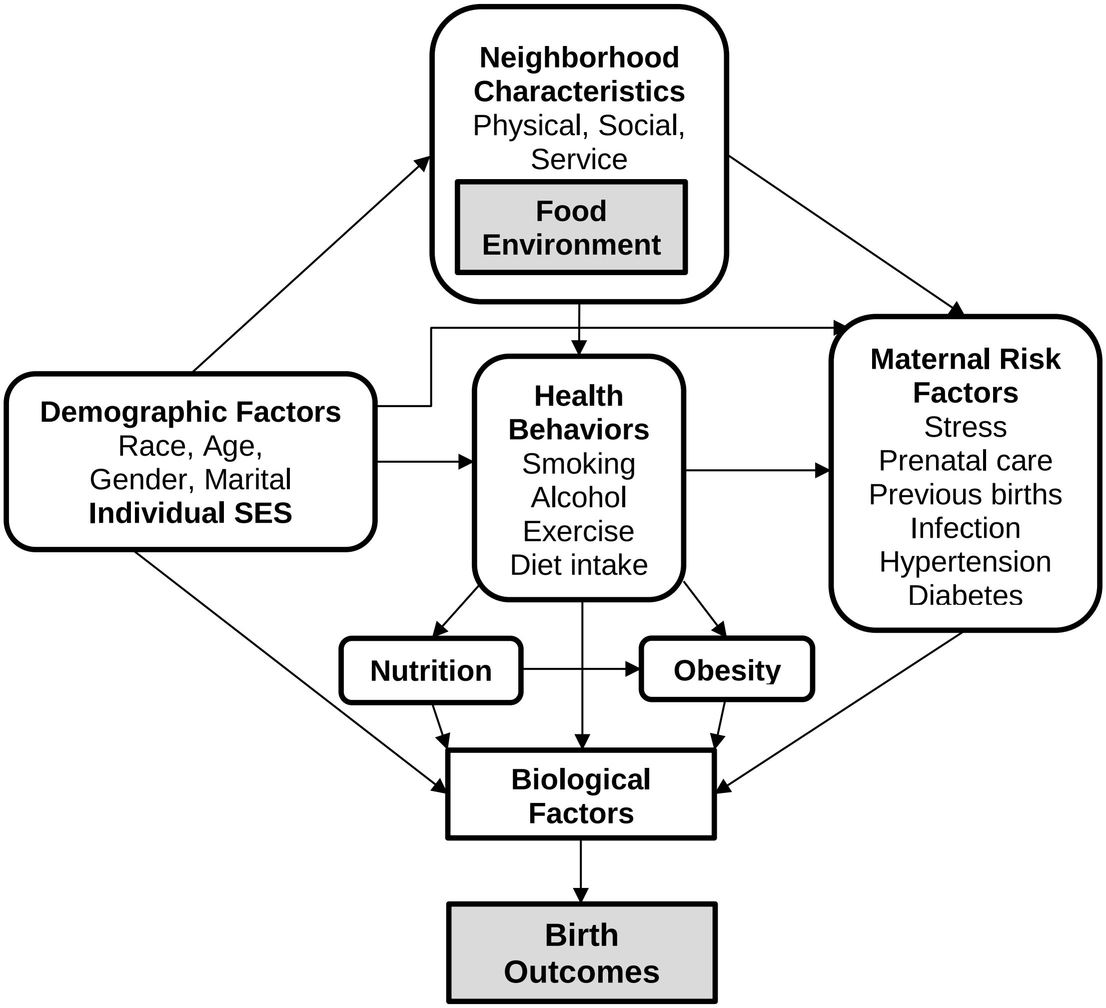

Figure 1.2 Conceptual framework of food environment and birth outcomes

CHAPTER 2

Literature Review

Birth Outcomes: Incidence, Definition and Consequences

Approximately 6 million pregnancies occur each year in the United States. While most women have a normal term pregnancy and deliver a normal infant, a safe and healthy pregnancy is not experienced by all women. Infant mortality is the most important indicator to evaluate the birth outcome. Infant mortality is defined as when an infant dies before he or she is 1 year old. The infant mortality rate is an estimate of the number of infant deaths for every 1,000 live births. This rate is often used as an indicator to measure the health and well-being of a nation, because factors affecting the health of entire populations can also impact the mortality rate of infants. Unfortunately in the United States, about 25,000 infants die each year (Hoyert *et al.*, 2012).

LBW and PTB are two main predictors of infant mortality. The quality of gestation is usually evaluated by two measures: length of gestation and birth weight. Normal term pregnancy lasts between 37 and 41 completed weeks. Less than 37 completed weeks of gestation is defined as PTB. More than a half million babies in the United States, which means 1 of 8 births are born premature each year (Martin *et al.*, 2012). LBW is usually defined as a weight at birth of less than 2,500 grams, or 5 pounds 8 ounces. LBW may result from being born too small

or too early: small-for-gestational-age (SGA) and PTB. SGA is commonly defined as a weight below the 10th percentile for the gestational age. SGA usually includes constitutionally small but otherwise normal (e.g. born to parents who are small and/or into an ethnic population that is smaller than the reference population), and pathologically growth-restricted which is called the intrauterine growth restriction (IUGR). IUGR refers to a condition in which a fetus is unable to achieve its genetically determined potential size. LBW occurs in approximately 1 of every 12 babies born each year in the United States (JAMA, 2002).

PTB and LBW infants are at greater risk for mortality and a variety of health and developmental problems. Conditions related to PTB and LBW are the second leading cause of infant death in the United States (after birth defects) (Mathews *et al.*, 2008). The infant mortality of LBW is approximately 25 times that of the infant mortality rate of normal birth weight. Likewise, the infant mortality rate for late PTB (34–36 weeks of gestation) is about three times the infant mortality rate for normal term birth, and the infant mortality rate for very PTB (less than 32 weeks of gestation) is about 75 times that of normal term birth (Mathews *et al.*, 2008). LBW has been linked to several health consequences in adulthood, including learning problems (Frisk *et al.*, 2002), increased risk of heart disease, high blood pressure, and type II diabetes (Simeoni *et al.*, 2005). PTB infants need special care and extra hospitalization after birth and cost the US health care system more than $26 billion each year (Behrman *et al.*, 2007). PTB may experience complications such as acute respiratory, gastrointestinal, immunologic, and central nervous system problems. Surviving LBW or premature

infants may face lifelong health problems, including intellectual disabilities, cerebral palsy, breathing and respiratory problems, and vision and hearing loss (JAMA, 2002). In addition, the birth of a preterm or LBW infant can have significant emotional and economic impacts on the infant’s family (Behrman *et al.*, 2007).

Individual-Level Risk Factors of Birth Outcomes

A variety of factors influence fetal growth, which can be classified into several categories: factors originating from the fetus, maternal factors, placental factors and, the factors produced from the interaction of these factors. In general, it was estimated that approximately 40% of birth weight is due to heredity, and the remaining 60% to the environmental factors. For instance, mother's birth weight has been associated with infant birth weight in early years (Ounsted *et al.*, 1968). The influence of the mother’s birth weight is greater than that of the father’s. A number of studies had identified the association between maternal age and birth weight. Studies showed that the incidence of LBW increased in extremes of maternal age; that is, between 15-19 years and between 35-40 years old (Friede *et al.*, 1987; Valero De Bernabe *et al.*, 2004). However, the increased risk of LBW might be due to the related risk factors rather than maternal age self. For instance, most adolescent mothers are with risk factors for birth outcomes, including being single, with low income and with inadequate prenatal care (Roth *et al.*, 1998), which may cause adverse birth outcome. Older women have a higher incidence of pregnancy complications such as chronic and gestational

hypertension and diabetes (Cnattingius *et al.*, 1992). Marital status is another important risk factor of LBW. In Holt et al.'s study, they examined the effect of change of marital status on LBW between two births. They found that women who were married during the first pregnancy had a lower incidence of LBW than single mothers, whereas the risk of LBW increased if they separated during the second birth compared to those remained married (Holt *et al.*, 1997). However, there were many confounders in this research. The age increased between two births and separation might impact the mother's stress level and other health behaviors.

SES factors, such as maternal education, income, and occupation, have been linked to birth weight in a large number of studies (Aach *et al.*, 1980; Millar *et al.*, 1998; Valero De Bernabe *et al.*, 2004). Women with higher SES levels were less likely to give births with LBW. Health behaviors such as smoking, alcohol use, substance use and sexual behaviors were also associated with birth weight (Chomitz *et al.*, 1995). Smoking during pregnancy leaded to approximately 200 grams less of birth weight than no smoking (Bouckaert, 2000; Haustein, 1999). The evidence on alcohol consumption was not as strong as cigarette smoking, however, many studies reported that there was often concurrent consumption of tobacco, alcohol and other drugs (McFarlane *et al.*, 1996). Maternal stress was also a risk factor of LBW. Studies showed that continuous stress during the pregnancy could decrease the length of gestation and birth weight (Hedegaard *et al.*, 1996; Lesage *et al.*, 2004; Orr *et al.*, 1996).

In addition to the sociodemographic factors, malnutrition was an important predictor of birth weight (Mitchell *et al.*, 2004; Sram *et al.*, 2005; Wu *et al.*, 2004). In a case-control study of 844 cases (SGA) and 870 controls (appropriate size for gestational age (AGA)), mothers of AGA infants ate significantly more servings of carbohydrate rich food and fruit, and were more likely to have taken folate and vitamin supplements than mothers of SGA infants (Mitchell *et al.*, 2004). Sram et al. confirmed the effect of folate on birth weight that folate has potential to decrease the risk of IUGR in European population and LBW in smoking European mothers (Sram *et al.*, 2005). Medical risk factors such as hypertension, renal diseases, diabetes, asthma, and obstetrical history, and health care pre- and during pregnancy could also affect the birth weight (Demissie *et al.*, 1998; Deshmukh *et al.*, 1998; Easterling *et al.*, 1991; Fink *et al.*, 1998; Mandelson *et al.*, 1992; Valero De Bernabe *et al.*, 2004).

Previous studies have claimed that the risk factors are shared but not identical between LBW and PTB (Lang *et al.*, 1996). Known risk factors for PTB are multiple pregnancies, problems with the uterus or cervix (Flynn *et al.*, 1999), maternal health behaviors (smoking, alcohol, substance use, and sexual behaviors) (Nordentoft *et al.*, 1996; Peacock *et al.*, 1995; Windham *et al.*, 1995), maternal infections (Goldenberg *et al.*, 2000), low maternal SES (Blumenshine *et al.*, 2010; Peacock *et al.*, 1995), and stress (Dole *et al.*, 2003; Nordentoft *et al.*, 1996; Peacock *et al.*, 1995). In a meta-analysis, Flynn et al. concluded that bacterial vaginosis is an important risk factor for prematurity (Flynn *et al.*, 1999). Effects of socioeconomic factors, psychological stress and smoking were

associated with PTB based on 1,513 women in Peacock's study (Peacock *et al.*, 1995). Intrauterine infection was identified to be related with preterm delivery by Goldenberg et al. (Goldenberg *et al.*, 2000).

A number of studies have examined the association between individual SES factors and adverse birth outcomes. There were also several systemic review studies on this topic since 1980s (Blumenshine *et al.*, 2010; Kramer, 1987; Kramer *et al.*, 2000). Most of the studies reported a significant association between an SES measure and adverse birth outcomes. Many studies observed racial/ethnic differences in the effect of SES measures. The individual-level SES factors were not the main focus of this study, thus we will focus on neighborhood-level risk factors in next section.

Neighborhood-Level Risk Factors of Adverse Birth Outcomes

More and more studies examined the association between neighborhood-level risk factors and birth outcomes. Early studies examining these associations tended to be ecological in design, while recently conducted work has included multilevel studies which examine the impact of neighborhood-level variables on birth outcomes after controlling for individual-level variables. Several studies found that neighborhood-level income was associated with lower birth weights (Cubbin *et al.*, 2008; Finch *et al.*, 2007; Masi *et al.*, 2007; Metcalfe *et al.*, 2011; Pearl *et al.*, 2001), while other studies did not find the association (Grady, 2006; Reichman *et al.*, 2009; Sellstrom *et al.*, 2007). Pearl et al. found that in addition to individual socioeconomic characteristics, living in neighborhoods that are less

socioeconomically advantaged may differentially influence birth weight, depending on women's ethnicity and nativity (Pearl *et al.*, 2001). Less favorable neighborhood socioeconomic characteristics were associated with lower birth weight among Blacks and Asians but not among Whites, US-born Latinas, or foreign-born Latinas. In a meta-analysis on neighborhood income and LBW, Metcalfe et al. found that women living in low income areas defined based on federal poverty level had 11% higher odds of having LBW infants than those living in high income areas (odds ratio=1.11, 95% confidence interval: 1.02, 1.20) (Metcalfe *et al.*, 2011). Cubbin et al. conducted a study in two geographic areas on neighborhood-level income and birth weight, Florida and Washington, and found a null effect in Washington, and a positive association in Florida (Cubbin *et al.*, 2008). In Masi et al.'s study, neighborhood violent crime rates were found to explain the variance in birth weight (Masi *et al.*, 2007). Findings on racial compositions of neighborhoods and birth weight were inconsistent. Finch et al. found that living with residents from the same ethnicity was found to be protective against lower birth weights (Finch *et al.*, 2007); however, Grady found that residential segregation was associated with LBW (Grady, 2006). Moreover, studies also found that ethnic diversity had a negative impact on birth weight (Reichman *et al.*, 2009). Several studies have reported that neighborhood unemployment rate was associated with a reduction in birth weight (Masi *et al.*, 2007; Pearl *et al.*, 2001).

Studies on neighborhood factors and PTB are a little limited and most of these studies focused on racial disparities between African-Americans and

Caucasian or Hispanic women (Kaufman *et al.*, 2003; Masi *et al.*, 2007; Messer *et al.*, 2006a; O'Campo *et al.*, 2008; Pickett *et al.*, 2002). Messer et al. and Kaufman et al. found that living in less deprived or higher income neighborhoods was associated with an increased risk of PTB among African-American but not Caucasian women (Kaufman *et al.*, 2003; Messer *et al.*, 2006a). Masi et al. concluded that living in an economically disadvantaged neighborhood put African-American women, but not Caucasian or Hispanic women, at an increased risk of having a PTB (Masi *et al.*, 2007). O'Campo et al. reported the association between neighborhood deprivation and risk of PTB in both African-American and Caucasian women (O'Campo *et al.*, 2008). Pickett et al. indicated that African-American women were at an increased risk of PTB if they lived in neighborhoods at the highest or the lowest ends of the median neighborhood income, whereas, living in neighborhoods at the extreme ends of high or low male employment was associated with decreased odds of PTB (Pickett *et al.*, 2002).

Neighborhood Deprivation Index and Birth Outcomes

Although the neighborhood factors have been associated with birth outcomes among many studies, the results can be difficult to interpret and compare because of the variety of indicators used to measure the neighborhood context. In 2006, Messer et al. developed a standardized Neighborhood Deprivation Index (NDI) to evaluate the neighborhood deprivation and reported the association between the index and adverse birth outcomes (Messer *et al.*, 2006c). Eight sociodemographic factors were chosen from the US Census 2000

data to weigh the final index. This approach was well accepted by the researchers in reproductive health, and the index was used and linked to several birth outcomes (Elo *et al.*, 2009; Janevic *et al.*, 2010b; O'Campo *et al.*, 2008). Elo et al. identified the association between the NDI and SGA. They reported that one standard deviation increase in the deprivation score was associated with 1.15 and 1.09 times the odds of SGA among non-Hispanic whites and non-Hispanic blacks, respectively. The association between neighborhood deprivation and SGA did not vary significantly by race/ethnicity (Elo *et al.*, 2009). The association between NDI and PTB was examined in O'Campo et al.'s study. They demonstrated that increased NDI was associated with increased risk of PTB. The associations were much stronger among non-Hispanic whites than among non-Hispanic blacks (O'Campo *et al.*, 2008). Based on the birth certificate data in New York City, Janevic et al. examined the effect of neighborhood deprivation on both PTB and LBW. Women in the highest quartile of NDI (most deprived) were more likely to give PTB births and term LBW births. The greatest magnitude of the association was found among Hispanic Caribbean women for PTB and among African women for LBW (Janevic *et al.*, 2010b).

Food Environment and Dietary Intake

Good nutrition is vital to good health, disease prevention, and essential for healthy growth and development of children and adolescents. The nutrition status of the individuals is not only influenced by their eating habits and dietary behaviors, but also determined by the neighborhoods in which they lived. Studies found that low-income and underserved communities often have limited access

to stores that sell healthy food, especially high-quality fruits and vegetables (Larson *et al.*, 2009b). Individuals living in such communities might have limited access to healthy food (Larson *et al.*, 2009b). In addition, rural communities often have a higher number of convenience stores, where healthy foods are less available and unhealthy foods are the main food options.

The neighborhood food environment has been associated with dietary intake and health outcomes (Bodor *et al.*, 2008; Franco *et al.*, 2009; Jago *et al.*, 2007; Laraia *et al.*, 2004; Larson *et al.*, 2009a; Moore *et al.*, 2008b; Morland *et al.*, 2002; Pearce *et al.*, 2008, 2009). However, a large number of Americans have limited access to healthy foods, especially those living in urban areas where there is a dearth of supermarkets (Morland *et al.*, 2002). In a study examining food environment and recommended dietary intake, Morland et al. found that fruit and vegetable intake increased 32% in black Americans for each additional supermarket in the Census tract. They also found an 11% increase for white Americans though the results were not statistically significant (Morland *et al.*, 2002). Based on a sample of 102 households, Bodor et al. found that better availability of fresh vegetables was associated with higher intake of vegetables, however, the better availability of fruits was did not improve the intake of fruits (Bodor *et al.*, 2008). Moore et al. confirmed the above associations between food environment and dietary intake for supermarkets by both GIS-based and survey of perception measures. They claimed that people with no supermarkets within 1 mile around their home were 25-46% less likely to have a healthy diet, and people living in the worst-ranked food environments were 22-35% less likely to

have a healthy diet than those in the best-ranked food environments (Moore *et al.*, 2008b). Prevalence of convenience stores and fast food restaurants were also found to relate to dietary intake. Jago et al. found that living far away from a small food store (convenience and drug store) was associated with increased fruit and juice and low fat vegetable consumption, while living near fast food restaurants was associated with increased high fat vegetable and fruit and juice consumption among adolescents (Jago *et al.*, 2007).

Measures of Food Environment

More and more studies have examined the effects of built food environment on health behaviors and outcomes in the past decade. How to characterize food environment is a challenge in research about food environment and health outcomes. Food environment measures could be grouped by dimension of food environment (availability, accessibility, and affordability), by methods of assessment (Geographic Information System (GIS), survey, store audit, and other), or by level of evaluation (neighborhood level and individual level). The main measures were summarized in **Table 2.1** by dimension of food environment and methods of assessment.

Food environment has three dimensions, availability, accessibility, and affordability of the food. Availability refers to the adequacy of the supply of healthy food. The examples might include the presence of certain types of food outlets around residents' homes, and sometimes the term is also used to describe the presence of healthier food within the stores (Caspi *et al.*, 2012). The

dimension of accessibility may be more inherently geographic, as it refers to the location of the food supply and ease of getting to that location taking account of resident transportation resources and travel time, distance, and cost. Affordability refers to the cost, and is often measured by store audits of specific foods, or regional price indices (Caspi *et al.*, 2012).

Most studies have characterized food environment using measures such as number of food outlets in the area, density of food outlets, and distance to specific food outlets based on geographic technique, i.e. GIS. More recently, questionnaires were used in the surveys to evaluate the food environment, in which perceptions of food environment could be measured to provide more subjective information (Moore *et al.*, 2008a; Moore *et al.*, 2008b). Compared to surveys on individuals, GIS was capable to define the food access in both individual- and neighborhood-level. Taking the studies among pregnancy and birth outcomes for example, individual-level food access include distance to the nearest special food outlet and number of food outlets around a special buffer size of the residence address (Laraia *et al.*, 2004). Neighborhood-level measures may include the density and number of type of food outlet in an area, i.e. in a Census tract (Farley *et al.*, 2006), and if there is a specific food outlet in the area (Lane *et al.*, 2008). Survey-based measures captured different dimension of the food desert. In some context, perception-based measures may be more efficient to capture the variation in food outlet availability and quality than other measures. However, perception-based measures are more likely to be affected by individual factors. Studies have compared the perception-based and GIS-based

characterizations of the local food environment and found that perceptions of food environment were reliable but not identical compared to GIS-based measurement (Echeverria *et al.*, 2004; Freedman *et al.*, 2009; Moore *et al.*, 2008a).

Community Food Access Measures

Improving access to healthy and affordable food is an explicit goal of several federal policy initiatives in the United States. These include the Healthy Food Financing Initiative (HFFI) which is a partnership of the Department of Agriculture (USDA), Department of The Treasury (Treasury), and Department of Health and Human Services (DHHS) ("Healthy Food Financing Initiative," 2011), and other initiatives such as the Pennsylvania Fresh Food Financing Initiative (FFFI) ("Pennsylvania Fresh Food Financing Initiative (FFFI)," 2010), and the initiatives from the Centers for Disease Control and Prevention (CDC) ("Communities Putting Prevention to Work," 2011). To identify areas eligible for these federal support initiatives, these agencies have developed different measures of community food access, including the food desert (FD) by USDA (Ver Ploeg *et al.*, 2009), healthier food retail tract by CDC ("Children's food environment state indicator report, 2011," 2011; "State indicator report on fruits and vegetables, 2009," 2009), and limited supermarket access area (LSA) by the Reinvestment Fund (TRF) ("Searching for markets: the geography of inequitable access to healthy & affordable food in the United States," 2012).

The term “food desert” was first used in the early 1990s in Scotland by a resident of a public housing sector scheme (Cummins *et al.*, 2002). In the United States, the Obama Administration released an over $400 million HFFI in February 2010 ("Healthy Food Financing Initiative," 2011), which aimed to bring grocery stores and other healthy food retailers to underserved urban and rural communities across US. The initiative is a partnership between the Departments of Treasury, Agriculture, and Health and Human Services. To identify areas eligible for this federal support initiative, HFFI group developed a spatial food access measure called food desert. The food desert is defined as a low-income Census tract where a substantial number or share of residents has low access to a supermarket or large grocery store ("Food Desert Locator documentation," 2010). A tract is considered as low-income if 20 percent or higher of residents live below the poverty line, or the tract’s median family income is less than or equal to 80 percent of the State-wide median family income, or the tract is in a metropolitan area and has a median family income less than or equal to 80 percent of the metropolitan area's median family income. A tract is considered as low-access if at least 500 people and/or at least 33 percent of the Census tract's population reside more than 1 mile (for urban tracts) or 10 miles (for rural tracts) from a supermarket or large grocery store ("Food Desert Locator documentation," 2010).

In March 2013, USDA ERS (Economic Research Service) uploaded the most recent version of low food access locator named the Food Access Research Atlas. Methods used to estimate low-income and low-access Census

tracts in new version are largely the same as methods used in previous estimates. However, there are several differences. First, the new analysis uses 2010 Census tract geography, while previous estimates used 2000 Census tract geography. Second, the 2010 analysis uses 0.5 kilometer-square grids to estimate distances from supermarkets, whereas the previous analysis used 1-kilometer-square grids. Third, a new method for designating whether a Census tract is urban or rural is used. In new version, the population-weighted centroid was used to designate a Census tract as urban or rural. Based on the new version of low food access locator, there are 29,134 low-income tracts, 28,328 low-access tracts, and 8,894 food-desert Census tracts (both low-income and low-access) in the continental US ("Food Access Research Atlas documentation," 2013).

In CDC's report "state indicator report on fruits and vegetables" in 2009 ("State indicator report on fruits and vegetables, 2009," 2009), they presented an indicator to evaluate the availability of healthier food retail in communities, "percentage of Census tracts that have healthier food retailers located within the tract or within 0.5 miles of tract boundaries". In the United States, about 72% Census tracts have healthier food retailers within the boundaries. Based on this percentage indicator, a community food access measure called non-healthier retailer tract could be defined as the Census tract that do not have healthier food retailers located within the tract or within 0.5 miles of tract boundaries. The healthier food retailers include supermarkets, large grocery stores, warehouse clubs and fruit and vegetable markets in this definition. However, compared to

USDA food desert discussed above, CDC non-healthier retailer tract focuses only on access to healthy stores rather than poverty/median income of the tracts. This food access measure is much easier to compute methodologically.

TRF defines the LSA areas as the areas in which residents must travel significantly farther to the nearest full-service grocery store than residents of areas showing similar population density and car-ownership characteristics as well as median household incomes greater than 120% of the area median ("Searching for markets: the geography of inequitable access to healthy & affordable food in the United States," 2012). An estimated 24.6 million Americans live in areas with inadequate access to supermarkets, according to TRF's 2011 LSA analysis ("Searching for markets: the geography of inequitable access to healthy & affordable food in the United States," 2012). No studies so far examined the effects of food desert on health outcomes, particularly on birth outcomes.

Food Environment and Birth Outcomes

Only one study to date has examined the association between food environment and diet quality among pregnant women (Laraia *et al.*, 2004). Laraia et al. found that proximity of supermarkets was positively associated with diet quality among pregnant women. In particular, they found pregnant women living greater than 4 miles from a supermarket were more than twice the odds of falling into the lowest compared to highest diet quality index tertile compared to women living within 2 miles of a supermarket, after controlling for individual

characteristics, other food retail outlets (Laraia *et al.*, 2004). Nutritional intake during pregnancy is important for fetal growth and development, and poor nutrition before and during pregnancy is associated with adverse birth outcomes (Mitchell *et al.*, 2004; Sram *et al.*, 2005; Wu *et al.*, 2004). Therefore, deprived food environment may cause adverse birth outcomes by affecting dietary quality. Food environment may also be related to health behaviors (smoking, alcohol and substance use, sexual behavior) (Gruenewald *et al.*, 1993; Turner *et al.*, 2004), stress (Laraia *et al.*, 2006), SES (income/wealth, employment, population composition and et al) (Hemphill *et al.*, 2008; Seliske *et al.*, 2009) and diseases risks (obesity, maternal diseases and infections during pregnancy) (Bodor *et al.*, 2010; Janevic *et al.*, 2010a), which may cause adverse birth outcomes as well.

However to date, the studies on food environment and birth outcomes were extremely limited (Farley *et al.*, 2006; Lane *et al.*, 2008). After merging birth data and existing sources on neighborhood SES, neighborhood physical deterioration, and neighborhood density of retail outlets selling tobacco, alcohol and foods, Farley et al. examined the relationship between adverse birth outcomes and neighborhood environment including retail outlets selling food. However, they did not identify any significant associations of gestational age or birthweight-for-gestational-age with density of alcohol outlets, tobacco outlets, fast-food restaurants or grocery supermarkets (Farley *et al.*, 2006). This may be because the researchers did not have appropriate measures of food environments in this study. Only one tract-level measure, density of food outlets, was used to estimate food access in the study. Density of food outlets in tracts

does not fully account for food access and the neighborhood analysis on this measure will ignore the variance between individuals. A later study by Lane et al. demonstrated a positive relationship that women living in proximity to a supermarket had significantly fewer LBW births than those living farther away. Similar to Farley's study above, the food environment in this study was also evaluated by tract-level measure (with or without supermarkets in the tract) (Lane *et al.*, 2008).

Racial Disparities on Adverse Birth Outcomes

Pregnancy and birth outcomes can vary greatly by maternal race/ethnicity. Black women have consistently worse outcomes than white women. Since 1940, mortality ratios among blacks have been at least three to four times higher than those for whites (Chang *et al.*, 2003). For risk of dying from complications of pregnancy only, the risk has consistently been 3-4-fold higher for black women (Callaghan, 2012). In 2009, the prevalence of pregnancy-associated hypertension was 46.1 per 1,000 live births for Non-Hispanic white compared to 50.2 per 1,000 live births for Non-Hispanic black. The rate of LBW was 7.2% for Non-Hispanic white and 13.6% for Non-Hispanic black in the United States in 2009. For PTB, Non-Hispanic white experienced a rate of 10.9% and Non-Hispanic black had a rate of 17.5% (Martin *et al.*, 2012).

However, the causes of this disparity are unclear so far (Lu *et al.*, 2003). A study showing that African-born black infants have similar birth weight to White-American infants strongly suggested that biological factor was not the

determinant for this racial difference in the United States (David *et al.*, 1997). Previous discussions about individual-level risk factors for adverse birth and pregnancy outcomes, such as SES, risky behaviors, prenatal care, and stress have identified that these factors could not account for the racial disparities in pregnancy and birth outcomes (Goldenberg *et al.*, 1996; Lu *et al.*, 2003). In the past decade, more and more studies have investigated the effects of neighborhood factors on racial difference of birth outcomes (Grady, 2006; Janevic *et al.*, 2010b; Love *et al.*, 2010; Messer *et al.*, 2008; Pearl *et al.*, 2001). With multilevel modeling techniques, these studies examined both individual- and neighborhood-level factors on birth outcomes stratified by race (Gorman, 1999; Pearl *et al.*, 2001; Rauh *et al.*, 2001). After adjusting individual-level risk factors, Pearl et al. found that less-favorable neighborhood socioeconomic characteristics were associated with lower birth weight among Blacks and Asians but not among Whites, US-born Latinas, or foreign-born Latinas (Pearl *et al.*, 2001). Grady et al. demonstrated that residential segregation and neighborhood poverty are important determinants of racial disparity in LBW in New York City (Grady, 2006). With 158,174 singleton births in the US, Rauh et al. identified that older maternal age is associated with reduced birth weight among infants born to African American women (Rauh *et al.*, 2001). In addition, previous studies indicated the racial differences in access to fast food (Dunn *et al.*, 2012) or healthy food (Bader *et al.*, 2010). The studies found that non-whites tend to exhibit greater access to fast food, higher consumption of fast food meals and worse access to healthy food (vegetables and fruits) compared to their white counterparts. Therefore, the

racial difference on the association between food environment and adverse birth outcomes needed to be understood. However to date, no studies have examined the racial difference of the association between food environment and birth outcomes.

Table 2.1 Food environment measures by dimension of access

Dimension	**Assessment**	**Measures**
Availability	Survey	Perceived health food availability (neighborhood or store)
	Store audit	Shelf-space
		Product-availability
		Variety of product
	GIS	Store presence
		Store density
		Store variety
	Other	Informant report
		Opening of a new store
Accessibility	Survey	Perceived access to healthy food
	GIS	Distance to the store
		Travel time to the store
Affordability	Survey	Cost/affordability
	Store audit	Price
	Other	Regional food price index

GIS, geographic information system.

CHAPTER 3

Methods

Study Area

Data from all births from 2008-2009 in South Carolina were used to identify the association between food desert (neighborhood income and community food access) and birth outcomes (**Chapter 4**) and the association between neighborhood deprivation and adverse birth (**Chapter 6**). Geographically, there are 867 Census tracts in South Carolina according to Census 2000. When it comes to the individual-level analysis (accessibility and availability of food outlets and birth outcomes in **Chapter 5**), the study area included eight contiguous counties in the midlands region of South Carolina (**Figure 3.1**). This eight-county area was chosen because the ground-truthed food outlet data are only available in these counties. In the eight counties, there is one urban county (Richland) and seven rural counties (Calhoun, Chester, Clarendon, Fairfield, Kershaw, Lancaster, and Orangeburg). The eight-county area approximately covers a total of 5,575 square miles and a population of more than 620,000 (15% of South Carolina's total population). Based on Census 2000, there are 150 Census tracts in the eight-county study area.

Study Design

All three studies were cross-sectional studies. For **Specific Aim 1** & **3** in which association will be estimated between mothers' residential neighborhood areas (food desert dimension or neighborhood deprivation) and birth outcomes, the analysis was multilevel with exposures in Census tract-level and with outcomes in individual-level. In **Specific Aim 2**, the analysis was individual-level. In these three studies, the outcomes were all birth outcomes including birth weight (or LBW) and gestational age (or PTB). In **Specific Aim 1**, the exposure was neighborhood income (low or high), community food access (low or high), and combination of these two measures (high-income and high-access, low-income and high-access, high-income and low-access, and low-income and low-access). Low-income and low-access tract was the food desert. In **Specific Aim 2**, the exposures included the accessibility (distance from mother's home to the nearest food outlet) and availability (number of food outlets within 1-mile buffer around mother's home) of food outlets. For **Specific Aim 3**, the exposure was neighborhood deprivation defined by the NDI.

Food Outlet Data

Community food access in the South Carolina State (**Specific Aim 1**) and the mothers' access to food outlets in eight-county study area (**Specific Aim 2**) were needed to be evaluated. To estimate these food access measures, food outlet data (number, type and location) were essential. In this study, three data sources were used, including the ground-truthed food outlet data for the eight-

county study area, InfoUSA (Omaha, Nebraska), and the Licensed Food Services Facilities Database (LFSFD) from the DHEC for the areas out of the eight-county area in the state.

The ground-truthed foot outlet data were from a previous field census study led by Liese et al. which was designed to verify three readily available food outlet databases within an eight-county region of South Carolina, including InfoUSA, Dun&Bradstreet (D&B) (Short Hills, New Jersey), LFSFD from SC DHEC (Liese *et al.*, 2010). At first, the data from these three databases were merged and cleaned by name and address, and then ineligible outlet types and duplicates were removed. Then, starting with the merged database, the field census was conducted to verify the presence and location of each food outlet in the merged list to identify new and unlisted outlets by a global positioning system (GPS) device. In total 114 trips entailing 7,000 miles ground-truth verification were performed from September 2008 to July 2009 and all the food outlets within the study area were located and verified. In the end, a total of 2,745 outlets were verified in the field census and a total of 2,208 outlets were verified and open. Among these verified food outlets, there are 160 supermarkets, supercenters, grocery stores, and warehouse clubs (SSGW), 504 convenience stores, 120 dollar stores, 659 limited service restaurants, 650 full service restaurants, 79 drug/pharmacy stores, and 36 specialty stores. The type of food outlet was assigned based on North American Industry Classification System (NAICS) codes ("Economic Classification Policy Committee. North American Industry Classification System (NAICS)," 2012) with additional refinements including a

name-based algorithm and knowledge of food outlet from internet or calling the stores. In this eight-county food environment dataset, all open stores were geocoded from the verified addresses. This dataset could be considered as a gold-standard data source about food outlets within the eight counties to date, because all the food outlets in the dataset were verified through field census. The validity and reliability of this dataset have been found to be the best compared to other commercial and agency datasets, i.e. InfoUSA, D&B, and DHEC database (Liese *et al.*, 2010).

However, the ground-truthed data were only available in eight-county area. In **Specific Aim 1**, food outlet data outside eight-county area were needed. We used secondary food outlet data to compensate the missing of gold-standard data on food outlets. Studies showed that the combination of secondary food outlet data sources improved the validity of the data (Liese *et al.*, 2010). Thus, we combined two secondary data sources (InfoUSA and DHEC LFSFD) to achieve the best estimation of the food environment in the areas.

InfoUSA is a readily available secondary commercial datasets from InfoUSA, Inc.. Most previous epidemiological studies relied on this dataset to estimate the availability and proximity of certain types of food outlets (Larson *et al.*, 2009b). InfoUSA listings were queried for specific NAICS codes corresponding to facilities that sell food. These include supermarkets and other grocery stores retailing a general line of food (445110), convenience stores (445120), pharmacies and drug stores (446110), gas stations with convenience stores attached (447110), other gas stations (447190), discount department

stores or dollar stores (452112), warehouse clubs (452910), supercenters (452910), all other general merchandise stores (452990), specialty food stores (e.g. meat (445210), fish (445220), fruit/vegetable (445230) markets, bakeries (445291), confectionery (445292) or other specialty stores)), all other miscellaneous store retailers except tobacco stores (453998), full service restaurants (722110), commercial cafeterias (722212), limited service restaurants (722211), and snack & nonalcoholic beverage bars (722213). The InfoUSA listings contained two NAICS codes per food outlet.

The LFSFD from DHEC lists all facilities that sell prepared foods in SC. The LFSFD was queried for NAICS code 206 (foodservice facilities) and 211 (grocery stores). Because the study led by Liese et al. was focus on the retail food environment, the following types of outlets were ineligible: sporadic or temporary food vendors at sports stadiums or theme parks, outlets that serve special populations (e.g. cafeterias in schools or nursing homes, assisted living facilities or institutionalized settings, military settings, and catering businesses without a retail store). They further excluded alcoholic beverage drinking places (722410) and liquor stores (445310) (Liese *et al.*, 2010).

In **Specific Aim 2**, we added a 10-mile buffer around the boundary of the eight-county study area to accurately estimate the food access of the women living in the edge areas. For the 10-mile buffer areas, we also used the combination of the InfoUSA and DHEC LFSFD as the food outlet data source.

South Carolina Birth Certificate Data

National birth registration was proposed in 1850 and established in 1915. By 1933, all 48 states and the District of Columbia participated in the birth registration. The US birth certificate includes national standard items and state-specific items. The version of birth certificate has been revised periodically by national vital statistics agency, most recently in 1989 and 2003. Birth certificate data are an important resource for researchers, policy makers, and state officials to evaluate the quality of care being delivered to pregnancy women.

In this study, all live-birth certificates from January 1, 2008 to December 31, 2009 were requested from the SC DHEC. Each live-birth certificate includes information in mother's characteristics (age, marital status, education, race, ethnicity, height, weight before pregnancy and at delivery) and father's characteristics (age, education, race, and ethnicity), maternal risk factors (prenatal care, number of previous live births, smoking, diabetes and hypertension, infections, characteristics of labor/deliver), and newborn's characteristics (sex, birth weight, obstetric estimate of gestation, APGAR score, plurality, abnormal conditions, and breastfeeding). Due to the restriction on data release by the state law, marital status and father-related variables were not released by SC DHEC. Because the geographic information was needed for the mothers (Census tract ID for **Specific Aim 1 & 3** and home address for **Specific Aim 2**), the mothers without residential information were not included in this study. Because of the restriction on data release and security, the mothers' home addresses could not be released to us. Thus in **Specific Aim 2**, the calculations

of the individual food access measures based on the locations of the mothers were performed by the staff in SC DEHC. In the end, the only geographic identifier in our birth certification data was Census 2000 tract code, which was used to link with food outlet data (**Specific Aim 1**) and Census 2000 data (**Specific Aim 3**).

According to the South Carolina Community Assessment System (SCAN) ("South Carolina Community Assessment System (SCAN) birth certificate tables ", 2012), there were 123,759 and 18,963 births in whole South Carolina State and the eight-county study area, respectively from 2008 to 2009. **Table 3.1** shows the characteristics of all births in South Carolina and **Table 3.2** shows the characteristics of the birth in the eight-county study area. In the South Carolina, approximately 65% of births were non-Hispanic white. While in the eight-county area, about 51% of births were non-Hispanic black. Most mothers aged in the range of 20-29 years old. Approximately half of the mothers were not married when gave the births. The prevalence of LBW was about 10% and 12% among all births in South Carolina and the eight-county study area, respectively. The prevalence of PTB was about 12% in both whole state and eight-county area. Despite only one urban county (Richland) among eight-county area, approximately 54% mothers of the eight-county study area lived in this urban county.

The data flow of birth certificate was illustrated in **Figure 3.2** (whole state) and **Figure 3.3** (eight-county area). In whole South Carolina state (**Figure 3.2**), we removed 8,160 births with the geographic information in Tier 3 or below

(larger than Census tract) from the total births from 2008-2009 (N=123,759). Because plurality has been identified as a strong predictor for LBW, SGA, and PTB, we focused only on singletons in this study (4,006 twins were excluded). In the end, we excluded 13,137 mothers in other race groups, and 98,456 (80%) non-Hispanic white and black mothers were included in the final analysis. In the eight-county study area (**Figure 3.3**), we excluded 1,077 with Tier 3 or below geographic information, 22 with bad network (failing to compute the distances), 23 with bad boundary of Census tracts (failing to link to Census data), 635 twins, and 1,420 in other race groups. Finally, 15,786 (83%) entered the final analysis.

The number and proportion of missing data were summarized in **Table 3.3** for all singleton births in whole state and eight-county area. According to the table, the missing data were sparsely represented in demographic variables, maternal education, prenatal care, previous live birth, birth weight and gestational age. Approximately 1.25% to 8.00% of the births were with missing data on other variables. The Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) participation, body mass index (BMI), and smoking pre-pregnancy had the highest percentage of missing ranged from 6.25% to 8.00% in whole state and 5.47% to 6.32% in eight-county area. During the statistical analysis, we excluded the births with missing data on outcomes and exposures in the model. For covariate factors, we excluded the births with less than 1% missing data on the variables. If the percentage of missing was more than 1% in the covariate, we coded the births with missing data as a separate subgroup in the covariate. In this way, we tried to retain the highest sample size in the analysis. Because we

have a huge sample size in this study, the missing data did not influence the results significantly. As a sensitivity analysis, we re-estimated the analysis excluding all the births with missing data, and none of the inference of the study changed.

2000 US Census Data

In **Specific Aim 1 & 3**, US Census 2000 data were used to define USDA food desert and the NDI, respectively. When defining USDA food desert measure, the population and demographic data were readily available to use from the U.S. Census 2000. Household income was obtained from Census 2000 Summary File 3 ("US Census 2000 data: Summary File 3 (SF 3)," 2011). Additionally, 1km x 1km gridded population data were obtained. These data were downloaded from the Socioeconomic Data and Applications Center (SEDAC) hosted at Columbia University (Seirup *et al.*, 2006). Eight Census tract-level sociodemographic variables were used to define the NDI in South Carolina, including % males and females with less than high school, % males and females unemployed, % males in management occupations, % crowded housing, % household in poverty, % female head with child, % households earning <$30,000/year, % households on public assistance (Messer *et al.*, 2006c). All these variables were calculated based on SF3 data in Census tract-level ("US Census 2000 data: Summary File 3 (SF 3)," 2011).

USDA Food Desert

USDA food desert was used as the exposure variable to evaluate community food access in **Specific Aim 1**. There are two components in USDA food desert measure, low neighborhood income and low community food access. Low neighborhood income is defined as a poverty rate in the tract of at least 20 percent, or a median family income in the tract of less than 80 percent of statewide median family income in non-metropolitan areas. Low community food access was defined as at least 33 percent of the tract's population or a minimum of 500 people in the tract with low access to a supermarket or large grocery store. In the analysis in **Specific Aim 1**, at first, we defined the two components of USDA food desert separately. To identify the effect of food desert, we then created a four-level variable by the interaction of the two components, including high-income and high-access, low-income and high-access, high-income and low-access, and low-income and low-access (food desert) areas. All the exposure variables in **Specific Aim 1** were in Census tract-level.

The procedure of computing USDA food desert measure was summarized in **Figure 3.4**. At first, we identified the low income Census tracts. Then, polygonal 1km x 1km SEDAC population grids were used to evaluate distance to supermarkets or grocery stores. To examine the distance, we converted the SEDAC grids to point data using a centroid approach retaining the SEDAC population estimates of all people living within each grid cell (Seirup *et al.*, 2006). Distance from each SEDAC grid cell centroid to the nearest food outlet was

calculated in miles using Euclidean (straight-line distance) and network (shortest street distance) approaches. For network distance, street centerlines from Streetmap Premium (ESRI, 2011) based on commercial street centerline data from NAVTEQ and Tom Tom were used. Distances were calculated using the Network Analyst (ESRI, 2011) extension for ArcGIS. Low access was evaluated differently according to USDA guidelines for urban and rural areas ("Guidelines for using rural-urban classification systems for public health assessment," 2009). Urbanicity was determined by the intersection of tract centroids with Census-designated urban areas. A tract was considered “urban” if its centroid fell within an urban area, otherwise the tract was considered to be “rural.” SEDAC population data points located in low income tracts that exceeded a threshold distance of 1 mile (urban) or 10 miles (rural) were summed within their corresponding tract boundary to obtain a total population of low access individuals.

The mothers were assigned to various areas (high or low neighborhood income, high or low community food access, and the interaction of these two components) by the Census tract ID. All the procedures of USDA food desert designation were performed by ArcGIS software (version 10.0, ESRI).

Accessibility and Availability of Food Outlets

In **Specific Aim 2**, the exposures are accessibility and availability of food outlets. Specifically, they included the distance to the nearest certain type of food outlets and the density of certain type of food outlets within 1-mile buffer around a

mother’s resident address. We included three types of food outlet in the study, healthy food outlet, convenience store, and limited service restaurant. The healthy food outlet consists of supermarket, supercenter, grocery store and warehouse club. In the eight-county study area plus the 10-mile buffer zone around the boundary discussed above, there are 243 healthy stores, 504 convenience stores, and 971 limited service restaurants according to the food outlet data (**Table 3.4**). Both the Euclidean distance (straight line distance between two points) and network distance (distance along the street network) were calculated from each mother’s home address to the nearest various types of food outlets. A 1-mile buffer was added around each mother’s home, and the number of each type of food outlets was summarized. The distances to the nearest and number of food outlets were calculated by the GIS experts in DHEC due to the concern of data security discussed above. After the calculation by the GIS expert, all the identifiers and individual home address information will be removed from the final dataset.

Neighborhood Deprivation Index

In **Specific Aim 3**, the NDI was used to evaluate the neighborhood deprivation in this study. The development of NDI was based on the algorithm presented in Messer et al.’s study in 2006 (Messer *et al.*, 2006c). Eight Census tract-level sociodemographic variables were computed based on the Census 2000 data ("US Census 2000 data: Summary File 3 (SF 3)," 2011). The eight variables included % males and females with less than high school, % males and

females unemployed, % males in management occupations, % crowded housing, % household in poverty, % female head with child, % households earning <$30,000/year, % households on public assistance. The first principal component analysis (PCA) was used to create the NDI using these eight variables. Although it is possible to form as many independent linear combinations as there are variables, we retained only the first principal component, which is the unique linear combination that accounted for the largest possible proportion of the total variability in the component measures (Tabachnick *et al.*, 1996). The NDI was then predicted using the loadings of the eight variables in the first principal component. The predicted NDI was standardized with mean of 0 and standard deviation (SD) of 1. The standardized NDI was then coded into categorical quartiles to allow for potential dose response relations and to avoid linearity assumptions in the association of deprivation and birth outcomes.

Birth Outcomes

There were four outcome measures including birth weight in grams, LBW coded in yes or no, gestational age in weeks, and PTB coded in yes or no. In **Specific Aim 3**, only LBW and PTB were used as adverse birth outcomes. All these variables were from the birth certificate data. The LBW was determined as the recorded weight at birth of less than 2,500 grams. The PTB will be defined as gestational age less than 37 weeks (259 days). The birth weight and gestational age were treated as continuous variables, and the LBW and PTB were treated as dichotomous variables during analysis.

Confounders, Effect Modifiers, and Mediators

The Directed Acyclic Graph (DAG) of this study was summarized in **Figure 3.5**. In the DAG, individual sociodemographic factors such as maternal age, maternal education, race, urbanicity and WIC participation could influence food environment and neighborhood deprivation. Neighborhood characteristics may cause birth outcomes directly or via various pathways including smoking, obesity, dietary intake, chronic disease (hypertension and diabetes mellitus), and maternal risk factors (prenatal care, previous live birth, previous preterm birth, previous other outcome, infection, etc.). In the DAG, we usually did not adjust the factors caused by the exposure variable (Fleischer *et al.*, 2008). Thus, we did not adjust these factors in the multivariate regression models. The sociodemographic factors were associated with both exposures and outcomes and did not stand in the pathways. Therefore, we controlled those factors in the models as the confounders. According to the DAG, several factors, such as smoking, obesity, hypertension and diabetes (absence of work by the diseases) could impact health and in turn impact the income (using WIC to estimate in my study). However, if the income (WIC) has been controlled, we did not need to control these factors. In the end, we need only to adjust maternal age, maternal education, race, urbanicity and WIC participation in the models.

Previous studies suggested potential interactions between race and neighborhood characteristics when predicting birth outcomes. In this study, no interactions were found between race and food environment measures in

Specific Aim 1 & 2. Thus, race was considered as a confounder variable in these two studies. In **Specific Aim 3**, race was found to be an effect modifier between neighborhood deprivation and adverse birth outcomes, so all the analyses were stratified by race in that study. No effect modification was found for urbanicity between exposures and birth outcomes in all three manuscripts.

In **Specific Aim 3**, we generated the propensity scores for all mothers with NDI as the dependent variable and all potential covariates in birth certificate data as the independent variables. To obtain the best prediction of propensity score, we included as many as possible variables in the models. Thus, all above mentioned covariates were included.

In summary, the covariates in this study included maternal age (years), maternal education (high school, some college, and bachelor or above), race (non-Hispanic white and non-Hispanic black), urbanicity (urban, rural), BMI (<25, 25-30, >30), WIC participation (yes, no), prenatal care (within 1^{st} trimester, >1^{st} trimester), number of previous live birth (n), smoking during pregnancy (yes, no), previous preterm birth (yes, no), previous other outcome (yes, no), vaginal bleeding (yes, no), chronic and gestational diabetes and hypertension (yes, no), infection during pregnancy (yes, no), birth gender (male, female). Urban areas were defined as the Rural Urban Commuting Area (RUCA) code equals 1 (urban core). All other RUCA codes (sub-urban, large rural town, small town/isolated rural) were defined as rural area ("Guidelines for using rural-urban classification systems for public health assessment," 2009). Dummy variables were created for categorical variables with more than two subgroups.

Edge Effects

Edge effects are boundary effects that originate from the ignorance (through unknown or missing data) of interdependences that occur outside the bounded region. Edge effects may mitigate through the use of guard areas, which include or exclude existing data along the boundary of a region. To account for potential edge effects when evaluating accessibility and availability of food outlets in **Specific Aim 2**, a 10-mile guard area was established beyond the original eight-county study area by creating a buffer within a GIS. The above verified food environment dataset in the eight county study region was supplemented with contemporaneous supermarket location data outside the study region and the analyses re-run. This supplementary dataset originated as two datasets (InfoUSA and LFSFD) which were merged, de-duplicated, and cleaned.

Regression Models and Multilevel Analysis

More and more studies have analyzed data in complex multilevel structures. Individuals from these studies are grouped together in communities or institutions or neighborhoods. An understanding of appropriate analytical methods is important for analyzing such data. Single level models are usually inappropriate for such data because they assume all outcomes are independent and thus underestimate standard errors which increase type II error (Osborne, 2000).

Because the live births are clustered together in a neighborhood setting (e.g. Census tracts) in this study, multilevel analysis will be performed to examine the effects of community food access (**Specific Aim 1**) and neighborhood deprivation (**Specific Aim 3**) on birth outcomes. The multilevel analysis will also allow us to adjust covariates in different levels (Rabe-Hesketh *et al.*, 2008). In **Specific Aim 1**, multilevel linear regression models were used for birth weight and gestational age, and multilevel logistic regression models were used for LBW and PTB. In **Specific Aim 3**, we focused only on adverse birth outcomes (LBW and PTB), thus multilevel logistic regression models were utilized. Both of a multilevel model with a random effect and a marginal model were appropriate for this study. I prefer to infer results from a multilevel model with a random effect because (1) the coefficients from random-effect multilevel models were easier to interpret than those from marginal models, and (2) the random-effect multilevel model was recommended if the aim was estimation of the effects of neighborhood-level risk factors (such as community food access and neighborhood deprivation) while adjusting for between neighborhood heterogeneity as focused on this study. However, these two models were not significantly different and both of them provide appropriate effect estimates for studies with two-level data.

In all regression models, we performed the analysis in following steps. First, an ordinary logistic regression model will be used to estimate the unadjusted relationship between the exposures and birth outcomes. Indicator variables were created for levels of categorical exposure variables with more

than two subgroups (combination of two components of USDA food desert in **Specific Aim 1**, the number of food outlets within 1-mile buffer in **Specific Aim 2**, and NDI quartiles in **Specific Aim 3**) with the first subgroup as the reference group. Second, we added demographic factors (maternal age and race) in the models. In the final step, SES factors were additionally adjusted in the models in step two including maternal education (indicator variables were created for education), WIC participation, and urbanicity. Because the covariates in **Specific Aim 1 & 3** were in two different levels (tract-level and individual-level), regression models with a random effect were used in these studies. In **Specific Aim 2**, individual-level regression models were used.

All regression analyses were performed using Stata (version 12, College Station, TX). The random-effect regression models were estimated with Stata's xtregress and xtlogit command for continuous and dichotomous outcomes, respectively. P<0.05 was set as the significance level.

Propensity Score Matching

Observational epidemiological studies are always troublesome due to the potential for confounding, a condition which implies improper comparisons and potentially biases effect estimates. Covariance adjustment through regression models has long been the principal tool to deal with the confounding. However, the regression models are too easy to abuse. In general, the most pressing concerns with regression models are omitted variable bias and off-support inference (Oakes *et al.*, 2006). Omitted variable bias means failing to measure

and adjust for all confounders. Off-support inference refers to extend inference beyond the bounds of the data. In the regression models, the parameter estimates may be based not only on comparisons between actual observations but also on extrapolation, interpolation, regression smoothing, and imputation etc. The inferences based on off-support data or imputed data could cause bias during statistical analysis.

In studies about neighborhood characteristics and birth outcomes, the SES factors as well as racial composition were dramatically different between individuals living in deprived and in non-deprived neighborhoods. When these variables were adjusted in the regression models, there might cause no actual data in some subgroups. In this situation, the inferences from regression models might be based on off-support or imputed data (Messer *et al.*, 2010).

Matching is a standard alternative to regression models to control confounding. Because each matched pair represents an (un)exposed subject and its counterfactual substitute, causal contrasts are easily computed. Usually, matching was on several key confounders. However, the propensity score matching (PSM) method could simultaneously match the subjects on many covariates to mimic randomization in observational study designs.

PSM methods were introduced by Rosenbaum and Rubin in 1983 (Rosenbaum *et al.*, 1983). A propensity score is defined as the conditional probability of being exposed or treated (or both) (Rosenbaum *et al.*, 1983, 1984). The propensity score reduces the dimensionality of a large set of potential confounders to unity, and this is conducive to simple pair matching (Oakes *et al.*,

2006). After the exposure groups were matched by propensity score, the exposure groups have been balanced on all relevant and available covariates. In this way, we reduce the observable bias while maintaining the support of the data. In **Specific Aim 3**, we used logistic regression to estimate the predicted probability of a mother's exposure to neighborhood deprivation given the confounders discussed above for the mothers. We then matched the mothers with the same predicted probability of exposure (i.e. propensity score) to neighborhood deprivation-only some were actually exposed and some were not-by using the psmatch2 module in Stata. The exposed mothers were matched 1:1 with replacement to unexposed mothers with the same predicted probability of exposure to neighborhood deprivation within a range of ±0.01. Balance tests were performed to compare the means and % bias prior to and after matching, and % bias reduction, with a goal of a % bias reduction of less than 10% indicating sufficient balance. The % bias is the percentage difference of the sample means in the deprived and reference group as a percentage of the square root of the average of the sample variances (Rosenbaum *et al.*, 1985). The different prevalence of adverse birth outcomes (LBW and PTB) were computed as the average effect of the treatment on the treated. Bootstrap method with 1,000 repetitions was used to calculate the 95% confidence intervals (95% CI).

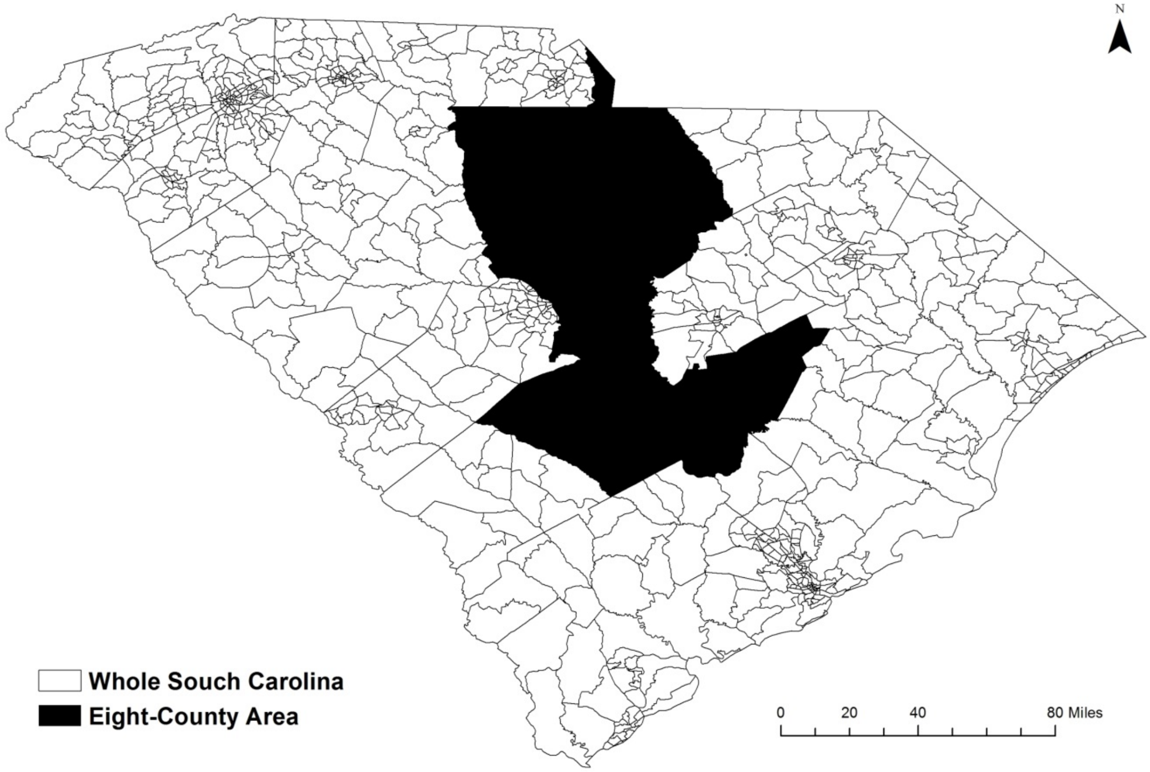

Figure 3.1 Study area

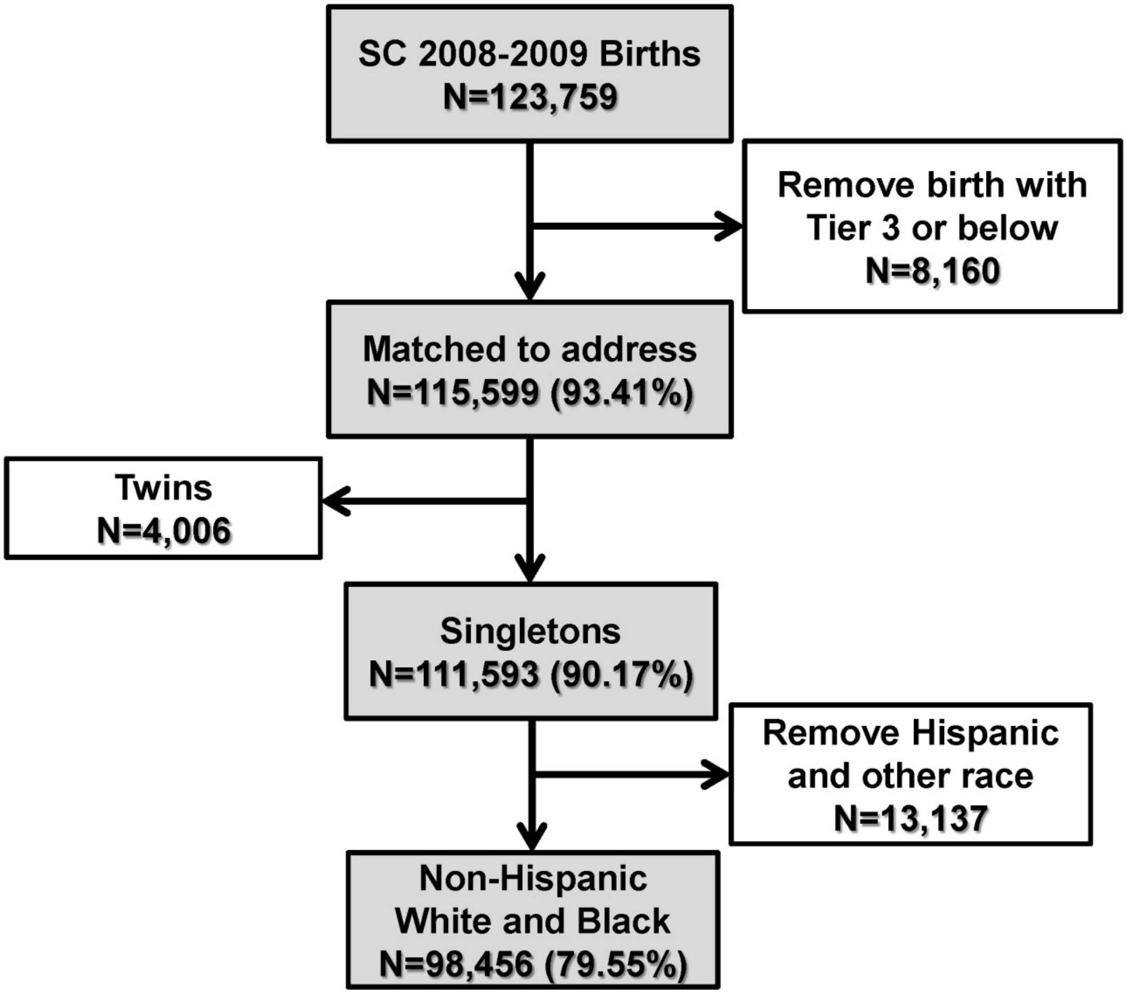

Figure 3.2 Birth certificate data flow for birth in South Carolina

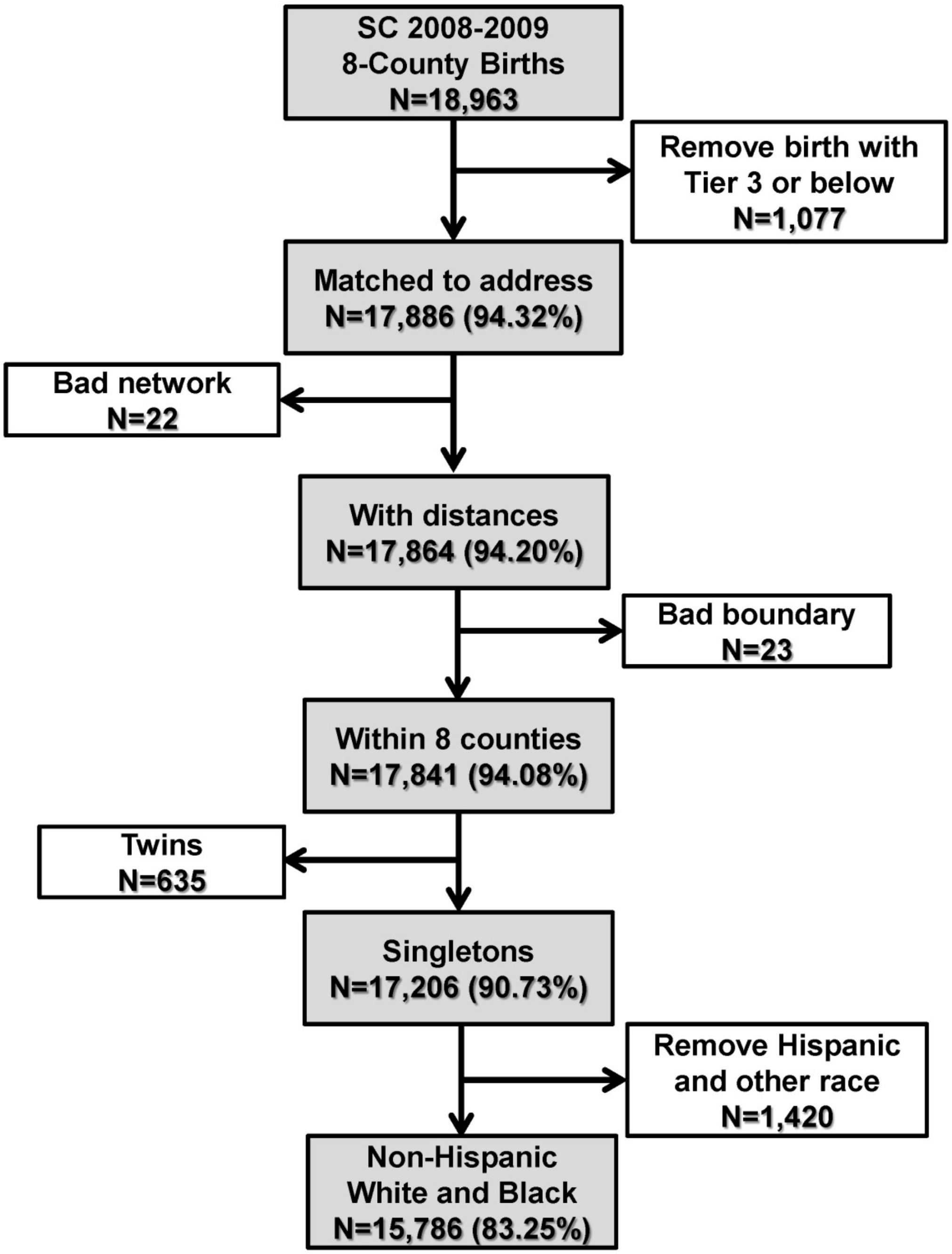

Figure 3.3 Birth certificate data flow for birth in eight-county in South Carolina

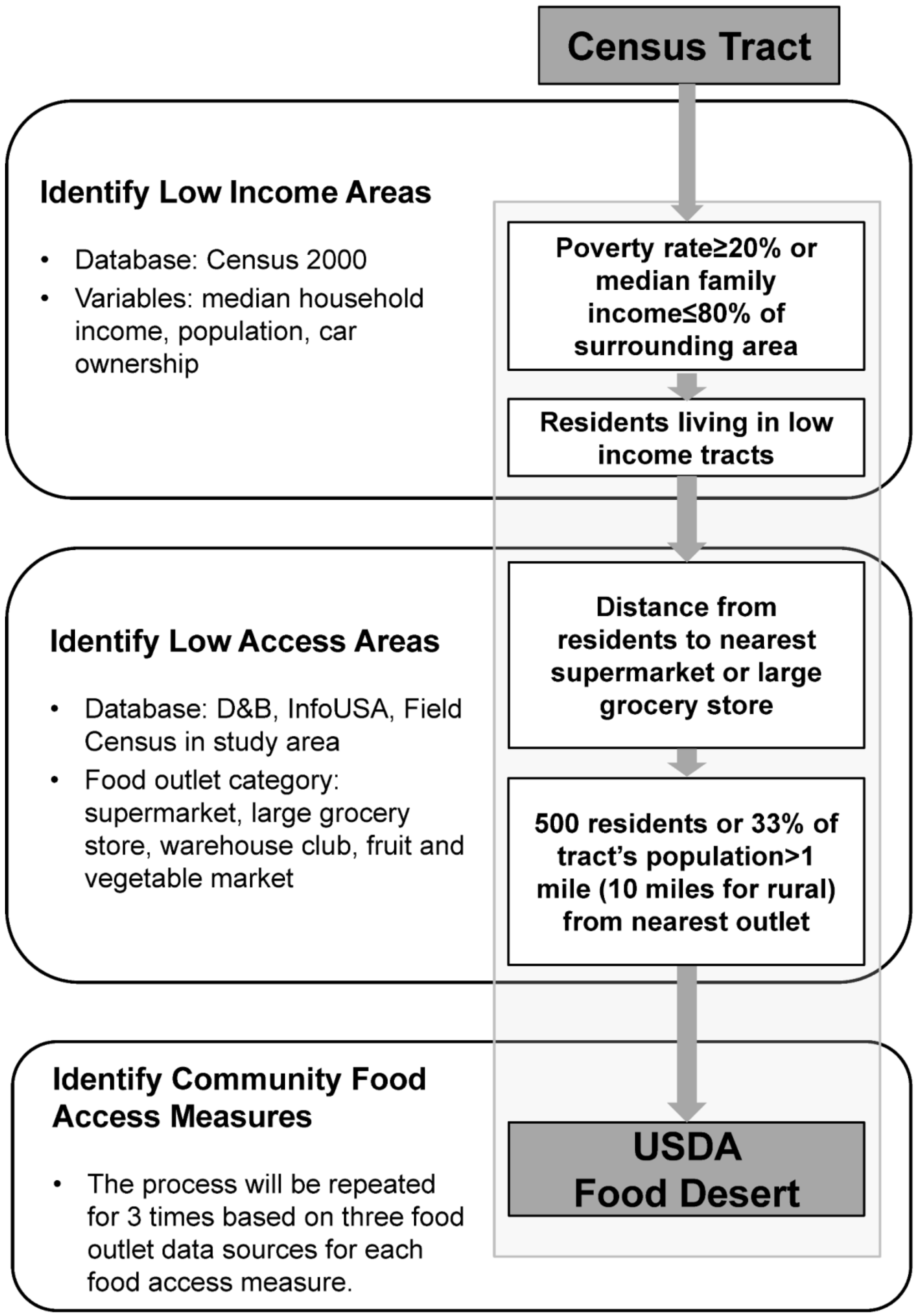

Figure 3.4 Diagram of data flow of USDA food desert designation

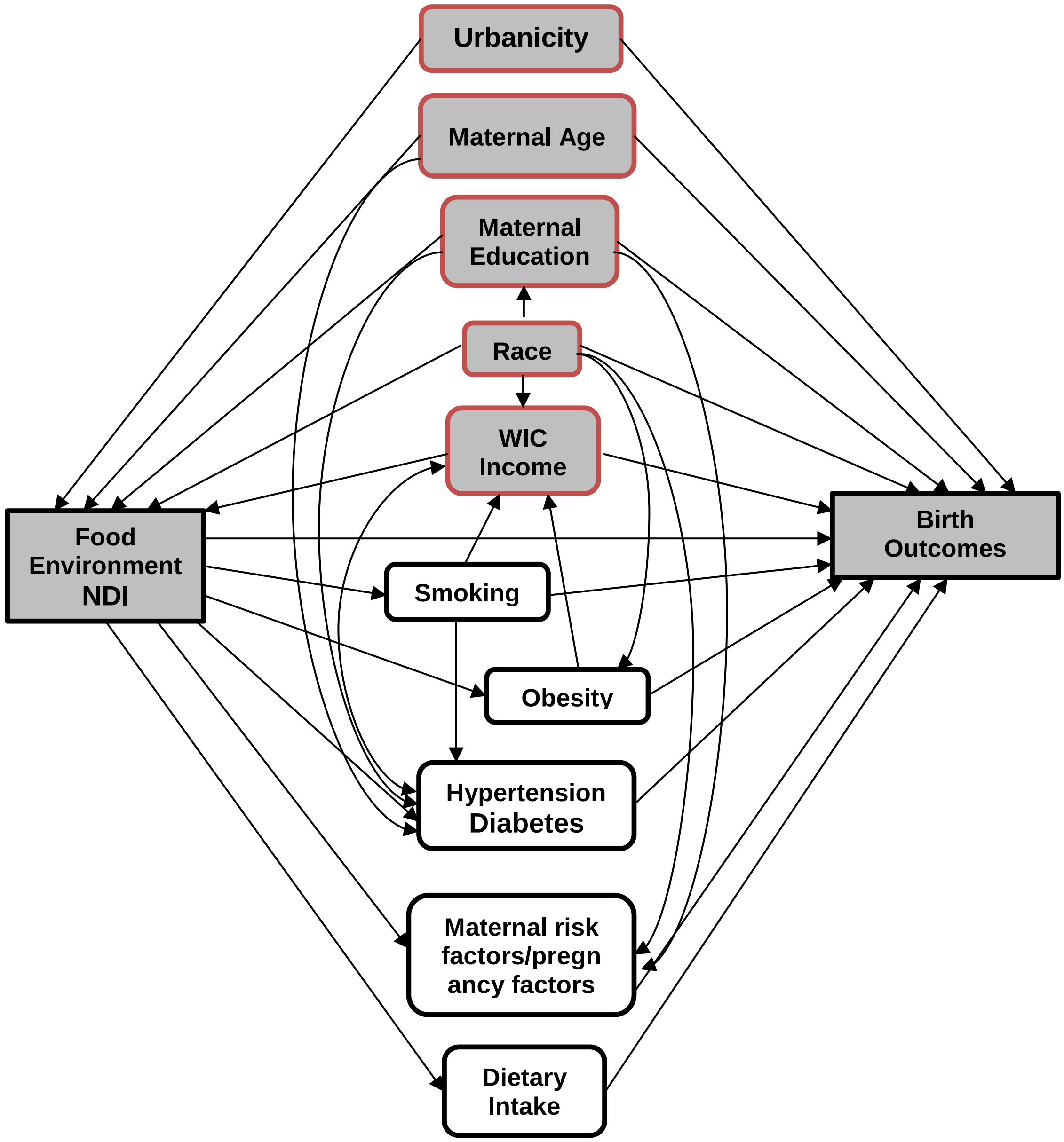

Figure 3.5 Directed Acyclic Graph in the study

Table 3.1 Characteristics of live births in South Carolina (N=123,759)

Characteristics	Number (N)	Proportion (%)
Race		
White	80,061	64.7
Black	40,752	32.9
Others	2,853	2.3
Unknown	93	0.1
Ethnicity		
Hispanic	11,786	9.5
Non-Hispanic	111,910	90.4
Unknown	63	0.1
Maternal Age, Year		
10-14	195	0.2
15-17	4,721	3.8
18-19	11,227	9.1
20-24	35,714	28.9
25-29	34,717	28.1
30-34	23,834	19.3
35-39	11,092	9.0
40-44	2,110	1.7
>45	145	0.1
Unknown	4	0.0
Marital Status		
Married	64,595	52.2
Not Married	58,273	47.1
Unknown	891	0.7
Birth Weight, Grams		
0-1249	1,628	1.3
1250-1499	663	0.5
1500-2499	10,004	8.1
2500-3999	103,236	83.4
>4000	8,123	6.6
Unknown	105	0.1
Gestational Age, Week		
1-31	2,469	2.0
32-36	12,062	9.7
37-41	108,834	87.9
≥42	312	0.3
Unknown	82	0.1
Year		
2008	63,077	51.0
2009	60,682	49.0

Table 3.2 Characteristics of live births in eight-county area (N=18,963)

Characteristics	Number (N)	Proportion (%)
Race		
White	8,773	46.3
Black	9,736	51.3
Others	439	2.3
Unknown	15	0.1
Ethnicity		
Hispanic	1,153	6.1
Non-Hispanic	17,805	93.9
Unknown	5	0.0
Maternal Age, Year		
10-17	740	3.9
18-19	1,721	9.1
20-24	5,449	28.7
25-29	5,286	27.9
30-34	3,656	19.3
35-39	1,739	9.2
40-44	348	1.8
>45	23	0.1
Unknown	1	0.0
Marital Status		
Married	8,767	46.2
Not Married	10,065	53.1
Unknown	131	0.7
Birthweight, Grams		
0-1249	262	1.4
1250-1499	102	0.5
1500-2499	1,716	9.1
2500-3999	15,908	83.9
>4000	970	5.1
Unknown	5	0.0
Gestational Age, Week		
1-31	380	2.0
32-36	1,906	10.1
37-41	16,635	87.7
≥42	34	0.2
Unknown	8	0.0
County		
Richland	10,187	53.7
Calhoun	353	1.9
Chester	885	4.7
Clarendon	787	4.2
Fairfield	514	2.7
Kershaw	1,627	8.6
Lancaster	1,890	10.0
Orangeburg	2,720	14.3

Table 3.3 Summary of missing data in birth certificate data

Variables	**SC State N=111,593**		**8-County N=17,206**	
	Missing	**%**	**Missing**	**%**
Mother's Age	3	0.00	1	0.01
Mother's Education	409	0.37	60	0.35
WIC Participation	6980	6.25	942	5.47
Mother's Weight at Delivery	4230	3.79	642	3.73
Mother's Weight	6030	5.40	709	4.12
BMI	7361	6.60	1021	5.93
Smoking Pre-pregnancy	8922	8.00	1088	6.32
Smoking During Pregnancy	4290	3.84	319	1.85
Mother Prenatal Care Begin	683	0.61	62	0.36
Previous Live Birth	648	0.58	7	0.04
Prenatal Visit Number	587	0.53	49	0.28
Other Pregnancy Outcome	1394	1.25	16	0.09
Previous Preterm Birth	3109	2.79	560	3.25
Previous Poor Outcome	3146	2.82	565	3.28
Previous Cesarean	3146	2.82	565	3.28
Vaginal Bleeding	5183	4.64	576	3.35
Gestational Hypertension	2974	2.67	531	3.09
Chronic Hypertension	5106	4.58	558	3.24
Gestational DM	3146	2.82	565	3.28
Diabetes Mellitus	3146	2.82	565	3.28

SC, South Carolina; WIC, women infants children; BMI, body mass index; DM, diabetes mellitus.

Table 3.4 Number of various types of food outlets in eight-county area

Food Outlet	**Number**
SSWC	178
Grocery Store	65
Convenience Store	504
Dollar Store	120
Pharmacy	79
Limited Service Restaurant	971

SSWC, supermarket, supercenter, warehouse club.

CHAPTER 4

Food Desert and Birth Outcomes:

Effects of Neighborhood Income and Community Food Access[1]

[1] Ma X, Liu J, Hardin J, Zhao G, and Liese AD. To be submitted.

Food Desert and Birth Outcomes: Effects of Neighborhood Income and Community Food Access

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Running title: Food desert and birth outcomes

Abstract

Introduction: Nutritional status and diet quality have been associated with birth outcomes in many studies. The diet quality and nutrition intake during pregnancy have been shown to be affected by the built food environment where the pregnant women live. To date, the studies on built food environment and birth outcomes are extremely limited. The food desert, developed by the US Department of Agriculture (USDA), is a community food access measure used to define poor food access in low income areas. This study aimed to examine the association between food desert and birth outcomes.

Methods: All Census tracts in South Carolina (N=867) were coded as high or low income tracts by poverty rate and family income, and high or low food access tracts by distance to supermarket. A four-level variable was then created by high or low of neighborhood income and food access. The tracts with low income and low access were defined as the USDA food deserts. All non-Hispanic white and black births from 2008 to 2009 in the state (N=98,456) were assigned to one of four levels according to the residential addresses of the mothers. Multivariate linear and logistic regression models with a random effect were used to identify the effect of neighborhood income and community food access on birth outcomes (birth weight, low birthweight (LBW), gestational age, preterm birth (PTB)).

Results: The overall prevalence of LBW and PTB was 8.3% and 10.0% among non-Hispanic whites and blacks in South Carolina. All birth outcomes were different across four levels of food desert variable. After adjustment for covariates, low neighborhood income was associated with decreased birth weight (β= -15.1; 95% confidence interval (CI): -23.1, -7.1), but low food access was associated with increased birth weight (β=18.7; 95% CI: 10.1, 27.3). Mothers living in food deserts did not experience different birth outcomes compared to those living in high-income and high-access areas.

Conclusion: The neighborhood income component is more important in predicting birth outcomes than the community food access component of the food desert. Future research with other food access measures is needed to understand the association between food environment and birth outcomes.

Key Words: food desert, neighborhood income, food access, low birthweight, preterm birth, adverse birth outcomes

Introduction

Infants with adverse birth outcomes such as low birthweight (LBW) and preterm birth (PTB), are at a greater risk of dying in infancy (JAMA, 2002; McCormick, 1985; McIntire *et al.*, 1999). In the United States, LBW occurs in approximately 1 of every 12 babies born each year. PTB affects more than 500,000, or 12.2% of live births (Martin *et al.*, 2012). Surviving LBW or premature infants may face lifelong health problems (Behrman *et al.*, 2007). A number of individual risk factors has been associated with LBW, including maternal age, maternal marital status, health behaviors such as smoking, alcohol use, substance use and sexual behaviors, malnutrition, low maternal socioeconomic status (SES), and stress (Gluckman *et al.*, 2004; Lesage *et al.*, 2004; Mitchell *et al.*, 2004; Parker *et al.*, 1994; Sram *et al.*, 2005; Valero De Bernabe *et al.*, 2004; Wu *et al.*, 2004). Predictors of PTB are less well established, but may include multiple pregnancies, problems with the uterus or cervix, maternal health behaviors such as smoking, alcohol, substance use, and sexual behaviors, maternal infections, low maternal SES, and stress (Dole *et al.*, 2003; Flynn *et al.*, 1999; Goldenberg *et al.*, 2000; Nordentoft *et al.*, 1996; Parker *et al.*, 1994; Peacock *et al.*, 1995; Windham *et al.*, 1995).

Neighborhood-level factors may influence individual-level biological and behavioral factors, and further relate to individuals’ health status. In particular, physical and social conditions of a deprived neighborhood may influence stress, nutrition, health behaviors etc. Increasingly, studies have started to examine the effect of neighborhood conditions on birth outcomes. Neighborhood factors

including income/poverty, employment, violence and crime, social support, and neighborhood deprivation were found to be related to LBW and PTB (Agyemang *et al.*, 2009; Buka *et al.*, 2003; Janevic *et al.*, 2010b; Love *et al.*, 2010; Masi *et al.*, 2007; Messer *et al.*, 2006a; Messer *et al.*, 2006b; Metcalfe *et al.*, 2011; Nkansah-Amankra *et al.*, 2010a; O'Campo *et al.*, 2008; Reichman *et al.*, 2009; Schempf *et al.*, 2009). In addition to these neighborhood factors, food environment was identified as affecting resident's dietary quality and nutrition intake in adolescents (Jago *et al.*, 2007), adults (Bodor *et al.*, 2008; Franco *et al.*, 2009; Larson *et al.*, 2009a; Moore *et al.*, 2008b; Morland *et al.*, 2002; Pearce *et al.*, 2008, 2009), and even in pregnant women (Laraia *et al.*, 2004). For instance, Laraia et al. found that proximity of supermarkets was positively associated with diet quality among pregnant women (Laraia *et al.*, 2004). For pregnant women, nutritional intake during pregnancy is extremely important for fetal growth and development, and poor nutrition before and during pregnancy has been demonstrated to predict adverse birth outcomes (Mitchell *et al.*, 2004; Sram *et al.*, 2005; Wu *et al.*, 2004).

To date, the studies on food environment and birth outcomes were extremely limited and the results were inconsistent. Lane et al. indicated that women living in proximity to a supermarket had significantly fewer LBW births than those living farther away in New York (Lane *et al.*, 2008). While neither the gestational age nor birthweight-for-gestational-age was associated with density of alcohol outlets, tobacco outlets, fast-food restaurants or grocery supermarkets in Farley et al.'s study (Farley *et al.*, 2006).

A large number of measures have been developed to evaluate food environment by researchers, commercials, and government agencies with different perspectives. For example, United States Department of Agriculture (USDA) Economic Research Service (ERS) developed a community food access measure named food desert, which is defined as a low-income Census tract where a substantial number or share of residents have low access to a supermarket or large grocery store (Ver Ploeg *et al.*, 2009). With both dimensions of neighborhood income and community food access included, the concept of food deserts is capable of catching information on both food accessibility and affordability in the neighborhood. To the best of our knowledge, no studies utilized this community food access measure to examine the effect of food environment and health outcomes.

One of the most well-known health disparities between African-Americans and White-Americans in the United States is that of birth outcomes. Previous discussions about individual risk factors could not account for the racial disparities (Goldenberg *et al.*, 1996; Lu *et al.*, 2003). Thus, more and more studies have investigated the effects of neighborhood factors on birth outcomes and tried to explain the racial disparities (Grady, 2006; Janevic *et al.*, 2010b; Love *et al.*, 2010; Pearl *et al.*, 2001). In addition, previous studies indicated the presence of racial differences in access to fast food or healthy food (Dunn *et al.*, 2012; Messer *et al.*, 2008). To the best of our knowledge, there are no published studies have examined whether neighborhood food environment could explain the racial difference on birth outcomes.

Using all births in South Carolina in 2008-2009, this study sought to examine the association between neighborhood food environment (measured by USDA food desert) and birth outcomes (birth weight, gestational age, LBW, and PTB). In particular, two dimensions of food desert (neighborhood income and community food access) were evaluated and compared by creating a four-level food desert variable (high-income-high-access, low-income-high access, high-income-low-access, low-income-low-access).

Methods

Study population and study area. The sociodemographic, and birth and pregnancy-related data were requested for all live births from January 1, 2008 to December 31, 2009 in South Carolina (N=123,759) from the birth certificate database from the South Carolina Department of Health and Environmental Control (DHEC). After excluding births without Census tract information, 115,599 remained in the database. In addition, we removed 4,006 twins and 13,137 births in Hispanic and other race/ethnic groups (American Indian and Alaska Native, Asian Native Hawaiian and other Pacific Islander). Finally, 98,456 births entered the final analysis in the end. The entire state of South Carolina State was considered as the study area. Based on US Census 2000, there were 867 Census tracts in South Carolina. This study was approved by Instructional Review Board at both University of South Carolina and SC DHEC.

Birth outcomes*.* Birth outcomes included birth weight (in grams), LBW (less than 2500 grams or not), gestational age (in weeks), and PTB (less than 37

weeks or not). The birth weight and gestational age were continuous, whereas LBW and PTB were coded into dichotomous variables.

Community food access measure (food desert). USDA food desert was used as the measure of neighborhood food environment. The computation of food desert was performed in ArcGIS (version 10.0, ESRI). At first, the low income tracts (with a poverty rate of 20 percent or higher or a median family income at or below 80 percent of the area's (state average for non-metropolitan areas and metropolitan average for metropolitan areas) median family income) were defined based on the US Census 2000 data. Then, polygonal 1km x 1km Socioeconomic Data and Applications Center (SEDAC) population grids were used to evaluate distance to supermarkets or grocery stores. Three food store data sources were used to supply information on supermarkets and grocery stores in the area: ground-truthed food store data from a field census for eight continuous counties in midland area (Liese *et al.*, 2013; Liese *et al.*, 2010), and InfoUSA retailer store data (Omaha, Nebraska) and the licensed food services facilities database from SC DHEC for the rest of the areas. To examine the distance, we converted the SEDAC grids to point data using a centroid approach retaining the SEDAC population estimates of all people living within each grid cell (Seirup *et al.*, 2006). Network (street distance) distance from each SEDAC grid cell centroid to the nearest food outlet was calculated in miles. A tract is considered as low-access if at least 500 people and/or at least 33 percent of the Census tract's population reside more than 1 mile (for urban tracts) or 10 miles (for rural tracts) from a supermarket or large grocery store. Urbanicity was

determined by the intersection of tract centroids with Metropolitan Statistical Areas (MSAs). A tract was considered “urban” if its centroid fell within an MSA, otherwise the tract was considered to be “rural.” In the end, we generated three exposure variables: neighborhood income (low or high), community food access (low or high), and four-level food desert variable (combination of neighborhood income and community food access), including high-income-high-access, low-income-high access, high-income-low-access, low-income-low-access tracts. Low-income-low-access tracts were defined as food deserts. The computed variable was then merged with birth certificate data by Census 2000 tract ID.

Covariates*.* Variables associated with both neighborhood environment and birth outcomes, but not considered on the causal pathway from neighborhood factors to birth outcomes, were included as covariates in this study. They included maternal age (in years), race/ethnicity (non-Hispanic white, non-Hispanic black), maternal education (high school of less, some college or equivalent, bachelor or above), the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) participation (yes, no), and urbanicity (urban, rural). Urban areas were defined as the Rural Urban Commuting Area (RUCA) code equals 1 (urban core). All other RUCA codes (sub-urban, large rural town, small town/isolated rural) were defined as rural area ("Guidelines for using rural-urban classification systems for public health assessment," 2009). Factors that mediated the association between the neighborhood factors and birth outcomes, such as maternal risk factors and health behavior factors, were not included in the adjusted models. The effect modification was not found for

race between food desert and birth outcomes, thus race was considered as a covariate variable in the analysis.

Statistical analysis. Characteristics were summarized in means (standard deviations) and proportion percentages for the entire sample and for subsamples by levels of the food desert variable. The high-income-high access group was considered as the reference group, and other three groups were compared to the reference group based on t-tests for continuous variables and Chi square tests of independence for categorical variables.

Because births are nested with Census tracts, ordinary single level models were inappropriate for such data because they assume all outcomes are independent and thus produce small standard errors which will increase type II error (Osborne, 2000). Therefore, multilevel models with individual births nested within Census tracts were performed to examine the effects of food environment on adverse birth outcomes. In particular, random effects linear regression models and random effects logistic regression models were utilized for continuous outcome variables (birth weight and gestational age) and dichotomous outcome variables (LBW and PTB), respectively. The raw models were firstly estimated without controlling any covariates. Then in the adjusted models, we controlled the covariates discussed above. All statistical analyses were performed using Stata (version 10, College Station, TX). P value less than 0.05 was set as the significance level.

Results

Characteristics of the study sample were presented in **Table 4.1** in total and by four-level food desert variable. In almost all non-Hispanic white and black births in 2008-2009 in South Carolina (N=98,456), the mean birth weight and gestational age were approximately 3230 grams and 38.4 weeks, respectively. Defined by cut-off of 2500 grams and 37 weeks, the overall prevalence of LBW and PTB was 8.33% and 9.96%, respectively. The average maternal age was 26.3 years old and 36.6% of the mothers were non-Hispanic blacks. Compared to mothers living in high-income-high-access areas, those living in low income (no matter low or high access) areas were younger, more likely to be non-Hispanic black, to receive less education, to participate WIC, were heavier before and at delivery and higher prevalence of obesity. Mothers living in these two areas also started the first prenatal care later, had more previous live births, more previous preterm births, more infections during pregnancy, and higher prevalence of chronic hypertension and diabetes mellitus than those living in reference area. In addition, mothers living in these two areas were more likely to give births with lower birth weight, shorter gestational age, and LBW and PTB. However, mothers living in high-income-low-access areas seemed to have better sociodemographic characteristics and birth outcomes than those living in high-income-high-access. For instance, mothers living in high-income-low-access areas were older, more educated, less likely to be WIC participants and to live in urban, with less obesity, and were more likely to give births with more birth

weight and longer gestational age, and were less likely to give LBW and PTB births.

The frequency distribution plots of the birth weight and gestational age by four-level food desert variable (**Figure 4.1**) suggested a downward shift in both birth weight and gestational age distribution between low income and high-income areas.

The associations between neighborhood income, community food access, four-level food desert variable and birth outcomes (birth weight, gestational age, LBW, and PTB) were examined by random-effect regression models and the results were summarized in **Table 4.2**. For birth weight, the births from low-income areas were about 115 grams lighter (113 grams in high-access and 79 grams in low-access areas) compared to those in high-income areas. Births occurring in low-access areas were a little heavier than those in high-access areas (47 grams). Within high-income areas, the difference remained (26 grams heavier). After covariates were included in the model, the differences in birth weight between areas became much smaller but still remained significant. Births in low-income-high-access areas were significantly lighter (17 grams), and births living in high-income-low-access were significant heavier (13 grams) than those living in reference group (high-income-high-access). When the birth weight was defined as the dichotomous LBW, the odds ratio (OR) showed similar pattern for birth weight. In the adjusted model with adjustment of all covariates, no significant difference was found for these areas.

When it came to gestational age, in unadjusted model, births from low income areas experienced much shorter gestational age but those from low access areas experienced much longer gestational age compared to those from reference areas. However, the significant differences disappeared after the covariates were included in the models. For PTB, the results are similar with gestational age. In the random-effect models, only less than 1% of the variance was due to the random effect, and the random effects in the models were all significant.

As discussed in previous studies, most covariate factors were found significantly associated with birth outcomes in this study. For all birth outcomes, the protective factors were maternal education and WIC participation, whereas the harmful factors were maternal age and non-Hispanic black race. Race showed the strongest effect among all the risk factors on all birth outcomes.

Discussion

In this study, low neighborhood income was associated with decreased birth weight, whereas poor community food access was associated with increased birth weight. Because the neighborhood income and food access were derived from the definition of the USDA food desert, according to the results of this study, neighborhood income dimension of the food desert seemed to be more important to predict birth weight than food access dimension. The different gestational age and different prevalence of LBW and PTB among four-level food

desert groups could be mainly explained by different composition of race in the areas.

This study confirmed the association between neighborhood income and birth weight as well as LBW which was indicated in previous studies (Cubbin *et al.*, 2008; Farley *et al.*, 2006; Grady, 2006; Metcalfe *et al.*, 2011; Nkansah-Amankra *et al.*, 2010a; Subramanian *et al.*, 2006; Williams *et al.*, 2007; Zeka *et al.*, 2008). For studies focusing on birth weight, most studies reported that increased neighborhood income (or decreased neighborhood poverty) was correlated with increased birth weight among live births (Farley *et al.*, 2006; Subramanian *et al.*, 2006; Williams *et al.*, 2007; Zeka *et al.*, 2008). For instance, Farley et al. presented that tract-level median household income was positively associated with birthweight-for-gestational-age in Louisiana (Farley *et al.*, 2006), and Zeka et al. reported that area-based median household income was positively associated with birth weight in eastern Massachusetts (Zeka *et al.*, 2008). Based on neighborhood poverty level, Subramanian et al. (Subramanian *et al.*, 2006) and Williams et al. (Williams *et al.*, 2007) found a negative association between the poverty rate and birth weight in Tennessee and Massachusetts, respectively. However, the relationship between neighborhood income/poverty was only identified among whole study population but not among race/ethnic subgroups by Pearl et al. in California (Pearl *et al.*, 2001), and no any significant relationships were identified in Masi et al.'s study in Chicago (Masi *et al.*, 2007). The inconsistent findings on birth weight may be due to different area settings among these studies. When it came to LBW, the findings were steadily

consistent that decreased neighborhood income/increased neighborhood poverty was associated with higher risk of LBW (Cubbin *et al.*, 2008; Grady, 2006; Nkansah-Amankra *et al.*, 2010a; Subramanian *et al.*, 2006). The significant relationship was also confirmed by a recent meta-analysis based on almost all potential studies (Metcalfe *et al.*, 2011). In this study, a Census tract was defined as a “low income” tract either having: 1) a poverty rate of 20 percent or higher, or 2) a median family income at or below 80 percent of the area's median family income (for tracts not located within a metropolitan area, it is statewide median family income; for tracts located within a metropolitan area, it is the greater of statewide median family income or the metropolitan area median family income) (Ver Ploeg *et al.*, 2009). Thus, the criteria for “low-income” were wider than those used in other studies. This might explain the relatively smaller effect size for birth weight models and ORs for LBW models in this study.

Previous studies on neighborhood income/poverty and gestational age/PTB showed conflicting results (Agyemang *et al.*, 2009; Farley *et al.*, 2006; Kaufman *et al.*, 2003; Masi *et al.*, 2007; Nkansah-Amankra *et al.*, 2010a; Pickett *et al.*, 2002; Zeka *et al.*, 2008). Farley et al. indicated a positive association between median household income and gestational age (Farley *et al.*, 2006), and several studies reported the negative association between neighborhood income and PTB (Agyemang *et al.*, 2009; Kaufman *et al.*, 2003; Pickett *et al.*, 2002). Nevertheless, a few studies failed to demonstrate a significant relationship (Masi *et al.*, 2007; Nkansah-Amankra *et al.*, 2010a; Zeka *et al.*, 2008). In this study, no significant results were found for both gestational age and PTB. Based on

Pregnancy Risk Assessment Monitoring System (PRAMS) data (randomly sampled from birth certificate data) in South Carolina, Nkansah-Amankra et al. found that neighborhood poverty was associated with LBW but not associated with PTB after adjusting covariate factors (Nkansah-Amankra *et al.*, 2010a). The results were consistent with those from the present study which was performed in the same place but several years earlier. However, the survey design of PRAMS was not considered during the analysis in their paper, which might cause biased results.

Proximity of supermarkets has been associated with diet quality among pregnant women (Laraia *et al.*, 2004). The diet quality was well known as an important factor to predict birth outcomes especially birth weight (Mitchell *et al.*, 2004; Wu *et al.*, 2004). However, the studies examining food access (such as proximity of supermarkets etc.) and birth outcomes were still extremely limited. Farley et al. reported that neighborhood density of food outlets (including supermarkets/grocery stores) was associated with neither gestational age nor birthweight-for-gestational-age (Farley *et al.*, 2006), whereas Lane et al. found that pregnant women living in proximity to a supermarket had significantly fewer LBW births than other pregnant women (Lane *et al.*, 2008). However, both these two studies relied on the density or presence of food outlets in the Census tracts, which meant that they did not assess the “proximity” or “accessibility” of food outlets but just the “availability” of food outlets in the tracts the mothers lived. In present study, we defined the “low access” to food outlet by the distance from the centroid of the 1-km square grid (where the mothers lived) to the nearest

supermarket/grocery store (Ver Ploeg *et al.*, 2009). Even though the low access was not defined for each resident, the low access tract had a large number of residents with limited access to supermarkets/grocery stores. According to the results in present study, access to supermarkets/grocery stores did not predict birth outcomes after considering other covariate factors. To some extent the low access to supermarket/grocery stores among high-income areas was more likely to be associated with better birth outcomes. This might be because the mothers living in these areas were usually with better SES (as described in **Table 4.1** in the results) and might have alternative ways to access healthy food. Thus, the findings that mothers living in food deserts (low-income and low-access areas) did not experience worse birth outcomes than those living in low-income-high-access areas were not unexpected. However, no studies to date used individual access measures to evaluate food access of the mothers. Future research is needed to test the effect of such measures (such as the distance from a mother's home to nearest food outlet and the number of food outlets around some buffer around a mother's home) on predicting birth outcomes.

Race was not found as an effect modification between neighborhood income/community food access and birth outcomes in this study. As a confounder, the point estimates of neighborhood income/food access levels were dramatically changed after race was added in the models, which meant that the most variance of birth outcomes among different levels of food desert (combination of neighborhood income and food access) could be explained by race. In this study, after including all covariates, non-Hispanic black mothers

experienced more than 2 times and 1.5 times the odds of giving LBW and PTB births than non-Hispanic white mothers, respectively. These results confirmed that individual factors (such as demographic, SES, health behavior, and birth/pregnancy factors) did not account for the racial disparities on birth outcomes (Goldenberg *et al.*, 1996; Lu *et al.*, 2003). This study also showed that neighborhood income and food access could not explain the racial disparities either. Because lifecourse factors were suggested to explain the racial disparities on birth outcomes (Love *et al.*, 2010; Lu *et al.*, 2003), future studies on longer phase of neighborhood factors are encouraged.

There are several limitations of this study worth noting. First of all, the cross-sectional design was lack of ability to explore potential temporal relationship between neighborhood income, food access, and birth outcomes. Although possibility is little for reverse causal effect for birth outcomes, the cross-sectional data collection on neighborhood factors could not identify the changes of exposure over years before birth. In addition, the ground-truthed food outlet data were only available in eight counties in South Carolina. To achieve the best validity, we combined two secondary datasets (DHEC and InfoUSA data) for other areas. However, errors might still exist in the combined dataset which might cause bias for the results. In the end, several risk factors which were found to relate to LBW or PTB were not included in this study, such as maternal stress, individual income, physical activity etc.. Current adjustments in the models may not be adequate to rule out the confounding bias. However, we did our best to

control the alternative factors in the models, e.g. using WIC participation instead of individual household income.

Despite these limitations, this study has several advantages. First, this study was the first study to date to examine the association between food accessibility and birth outcomes, and use the policy-related food access measure (food desert) to predict birth outcomes. Second, we included all live births from 2008-2009 in South Carolina in the analysis. Our results could be generalized to the whole South Carolina. In addition, for eight counties in the midland area, the food outlet data were ground-truthed with excellent validity and reliability.

Conclusion

Mothers living in USDA food desert areas were not found to have adverse birth outcomes compared to those living in high-income and high-food access areas. Increased neighborhood income was associated with increased birth weight, whereas improved food access was associated with decreased birth weight. As the two dimensions of food desert, neighborhood income is more important to predict birth weight rather than other birth outcomes compared to food access. Interventions to improve birth weight should be placed on mothers living in low income areas. Future research using individual-level food access measures was encouraged to explore the potential association between food environment and birth outcomes.

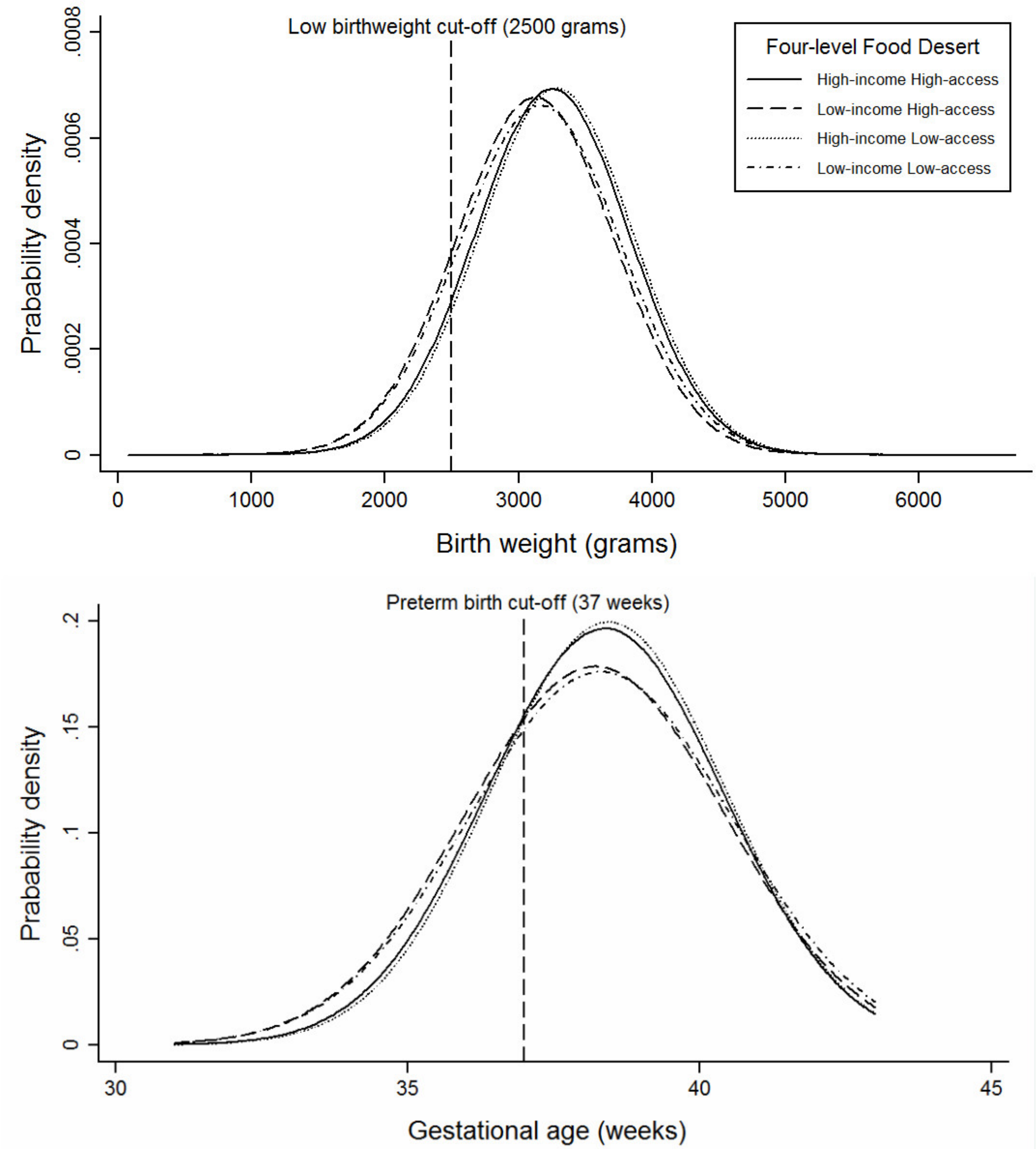

Figure 4.1 Birth weight (top) and gestational age (bottom) distribution for categories of four-level food desert

Table 4.1 Maternal and offspring characteristics of live births in South Carolina (2008-2009), according to neighborhood income and food access

Variables	**Mean (SD) or Percentage, %**				
	HI+HA	**LI+HA**	**HI+LA**	**LI+LA**	**Total**
Sample Size	26,660	19,219	41,813	10,764	98,456
Offspring Characteristics					
Birth Weight, g	3252.01 (575.67)	3125.16 (588.70)**	3284.35 (574.42)**	3163.21 (602.48)**	3231.27 (584.13)
Low Birthweight, %	7.70	10.76**	7.16**	10.09**	8.33
Gestational Age, w	38.37 (2.03)	38.21 (2.24)**	38.44 (2.00)**	38.30 (2.27)**	38.36 (2.09)
Preterm Birth, %	9.67	11.61**	9.14*	10.95**	9.96
Maternal Characteristics					
Mother's Age, y	26.41 (6.00)	24.83 (5.70)**	27.39 (5.99)**	24.73 (5.60)**	26.33 (6.00)
Non-Hispanic black, %	25.74	63.61**	25.78	57.28**	36.60
Mother's Education, %					
High school or less	43.82	59.21**	34.37**	59.51**	44.52
Some college	33.05	30.35	33.38	29.89	32.32
Bachelor or above	23.12	10.44	32.25	10.60	23.16
WIC Participation, %	52.42	72.51**	41.75**	68.55**	53.73
Living in Rural, %	83.11	75.60**	21.33**	15.13**	47.98
Mother's Weight at Delivery, lb	189.19 (43.22)	193.48 (46.90)**	188.78 (41.56)	193.55 (47.00)**	190.35 (43.77)
Mother's Weight, lb	161.50 (44.41)	169.41 (48.13)**	159.94 (42.49)**	168.03 (48.14)**	163.13 (44.99)
BMI, %					
Normal	46.69	38.83**	48.67**	40.80**	45.33
Overweight	25.20	25.28	24.88	24.84	25.04
Obese	28.10	35.89	26.45	34.37	29.62
Smoking During Pregnancy, %	13.42	12.38**	11.02**	13.30	12.19
Prenatal Care Begin in 1st trimester, %	74.52	67.16**	76.17**	64.24**	72.66
Previous Live Birth, %					
0	43.53	39.58**	43.17	40.18**	42.24
1	32.85	30.86	33.60	30.92	32.57
2 or more	23.61	29.57	23.23	28.89	25.19
Previous Preterm Birth, %	2.24	3.08**	2.73**	2.81**	2.68
Infection During Pregnancy, %	6.10	10.40**	6.28	10.61**	7.51
Gestational Hypertension, %	5.62	4.71**	5.65	5.42	5.43
Hypertension, %	2.37	3.31**	2.44	3.27**	2.69
Gestational Diabetes Mellitus, %	4.83	4.47	4.82	4.23*	4.69
Diabetes Mellitus, %	0.82	1.05*	0.87	1.03*	0.91

HI, high income; LI, low income; HA, high access; LA, low access; SD, standard deviation; WIC, the Special Supplemental Nutrition Program for Women, Infants, and Children; BMI, body mass index. High income and high access group was used as the reference group, and all other three groups were compared to the reference. T-test and Chi square were used to compare for continuous and categorical variables, respectively. *: $p<0.05$, **: $p<0.01$.

Table 4.2 The association between matrix of income and food access and birth outcomes in South Carolina

Birth Outcomes	Unadjusted Model	Adjusted Model
Birth Weight (grams)		
High-income	0	0
Low-income	**-114.85 (-126.95, -102.74)**	**-15.08 (-23.06, -7.09)**
High-access	0	0
Low-access	**46.59 (32.95, 60.22)**	**18.69 (10.09, 27.30)**
High-income High-access	0	0
Low-income High-access	**-112.93 (-129.11, -96.76)**	**-16.55 (-27.02, -6.07)**
High-income Low-access	**25.68 (11.17, 40.20)**	**12.96 (2.96, 22.96)**
Low-income Low-access	**-78.78 (-98.10, -59.47)**	6.54 (-7.10, 20.17)
Gestational Age (weeks)		
High-income	0	0
Low-income	**-0.16 (-0.20, -0.12)**	-0.02 (-0.06, 0.02)
High-access	0	0
Low-access	**0.10 (0.06, 0.14)**	0.03 (-0.01, 0.08)
High-income High-access	0	0
Low-income High-access	**-0.15 (-0.21, -0.10)**	-0.02 (-0.07, 0.04)
High-income Low-access	**0.07 (0.02, 0.12)**	0.03 (-0.02, 0.09)
Low-income Low-access	**-0.07 (-0.14, -0.01)**	0.01 (-0.06, 0.08)
Low Birthweight		
High-income	1.00	1.00
Low-income	**1.47 (1.38, 1.56)**	1.05 (0.99, 1.11)
High-access	1.00	1.00
Low-access	**0.86 (0.81, 0.92)**	0.98 (0.91, 1.04)
High-income High-access	1.00	1.00
Low-income High-access	**1.43 (1.32, 1.56)**	1.04 (0.96, 1.12)
High-income Low-access	**0.92 (0.86, 0.99)**	0.98 (0.90, 1.06)
Low-income Low-access	**1.35 (1.22, 1.49)**	1.04 (0.94, 1.14)
Preterm Birth		
High-income	1.00	1.00
Low-income	**1.23 (1.17, 1.30)**	1.04 (0.98, 1.10)
High-access	1.00	1.00
Low-access	**0.91 (0.86, 0.96)**	0.96 (0.90, 1.02)
High-income High-access	1.00	1.00
Low-income High-access	**1.20 (1.12, 1.30)**	1.01 (0.94, 1.09)
High-income Low-access	**0.93 (0.87, 1.00)**	0.95 (0.88, 1.02)
Low-income Low-access	**1.15 (1.06, 1.26)**	1.00 (0.91, 1.11)

Adjusted variables are maternal age, race/ethnicity, maternal education, WIC participation, urbanicity in adjusted model. CI, confidence interval; OR, odds ratio; HI, high income; LI, low income; HA, high access; LA, low access. For birth weight and gestational age, the models are random-effect linear regression models; for low birthweight and preterm birth, the models are random-effect logistic regression models. Bolded means p<0.05.

CHAPTER 5

Built food Environment and Birth Outcomes in South Carolina[1]

[1] Ma X, Liu J, Hardin J, Zhao G, and Liese AD. To be submitted.

Built Food Environment and Birth Outcomes in South Carolina

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Running title: Built food environment and birth outcomes

Abstract

Introduction: Evidence of the association between food environment and birth outcomes is were extremely limited. Moreover, the food environment in these studies was characterized only based on neighborhood-level availability of food outlets but without individual-level food access measures. Based on the food outlet data from a field census validation and the birth certificate data in eight counties in South Carolina, this study aimed to examine the association between individual food access (availability and accessibility of various types of food outlets of the mothers) and birth outcomes.

Methods: All birth certificates from January 1, 2008 to December 31, 2009 in eight counties were requested from South Carolina Department of Health and Environmental Control (DHEC). In total, 15,786 eligible mother/births were included in the analysis. Food access was evaluated by the distance to the nearest healthy store, convenience store, and limited service restaurant, and the count of each type of food outlets within 1-mile of the mothers' homes. Birth outcomes included birth weight, low birthweight (LBW), gestational age, and preterm birth (PTB). Linear and logistic regression models were conducted for birth weight and gestational age, and LBW and PTB, respectively.

Results: Farther distance to the nearest convenience store was associated with increased birth weight and gestational age. The births living in the areas with 2 or more convenience stores in 1-mile buffer weighted less than those living in the

areas without convenience stores in the neighborhood (2 stores: β=-46.8, 95% CI: -76.9, -16.6; 3 or more stores: β=-54.3, 95% CI: -83.4, -25.1). Having three or more convenience stores in the neighborhood was associated with increased risk of PTB compared to no convenience stores in the neighborhood. Accessibility and availability of supermarket and grocery store were not associated with any birth outcomes in multivariate analysis with covariates included.

Conclusion: Accessibility and availability of convenience stores were inversely associated with birth outcomes. No significant associations were captured for healthy food outlets and limited service restaurants. Future investigations with more comprehensive measures of food environment were encouraged.

Key Words: availability, accessibility, food outlet, low birthweight, preterm birth, adverse birth outcomes

Introduction

In 2010, the rate of low birthweight (LBW) was 9.9% in South Carolina with a ranking of 5th following Mississippi, Louisiana, Alabama, and District of Columbia among all states in the United States (Martin *et al.*, 2012). The rate almost doubled among non-Hispanic blacks (14.9%) compared to non-Hispanic whites (7.6%). South Carolina ranked in the 4th place in prevalence of preterm birth (PTB) (14.2%) among all states (Martin *et al.*, 2012). Remarkable difference in PTB was also found between non-Hispanic blacks (19.3%) and non-Hispanic whites (11.7%).

A number of individual risk factors have been associated with adverse birth outcomes by previous studies; however the racial disparities of birth outcomes could not fully explained by these risk factors (Goldenberg *et al.*, 1996). Increasing research interests were on neighborhood factors and their effects on birth outcomes. Neighborhood factors including income/poverty, employment, violence and crime, social support, and neighborhood deprivation were found to be related to birth outcomes (Agyemang *et al.*, 2009; Buka *et al.*, 2003; Janevic *et al.*, 2010b; Love *et al.*, 2010; Masi *et al.*, 2007; Messer *et al.*, 2006a; Messer *et al.*, 2006b; Metcalfe *et al.*, 2011; O'Campo *et al.*, 2008; Reichman *et al.*, 2009; Schempf *et al.*, 2009).

As an important neighborhood factor, built food environment plays an important role on residents' diet quality (Bodor *et al.*, 2008; Franco *et al.*, 2009; Jago *et al.*, 2007; Larson *et al.*, 2009a; Moore *et al.*, 2008b; Morland *et al.*, 2002; Pearce *et al.*, 2008, 2009), especially for pregnant women (Laraia *et al.*, 2004).

For instance, Laraia et al. found that proximity of supermarkets was positively associated with diet quality among pregnant women (Laraia *et al.*, 2004). The quality of diet might predict birth outcomes (Mitchell *et al.*, 2004; Sram *et al.*, 2005; Wu *et al.*, 2004). However until recently, studies about food environment and birth outcomes are extremely limited. Farley et al. computed the density of alcohol outlets, tobacco outlets, fast-food restaurants, and grocery supermarkets per 1000 population for each Census tract in the study areas and found no significant associations between these neighborhood retail densities with gestational age and birthweight-for-gestational-age (Farley *et al.*, 2006). In contrast, Lane et al. drew a 1.5-mile buffer around each supermarket, and defined the Census tract as a “supermarket Census tract” if the 1.5-mile radius fell within the boundary of the Census tract. After controlling for race and Medicaid participation, they concluded that mothers who resided in a non-supermarket Census tract were approximately 3.4 times as likely to have low birthweight (LBW) babies compared to those living in a supermarket Census tract (Lane *et al.*, 2008). To the best of our knowledge, there are no studies that have relied on individual-level food access measures or have evaluated measures of accessibility of the food outlets in addition to availability of the food outlets. In South Carolina, 68.3% of Census tracts were reported with healthy food retailers within 0.5 miles of boundary, which was lower than national level (72.0%) ("State indicator report on fruits and vegetables, 2009," 2009). It is still unknown whether the high prevalence of adverse birth outcomes and diverse racial difference in South Carolina were attributed to the neighborhood food environment.

Thanking to a field census on all food outlets in eight counties in South Carolina (Liese *et al.*, 2013; Liese *et al.*, 2010), we are able to assess the individual-level food environment measures by calculating the distance to the nearest food outlet and count of the food outlet around the residents. In present study, we have therefore examined the association between individual food environment measures and birth outcomes in a continuous eight-county area in South Carolina. To our knowledge, this is the first study using individual food access measures to characterize food environment in studies of birth outcomes. The findings of this study improved our understanding on the effects of built food environment on birth outcomes.

Methods

Study area. The study area included one urban county (Richland) and seven rural counties (Calhoun, Chester, Clarendon, Fairfield, Kershaw, Lancaster, Orangeburg) in the Midlands region of South Carolina (**Figure 1**). The eight-county area approximately covers a total of 5,575 square miles and a population of more than 15% of South Carolina's total population.

Study population. All birth certificates from January 1, 2008 to December 31, 2009 in eight counties were prepared by the South Carolina Department of Health and Environmental Control (DHEC). In total, there were 18,940 mother-birth pairs in the eight-county area. Among all births, 17,841 mothers could be geocoded with available residential geographic information. Because the home addresses of the mothers could not be released to the researchers, all the food access measures were calculated by the staff at DHEC based on mothers' home

addresses. After the spatial food access measures were calculated, a de-identified birth certificate dataset with pregnancy, and birth variables, and with the calculated food access variables, was delivered to us. In this study, we focused on singletons and non-Hispanic whites and blacks. After removing 635 twins and 1420 births of other race/ethnic groups (Hispanic and others such as American Indian and Alaska Native, Asian Native Hawaiian and other Pacific Islander), 15,786 births were included in the analysis. The data request was reviewed and this study was approved by the Institutional Review Board at DHEC.

Data sources. Each live-birth certificate includes information in personal contact, parental sociodemographic characteristics, health behaviors during pregnancy, pregnancy history, prenatal care, maternal risk factors, complications of labor and delivery, and newborn's characteristics. Marital status and father's information were not released to us due to some law restrictions in the state.

The food outlet data were from a previous field census conducted by Liese et al. in 2008-2009 in the eight-county area which has been described in detail (Liese *et al.*, 2013; Liese *et al.*, 2010). All the food outlets had been verified to be open and geospatial locations ascertained using Global Positioning System (GPS) units. To account for stores that could lie just outside the boundaries of our study area, a 10-mile exterior buffer corridor was created around the study area using two secondary food outlet data sources (InfoUSA and the Licensed Food Services Facilities Database from DHEC) (grey area in **Figure 5.1**). Thus, the food outlet data in the buffer area were not ground-

truthed. In the end, 1,718 food outlets were used to generate food access measures, including 243 healthy stores (including supercenter, supermarket, grocery store, and warehouse club), 504 convenience stores, and 971 limited service restaurants. All stores were plot in **Figure 5.1** as the dots. The food outlet data were sent to DHEC in advance for calculation of food access measures.

Measures. Four birth outcomes were included in this study, including birth weight (in grams), LBW (defined by birth weight less than 2500 grams), gestational age (in weeks), and preterm birth (PTB) (defined by gestational age less than 37 weeks). The birth weight and gestational age were continuous, whereas LBW and PTB were defined as dichotomous variables.

Individual food environment was characterized using the network distance (along the streets) from a mother's home to the nearest food outlet (accessibility) and the count of food outlets within 1 mile buffer around the mother's home (availability). These two measures were computed separately for healthy store (supermarket and grocery store), convenience store, and limited service restaurant. All the computations were performed in ArcGIS (version 10.0, ESRI) at DHEC. The distribution was left-skewed for the network distances, so we log-transformed the distances before conducting the models. Because only a few mothers lived with 2 or more healthy stores, and 3 or more convenience stores and limited service restaurants, we coded the counts of food outlets into categories (healthy store, 0, 1, 2 or more; convenience store and limited service restaurant: 0, 1, 2, 3 or more). The reference group was no stores within the buffer area group.

Covariates included maternal age (in years), race/ethnicity (non-Hispanic White, non-Hispanic African American), maternal education (high school of less, some college or equivalent, bachelor or above), the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) participation (yes, no), and urbanicity (urban, rural). The urbanicity of the mothers was coded based on the Census tract they lived. We define urban and rural Census tracts by U.S. Census definitions. Urban areas were defined as the Rural Urban Commuting Area (RUCA 2000) code equals 1 (urban core). All other RUCA codes (sub-urban, large rural town, small town/isolated rural) were defined as rural ("Guidelines for using rural-urban classification systems for public health assessment," 2009). Because we focused on the association between neighborhood food access and birth outcomes, the risk factors caused by neighborhood factors and mediated the associations were not included in this study, such as body mass index (BMI), smoking during pregnancy, prenatal care, and maternal risk factors. The effect modification was assessed for race and urbanicity and we did not find such effect between food access measures and birth outcomes. Therefore, these two factors were considered as confounders in the analysis.

Statistical analysis. Characteristics of the study sample were summarized by mean and standard deviation (SD) for continuous variables and proportion in percentage for categorical variables. The distance to the nearest food outlet and count of food outlets in 1 mile buffer were summarized in mean, standard deviation, minimum, median, and maximum by the type of the store.

At first, unadjusted models were used to identify the association between food environment measures and birth outcomes. Then, multivariate linear regression models were used for birth weight and gestational age, whereas multivariate logistic regression models were used for LBW and PTB. Covariates mentioned above were controlled in adjusted model 1. The measures for other types of food outlet were additionally controlled in adjusted model 2. The colinearity was checked between measures of different store types and was found to be acceptable. All statistical analyses were performed using Stata (version 12, College Station, TX). P value less than 0.05 was set as the significance level.

Results

The characteristics of the study sample in eight-county area in South Carolina are summarized in **Table 5.1**. The average maternal age was 26.3 years old and there were more non-Hispanic blacks than non-Hispanic whites in this eight-county area. The average birth weight and gestational age were 3173 grams and 38.26 weeks, and the prevalence of LBW and PTB were 9.39% and 10.45%, respectively. The distance to the nearest food outlet and count of food outlets in 1-mile buffer were summarized by store type in **Table 5.2**. The average distances from residence to the nearest healthy store, convenience store, and limited service restaurant were approximately 3,900, 2,600, and 3,400 meters, respectively. On average, there were 0.47 healthy stores, 1.58 convenience stores, and 2.19 limited service restaurants within 1 mile around the home.

The associations between accessibility to the food outlets (log-transformed distance to the nearest food outlet) and birth outcomes (birth weight, gestational age, LBW, and PTB) are summarized in **Table 5.3**. According to the unadjusted models, the significant associations were identified between distances to various types of food outlets and birth weight as well as LBW. For gestational age and PTB, only distance to nearest convenience store showed a significant relationship. After covariates were included in the adjusted model 1, the longer distance to the nearest convenience store was associated with higher birth weight (+15.5 grams per log meter distance). When the distances to other types of food outlets were added in the adjusted model 2, the distance to the nearest convenience store was positively associated with both birth weight (+22.4 grams per log meter distance) and gestational age (+0.05 weeks per log meter distance). No significant associations were identified between birth outcomes and distance to the nearest health store and limited service restaurant.

The associations of the availability of food outlets (count of food outlets in 1-mile buffer) and birth outcomes are shown in **Table 5.4**. When simultaneously controlling for maternal age, race, education, WIC participation, urbanicity and counts of other types of food outlets, mothers living with 2 or more convenience stores within 1-mile buffer were more likely to give births with lower birth weights (2 convenience stores: -46.8 grams; 3 or more convenience stores: -54.3 grams) than those living without convenience stores within 1 mile of the home. In addition, mothers living with 3 or more convenience stores within 1 mile of their homes experienced 1.22 times the odds of having PTB births compared to those

without convenience stores in the area. Some significant results were shown only in the multivariate models for accessibility and availability of limited service restaurant. We believed these results were artifact of the modeling because no significant differences were indicated in unadjusted models. No significant differences on birth outcomes were identified to be independent of covariates for both accessibility and availability of healthy stores in this study.

Discussion

Our study found that further distance to nearest convenience store was associated with higher birth weight and gestational age, and a larger count of convenience stores within 1-mile buffer was related to lower birth weight and higher risk of PTB. Accessibility and availability of supermarket and grocery store were not associated with any birth outcomes.

When researchers evaluated the built food environment, supermarkets, supercenters, grocery stores, and warehouse clubs were usually considered as healthy food outlets due to the availability of healthy foods in such stores. Evidence showed that lack of access to healthy food outlets contributed to poor diet quality (Franco *et al.*, 2009; Moore *et al.*, 2008b; Morland *et al.*, 2002). Laraia et al. indicated this relationship among pregnant women that women living greater than 4 miles from a supermarket were more than twice the odds of having poor diet quality compared to those living within 2 miles of a supermarket (Laraia *et al.*, 2004). As identified by a number of studies, poor diet quality before and during pregnancy contributed to adverse birth outcomes (Mitchell *et al.*, 2004;

Wu *et al.*, 2004). In this study, neither accessibility (distance to nearest healthy store) nor availability (count of healthy stores within 1 mile buffer) of supermarket and grocery store was associated with birth outcomes. Our results were consistent with those in Farley et al.'s study (Farley *et al.*, 2006), who reported that neither gestational age nor birthweight-for-gestational-age was associated with the neighborhood density of supermarkets. However, only availability (evaluated by density of food outlets) of health food stores was examined and the densities were computed in Census-tract level in that study. The significant relationship between supermarket access and birth outcomes was reported by Lane et al. that pregnant women living in Census tracts with supermarkets had fewer LBW births than those living in tracts without supermarket (Lane *et al.*, 2008). However, the measure of supermarket access in that study was in tract-level and could not characterize individual access to the supermarket, which might be the reason for inconsistent findings with ours. Nevertheless, there might be other interpretations. Access to healthy food is a relatively distal risk factor compared to other well-known risk factors for birth outcomes, such as race and SES. The benefit of access to healthy food outlets for birth outcomes may be attenuated by other risk factors which are more proximally situated in the causal sequence. In addition, even though healthy foods are provided in healthy foods stores, consumers may still choose unhealthy foods sold in those healthy stores. In this study, the information on shopping behaviors was not available. Moreover, we only used 1-mile buffer size when computing count of food outlets. Future

studies are needed to include shopping behavior information and measures on different buffer sizes.

Convenience stores and fast food restaurants, which usually offer foods high in calories but low in nutritional value, were defined as unhealthy food outlets ("State indicator report on fruits and vegetables, 2009," 2009). Previous studies demonstrated that residing further away from convenience stores was associated with higher intake of healthy food including fruits, juice and vegetables, among both adults (Pearce *et al.*, 2008) and adolescents (Jago *et al.*, 2007). In this study, we found that proximity to convenience store and the count of convenience stores in the local neighborhood was inversely associated with birth weight and gestational age. Our findings were in accordance with the hypothesis that access to unhealthy food impacted the diet quality which would cause adverse birth outcomes. There are several potential mechanisms behind the association. First of all, proximity to “unhealthy” foods was associated with decreased intake of nutritious foods such as fruits and vegetables (Jago *et al.*, 2007; Pearce *et al.*, 2008), which might be caused by limited supply of healthy foods or the replacement of healthy foods by energy dense unhealthy foods. Available evidence suggested that fetal growth is extremely vulnerable to maternal dietary deficiencies of nutrients (Wu *et al.*, 2004). Another potential explanation is that proximity to convenience stores implies a source of other harmful substances, such as tobacco and alcohol. However in Farley et al.’s study, neighborhood density of alcohol outlets and tobacco outlets was not found to be related to gestational age and birthweight-for-gestational age (Farley *et al.*,

2006). The alcohol and tobacco outlets in this study were all the outlets selling alcohol and tobacco for off-premise consumption which included convenience stores and other types of stores. In addition, Census tract-level rather than individual-level (like in our study) measures were used to evaluate the food outlet availability in their study. Last but not least, the proximity to convenience stores predicts the quality of neighborhood environment, including neighborhood income/poverty, education, employment, food access, crime/safety/stress etc. Previous studies have reported that deprived neighborhood was associated with adverse birth outcomes (Metcalfe *et al.*, 2011). In this study, we included the maternal education, urbanicity, and other types of food outlets (healthy stores, limited service restaurants) in the multivariate models, but the significant results for convenience stores remained.

The limited service restaurants were usually considered as a source of fast food (Creel *et al.*, 2008). According to the adjusted models, access to limited service restaurants was negatively associated with gestational age, and availability of these restaurants was positively associated with gestational age (2, 3 or more vs 0), and negatively associated with risk of PTB (1 vs 0). The results did not make sense that access to fast food should be associated with adverse birth outcomes. Moreover, the significant associations were only observed in the adjusted models but not in the unadjusted models. We believed the significant results from the adjusted models were not the true effects but the artifact of the statistical models. In Farley et al.'s study, no significant relationship between fast

food restaurant access and birth outcomes was found (Farley *et al.*, 2006), which was consistent with current study.

There were several limitations to this study. At first, the cross-sectional design limited temporal casual inference. We assumed that built food environment would not change a lot within one year (duration of pregnancy), and little possibility of reverse causation existed for food environment and birth outcomes. In addition, only distance to the nearest food outlet and count of food outlet within 1-mile buffer were requested for computation from DHEC. Studies showed that distance to the third nearest food outlet might capture more characteristics of the environment (Dutko *et al.*, 2013). Different buffer sizes allowed performing sensitivity analysis. Moreover, we would not know the mobility of mothers during pregnancy. Moving during pregnancy would cause misclassification on exposure. South Carolina DHEC provided us only computed spatial measures rather than the addresses (or other geographic information by which we could locate the mothers) of the mothers due to the security of data and protection of privacy. Without residential addresses, the potential spatial analysis was limited.

This study was a first attempt to examine the association between individual-level measures of accessibility and availability of food outlets and birth outcomes. The food outlet data were based on a ground-truthed field census which has been shown a significant improvement on data accuracy over other secondary data sources (Liese *et al.*, 2010). In addition, we included all births from 2008 to 2009 in the study area. Census survey data are more reliable and

accurate than those collected from sampling surveys. We also have large sample size in this study, which would increase the power of the statistical tests.

Conclusion

Farther away from a convenience store and smaller count of convenience stores around the residence were associated with larger birth weight and longer gestational age. No significant associations were captured for healthy food outlets and limited service restaurants. Future investigations with more comprehensive measures of built food environment were encouraged to understand the effect of access to healthy and unhealthy food outlets on birth outcomes. Spatial analysis might be needed to explore the correlation of various types of food outlets and its impact on birth outcomes.

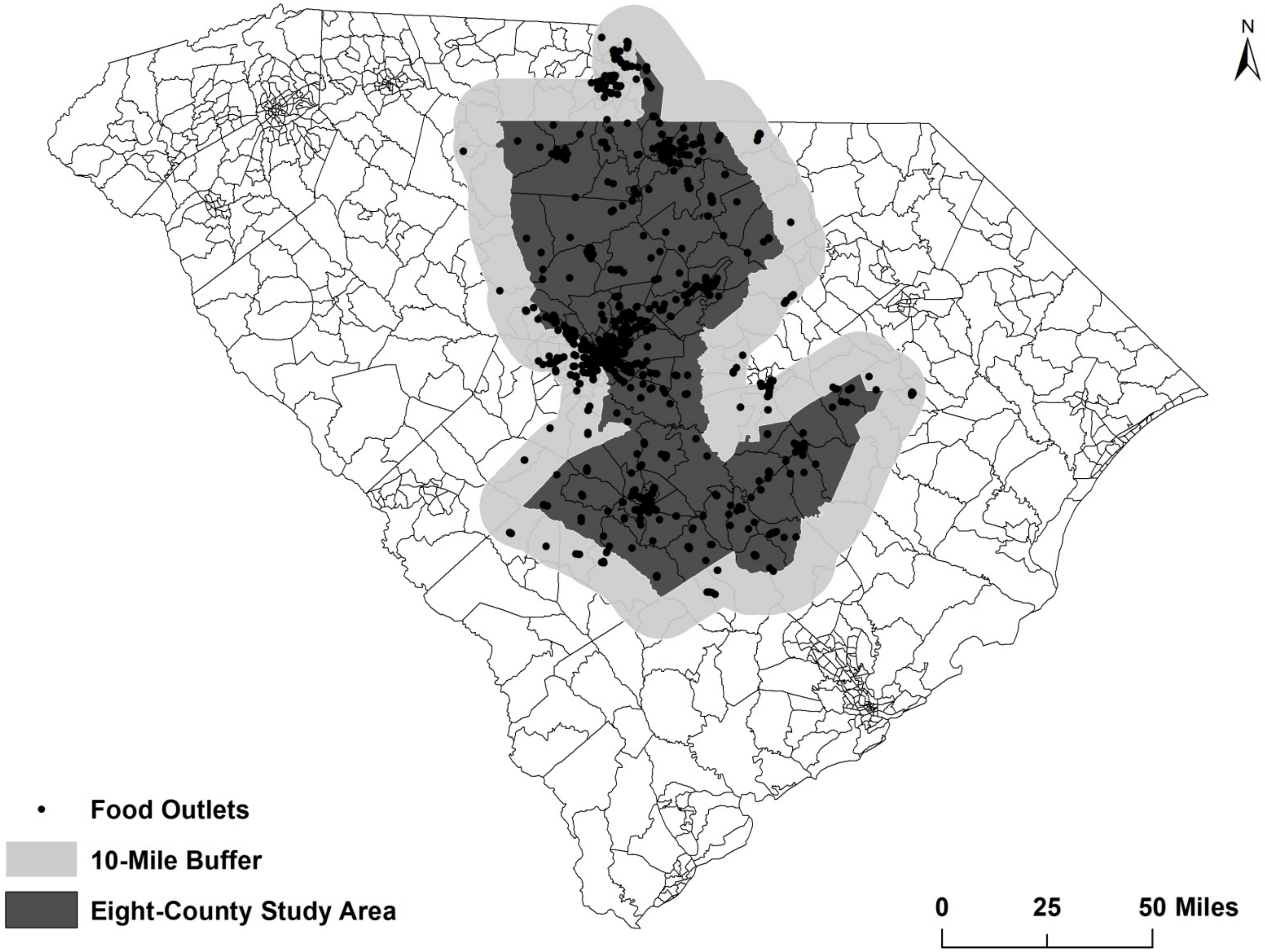

Figure 5.1 Study area with 10-mile buffer zone and food outlets

Table 5.1 Characteristics of sample in eight-county area in South Carolina

Variables	**Mean (SD) or Percentage, %**
Sample Size	15,786
Mother's Age, y	26.31 (6.03)
Male Birth	50.75
Non-Hispanic black	55.17
Mother's Education	
High school or less	42.82
Some college	33.15
Bachelor or above	24.03
WIC Participation	54.30
Living in Rural	51.99
Mother's Weight at Delivery, lb	192.36 (45.26)
Mother's Weight, lb	164.75 (45.68)
Body Mass Index	
Normal	43.45
Overweight	25.72
Obese	30.83
Smoking During Pregnancy	12.07
Birth Weight, g	3205.48 (506.56)
Low Birthweight	9.39
Gestational Age, w	38.26 (2.04)
Preterm Birth	10.45
Prenatal Care Begin <1st Trimester	73.25
Previous Live Birth	
0	42.34
1	31.95
2 or more	25.70
Previous Preterm Birth	3.86
Infection During Pregnancy	8.28
Gestational Hypertension	4.08
Hypertension	3.81
Gestational Diabetes Mellitus	5.91
Diabetes Mellitus	1.00

SD, standard deviation; WIC, the Special Supplemental Nutrition Program for Women, Infants, and Children.

Table 5.2 Summary of distance to the nearest food outlet and count of food outlet in 1 mile buffer by food outlet type in eight-county area in South Carolina

Food Outlets	**Mean**	**SD**	**Min**	**Median**	**Max**
Network Distance to the nearest food outlet, meters					
Healthy Store (N=243)	3902.6	3787.9	0	2595.1	33747.3
Convenience Store (N=504)	2580.9	2629.4	7.0	1638.5	24784.7
Limited Service Restaurant (N=971)	3402.0	3569.9	0	2026.1	29853.6
Count of food outlets within 1 mile buffer, N					
Healthy Store (N=243)	0.47	0.95	0	0	8
Convenience Store (N=504)	1.58	2.19	0	0	13
Limited Service Restaurant (N=971)	2.19	4.53	0	0	71

SD, standard deviation.

Table 5.3 The association between distance to the nearest food outlet (log-transformed) and birth outcomes in eight-county area in South Carolina

	Unadjusted Model	Model 1	Model 2
Birth Weight, β (95% CI)			
Distance to healthy store, miles	**24.6 (16.3, 32.8)**	4.9 (-3.9, 13.7)	-4.9 (-17.5, 7.7)
Distance to convenience store, miles	**40.6 (32.8, 48.3)**	**15.5 (7.4, 23.7)**	**22.4 (11.1, 33.7)**
Distance to limited service restaurant, miles	**21.7 (14.0, 29.4)**	5.5 (-2.8, 13.7)	-6.5 (-19.2, 6.1)
Low Birthweight, OR (95% CI)			
Distance to healthy store, miles	**0.92 (0.87, 0.97)**	0.99 (0.93, 1.05)	0.97 (0.89, 1.06)
Distance to convenience store, miles	**0.89 (0.85, 0.94)**	0.97 (0.92, 1.03)	0.94 (0.87, 1.01)
Distance to limited service restaurant, miles	**0.95 (0.90, 1.00)**	1.02 (0.96, 1.08)	1.09 (1.00, 1.19)
Gestational Age, β (95% CI)			
Distance to healthy store, miles	0.05 (0.02, 0.08)	-0.02 (-0.05, 0.02)	-0.00 (-0.06, 0.05)
Distance to convenience store, miles	**0.06 (0.02, 0.07)**	0.01 (-0.03, 0.04)	**0.05 (0.01, 0.10)**
Distance to limited service restaurant, miles	0.03 (-0.00, 0.06)	-0.03 (-0.06, 0.00)	**-0.06 (-0.11, -0.01)**
Preterm Birth, OR (95% CI)			
Distance to healthy store, miles	0.95 (0.90, 1.00)	1.03 (0.97, 1.10)	1.04 (0.96, 1.14)
Distance to convenience store, miles	**0.93 (0.89, 0.98)**	0.98 (0.93, 1.04)	0.94 (0.87, 1.01)
Distance to limited service restaurant, miles	0.96 (0.91, 1.01)	1.03 (0.97, 1.08)	1.04 (0.96, 1.13)

Adjusted variables are maternal age, race/ethnicity, maternal education, WIC participation, urbanicity in Model 1; distances to the nearest other food outlet types (log) were additionally adjusted in Model 2. CI, confidence interval; OR, odds ratio. For birth weight and gestational age, the models are multivariate linear regression models; for low birthweight and preterm birth, the models are multivariate logistic regression models. Bolded means $p<0.05$.

Table 5.4 The association between count of food outlets in 1-mile buffer (categorical) and birth outcomes in eight-county area in South Carolina

	Unadjusted Model	Model 1	Model 2
Birth Weight, β (95% CI)			
Count of healthy store			
1	**-46.6 (-68.4, -24.9)**	3.8 (-18.1, 25.7)	21.1 (-4.4, 46.6)
2 or more	2.4 (-35.8, 40.6)	-6.3 (-43.8, 31.2)	11.7 (-30.0, 53.3)
Count of convenience store			
1	**-51.6 (-77.2, -25.9)**	-15.0 (-40.8, 10.9)	-20.4 (-47.6, 6.8)
2	**-89.1 (-115.9, -62.4)**	**-36.4 (-63.2, -9.7)**	**-46.8 (-76.9, -16.6)**
3 or more	**-97.0 (-116.0, -78.1)**	**-34.9 (-54.6, -15.1)**	**-54.3 (-83.4, -25.1)**
Count of limited service restaurant			
1	**-62.4 (-88.4, -36.5)**	-14.7 (-40.8, 11.4)	5.4 (-24.2, 35.0)
2	**-57.4 (-93.8, -21.0)**	-17.6 (-54.5, 19.3)	3.5 (-37.5, 44.5)
3 or more	**-60.0 (-79.0, -41.0)**	-15.0 (-34.7, 4.6)	15.3 (-15.9, 46.5)
Low Birthweight, OR (95% CI)			
Count of healthy store			
1	**1.23 (1.07, 1.41)**	1.06 (0.91, 1.22)	1.07 (0.90, 1.26)
2 or more	0.81 (0.61, 1.07)	0.82 (0.61, 1.09)	0.83 (0.61, 1.14)
Count of convenience store			
1	1.09 (0.91, 1.29)	0.96 (0.80, 1.15)	0.97 (0.80, 1.18)
2	1.15 (0.96, 1.38)	0.95 (0.78, 1.14)	0.97 (0.79, 1.20)
3 or more	**1.26 (1.11, 1.43)**	1.01 (0.88, 1.16)	1.06 (0.86, 1.29)
Count of limited service restaurant			
1	**1.20 (1.02, 1.42)**	1.00 (0.84, 1.20)	0.98 (0.80, 1.20)
2	1.10 (0.86, 1.40)	0.96 (0.75, 1.24)	0.93 (0.70, 1.23)
3 or more	**1.15 (1.02, 1.31)**	0.97 (0.85, 1.11)	0.94 (0.76, 1.16)
Gestational Age, β (95% CI)			
Count of healthy store			
1	-0.13 (-0.21, -0.04)	-0.03 (-0.12, 0.06)	-0.08 (-0.19, 0.02)
2 or more	0.08 (-0.07, 0.23)	0.11 (-0.05, 0.26)	0.05 (-0.12, 0.22)
Count of convenience store			
1	**-0.10 (-0.21, -0.00)**	-0.07 (-0.17, 0.04)	-0.11 (-0.21, 0.00)
2	-0.10 (-0.21, 0.01)	-0.04 (-0.14, 0.07)	-0.09 (-0.22, 0.03)
3 or more	**-0.10 (-0.18, -0.02)**	0.02 (-0.06, 0.10)	-0.06 (-0.18, 0.06)
Count of limited service restaurant			
1	-0.05 (-0.15, 0.06)	0.04 (-0.06, 0.15)	0.10 (-0.02, 0.22)
2	0.04 (-0.11, 0.19)	0.10 (-0.05, 0.25)	**0.18 (0.01, 0.34)**
3 or more	-0.07 (-0.15, 0.00)	0.06 (-0.02, 0.14)	0.12 (-0.00, 0.25)
Preterm Birth, OR (95% CI)			
Count of healthy store			
1	**1.19 (1.05, 1.36)**	1.07 (0.93, 1.23)	1.09 (0.92, 1.28)
2 or more	0.83 (0.64, 1.08)	0.82 (0.62, 1.07)	0.84 (0.62, 1.13)
Count of convenience store			
1	1.07 (0.91, 1.26)	1.00 (0.84, 1.19)	1.06 (0.88, 1.27)
2	1.14 (0.96, 1.35)	1.04 (0.87, 1.24)	1.15 (0.94, 1.40)
3 or more	**1.20 (1.06, 1.35)**	1.06 (0.93, 1.21)	**1.22 (1.01, 1.48)**
Count of limited service restaurant			
1	1.03 (0.87, 1.21)	0.90 (0.75, 1.08)	**0.81 (0.67, 0.99)**
2	1.09 (0.87, 1.37)	1.00 (0.79, 1.27)	0.88 (0.67, 1.15)
3 or more	1.09 (0.97, 1.23)	0.96 (0.84, 1.09)	0.83 (0.67, 1.01)

Adjusted variables are maternal age, race/ethnicity, maternal education, WIC participation, urbanicity in Model 1; counts of other food outlet types in 1-mile buffer were additionally adjusted in Model 2. CI, confidence interval; OR, odds ratio. For birth weight and gestational age, the models are multivariate linear regression models; for low birthweight and preterm birth, the models are multivariate logistic regression models. Bolded means $p<0.05$.

CHAPTER 6

Neighborhood Deprivation and Adverse Birth Outcomes in South Carolina[1]

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Neighborhood Deprivation and Adverse Birth Outcomes in South Carolina

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Running title: Neighborhood deprivation and birth outcomes

Abstract

Background: An increasing number of studies have examined the association between neighborhood characteristics and birth outcomes. However, the results can be difficult to compare because of a variety of indicators used to measure the neighborhood. The neighborhood deprivation index (NDI), which measures several domains of neighborhood context, synthesizes multiple dimensions of neighborhood, and allows comparisons across geographic areas. This study aimed to examine the association between NDI and birth outcomes.

Methods: Level of Census tract deprivation was quantified by the NDI and computed from eight socioeconomic characteristics in Census 2000. All births from 2008-2009 in South Carolina (N=98,456) were assigned to an NDI quartile group based on residential addresses. Propensity score matching (PSM) was used to create matched pairs comprising NDI quartiles to avoid any potential inference on off-support data. The prevalence differences of low birthweight (LBW) and preterm birth (PTB) were then calculated between exposed and reference deprivation groups. As a comparison, random effects logistic regression models were also used to examine the association.

Results: Neighborhood deprivation was higher in non-Hispanic blacks than non-Hispanic whites. The overall prevalence of LBW and PTB was 5.9% and 8.5% for non-Hispanic whites, and 12.5% and 12.7% for non-Hispanic blacks. PSM results

suggested neighborhood deprivation was associated with increased risk of LBW among non-Hispanic whites, and with increased risk of PTB among non-Hispanic blacks. However, random effects logistic regression models identified the association between neighborhood deprivation and adverse birth outcomes only among non-Hispanic whites.

Conclusions: PSM and random effects logistic regression models generated inconsistent results. PSM might be an appropriate approach to avoid off-support inferences. Future research using PSM is encouraged to examine the effect of neighborhood deprivation on birth outcomes.

Key Words: neighborhood deprivation index, low birthweight, preterm birth, propensity score, matching, principal component analysis

Introduction

One of the most well-known health disparities between non-Hispanic whites and blacks in the United States is that of adverse birth outcomes. For instance in 2010, the prevalence of preterm birth (PTB) was 10.8% in non-Hispanic whites versus 17.1% in non-Hispanic blacks. The prevalence of low birthweight (LBW) was 7.1% and 13.5% among non-Hispanic whites and non-Hispanic blacks, respectively (Martin *et al.*, 2012). The racial disparities in birth outcomes were well documented but yet not explained. Previous discussions about known individual risk factors could not account for the racial disparities on adverse birth outcomes (Goldenberg *et al.*, 1996; Lu *et al.*, 2003).

Racial disparities vary across geographic regions with different political, economic, and social contexts (Nepomnyaschy, 2010; Teitler *et al.*, 2007), which suggests that studies focusing on neighborhood factors are needed to explain the racial disparities in birth outcomes (Metcalfe *et al.*, 2011). Neighborhood factors may shape individual maternal biological and behavior risk factors which may cause adverse birth outcomes through a variety of biological mechanisms (Masi *et al.*, 2007). For instance, physical and social conditions of the neighborhood may influence stress, nutrition, tobacco and substance abuse, and sexual behavior, which have been associated with adverse birth outcomes (Farley *et al.*, 2006; Metcalfe *et al.*, 2011). However, the relationships between neighborhood and birth outcomes are not consistent across studies. Some studies have identified the relationship between neighborhood factors and adverse birth outcomes (Agyemang *et al.*, 2009; Kaufman *et al.*, 2003; Masi *et al.*, 2007;

Messer *et al.*, 2006b; Schempf *et al.*, 2009), and some have not (Cubbin *et al.*, 2008), and some only demonstrated the associations among certain race groups (Buka *et al.*, 2003; Messer *et al.*, 2008; Pearl *et al.*, 2001; Pickett *et al.*, 2002).

A possible explanation for the inconsistency is that the various indicators have been used to characterize the neighborhood context. The results can be difficult to interpret and compare due to a variety of indicators being used. In 2006, Messer et al. developed a standardized Neighborhood Deprivation Index (NDI) to evaluate the neighborhood deprivation (Messer *et al.*, 2006c). This index has been linked to several birth outcomes such as LBW and PTB (Elo *et al.*, 2009; Janevic *et al.*, 2010b; O'Campo *et al.*, 2008).

NDI is usually coded as quartiles to allow for potential dose response relations in the association of deprivation and birth outcomes (Messer *et al.*, 2006c). However, the distribution of NDI quartiles can be extremely imbalanced across different race groups; often more white women live in less deprived areas, and more minority women live in more deprived areas. With the addition of covariates in an analysis, certain covariate strata may contain thin data or even only subjects who could never be exposed, leading to off-support inference (the inference based on no actual data) (Messer *et al.*, 2010). The propensity score matching (PSM) is a useful approach for dealing with these issues. A propensity score is defined as the conditional probability of being exposed to a condition (Rosenbaum *et al.*, 1983, 1984). The propensity score reduces the dimensionality of a large set of potential confounders to unity, making it conducive to simple pair matching (Oakes *et al.*, 2006). After exposure groups

are matched by propensity scores, they have been balanced on all relevant and available covariates. In this way, we reduce the observable bias while maintaining the support of the data.

This study aimed to examine the association between neighborhood deprivation (NDI) and adverse birth outcomes (LBW and PTB) based on all births in 2008-2009 in South Carolina, stratified by race groups. PSM was used to avoid any thin data among covariate categories caused by imbalanced distribution of data across race groups.

Methods

Study area and population. The study area was entire South Carolina State. According to US Census 2000, there were 867 Census tracts in SC. The populations of interest were non-Hispanic whites and non-Hispanic blacks. Birth certificates of all live births from January 1, 2008 to December 31, 2009 were obtained from the SC Department of Health and Environmental Control (DHEC). Within the period, there were 123,759 live births. After excluding births without Census tract information, multiple births, and births in Hispanic and other race groups (American Indian and Alaska Native, Asian Native Hawaiian and other Pacific Islander), and extreme outliers of birth weight (±3SD) and gestational age (less than 20 weeks), 98,456 births were included in the study. This study was approved by the Institutional Review Board at University of South Carolina and SC DHEC.

Measures. The algorithm published by Messer et al. was used to create the NDI for each Census tract in the study area using principal component analysis (PCA) (Messer *et al.*, 2006c). We used the same eight Census tract-level sociodemographic factors suggested by Messer et al. to compute the NDI to allow comparison with previous studies using this index. The factors include % population with less than high school, % unemployed population, % males in management occupations, % crowded housing, % households in poverty, % female head households with children, % households earning less than $30,000 per year, and % households on public assistance. The NDI was predicted based on the loadings of the eight factors in the first principal component. The NDI was standardized to have a mean of 0 and standard deviation (SD) of 1 by dividing the index by the square of the eigenvalue, and quartiles of NDI were then coded in to Q1 (least deprived), Q2, Q3 and Q4 (most deprived). Q1 was considered as the reference group. PCA analysis was conducted using the pca program in Stata (Version 10, College Station, TX).

Adverse birth outcomes included LBW and PTB, defined as birth weight less than 2,500 grams and gestational age less than 37 weeks, respectively.

In PSM analysis, to achieve best of fit of model to predict propensity scores, we included all appropriate covariates which were predictive of the exposure of interest and occurred prior to the outcome of interest. We included all the sociodemographic variables available in the dataset, including maternal age, maternal education, the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) participation, and urbanicity. Other

covariates expected to differ across exposure categories and which occurred prior to the adverse birth outcomes included body mass index (BMI), maternal smoking, prenatal care, number of previous live births, number of previous preterm births, and maternal risk factors such as infection, chronic and gestational hypertension, and diabetes.

Before the random effects logistic regression models were estimated, a directed acyclic graph (DAG) was used to identify potential confounders and mediators in the association between NDI and adverse birth outcomes. Sociodemographic factors, such as maternal age, maternal education, WIC participation, and urbanicity, were associated with both NDI and adverse birth outcomes, and were thought to cause or relate to NDI. Thus, they were considered as confounders in the analysis. Factors which were caused by NDI (or could not influence NDI) were thought to be mediators and were not included in the analysis, even if they were associated with both NDI and adverse birth outcomes, such as BMI, smoking during pregnancy, prenatal care, and birth or pregnancy risk factors.

Statistical analysis. A state-wide Census tract-level neighborhood deprivation map was created based on the quartiles of the NDI in ArcGIS (Version 10.0, ESRI). Effect modification was identified for race (non-Hispanic white and non-Hispanic black) by including the interaction term between race and NDI in logistic regression models, thus all analyses in this study were stratified by race. Population characteristics were summarized for the pooled sample and for

samples in each NDI quartile. Q2 to Q4 were compared to Q1 based on T-test for continuous variables and Chi square for categorical variables.

As shown in **Figure 6.1**, the distribution of NDI was imbalanced between non-Hispanic white and black women, with approximately 50% of non-Hispanic black women living in the most deprived areas. To avoid off-support inference due to the imbalanced distribution of NDI, we used PSM to analyze the relationship between NDI and adverse birth outcomes stratified by race. We used logistic regression to estimate the predicted probability of a mother's exposure to neighborhood deprivation to create matched pairs comparing NDI quartiles. All appropriate covariates discussed above were included in the models to achieve the best of the fit. The propensity scores were estimated for each mother, and computed separately for non-Hispanic whites and non-Hispanic blacks. We then matched the mothers living in deprived areas (Q2, Q3 and Q4, separately) with those living in the reference area (Q1) with the same propensity score. The matching procedure was conducted using the psmatch2 module in Stata. The mothers living in deprived areas were matched 1:1 with replacement to mothers living in reference areas with the same predicted probability of exposure to neighborhood deprivation within a range of ±0.01. We yielded a 100% matching between deprived group and reference group because of the large sample size. Balance tests were performed to compare the means and % bias prior to and after matching, and % bias reduction, with a goal of a % bias reduction of less than 10% indicating sufficient balance. The % bias is the percentage difference of the sample means in the deprived and reference group as a percentage of the

square root of the average of the sample variances (Rosenbaum *et al.*, 1985). The graph of propensity score overlap was drawn by level of neighborhood deprivation by race group. The differences in prevalence of adverse birth outcomes (LBW and PTB) were computed between matched deprived and reference group. The bootstrap method with 1,000 repetitions was used to calculate the 95% confidence intervals (CI).

To compare the PSM results to a typical regression analysis, we conducted random effects (women clustered in the Census tracts) multivariate logistic regression models to examine the association between NDI and adverse birth outcomes, stratified by race. The random effects regression models were fitted with xtlogit command for multilevel analysis in Stata.

Results

PCA results for the creation of NDI are shown in **Table 6.1**. Only the first principal component had an eigenvalue more than 1, accounting for 61.08% of the total variance. In the first principal component, all factors had acceptable high loadings from 0.28 for % males and females unemployed to 0.41 for % households earning <30,000/year. NDI was standardized with mean of 0 and SD of 1. After the mother/births were assigned to the Census tracts, the average NDI of the study population was -0.12 with SD of 0.95.

Based on the quartiles of NDI, a Census tract-level deprivation map was drawn in ArcGIS as shown in **Figure 6.2**. According to the map, the southeast half of South Carolina experienced more severe neighborhood deprivation than

the northwest half. City areas, such as Greenville, Columbia, and Charleston, were less deprived. However, several of the most deprived tracts in the state were centers of the cities.

Table 6.2 shows the characteristics of the sample. The overall prevalence of LBW and PTB were 5.9% and 8.5% for non-Hispanic whites, and 12.5% and 12.6% for non-Hispanic blacks. Average NDI was higher among non-Hispanic blacks than non-Hispanic whites in SC. Women residing in the second, third and fourth (most deprived) quartile of the NDI were more likely to experience younger age, lower level of education, higher proportion of WIC participation and rural residence, and worse birth outcomes than those living in the first (least deprived) quartile of the NDI, except for gestational age and PTB among non-Hispanic blacks.

PSM yielded 100% matching between deprived quartiles (Q2-4) and reference quartile (Q1) of the NDI. **Figure 6.3** graphically depicts the propensity score overlap by NDI quartiles among non-Hispanic whites (upper panel) and blacks (lower panel). The bars to the upper are propensity scores for the deprived group, those to the lower for the reference group. Generally, the overlap shown suggested comparability across the two exposure groups and there was adequate overlap between two exposure groups. Most of the overlap was in the middle of the propensity score distribution for Q2 vs Q1 and Q3 vs Q1, while most of the overlap for Q4 vs Q1 was on the left side of the distribution among non-Hispanic whites and the right side of the distribution among non-Hispanic blacks. Covariate balance tests are summarized in **Table 6.3**. After matching, %

bias reduction for covariates ranged from 0% to 7.4%, which achieved the 10% goal discussed in above. For most covariates the % bias was reduced after PSM.

Based on the matched pairs of deprived (Q2 or Q3 or Q4) and reference (Q1) mothers, prevalence differences were calculated for LBW and PTB in Non-Hispanic whites and blacks (**Table 6.4**). Among non-Hispanic whites, the prevalence difference between deprived and reference group ranged 0.02% to 2.02%, and 0.38% to 1.42% for LBW and PTB, respectively. According to the 95% CIs, only mothers living in the most deprived (Q4) areas had a significantly higher prevalence of LBW compared to those living in the least deprived (Q1) areas. For non-Hispanic blacks, compared to mothers living in the least deprived (Q1) areas, those living in the most deprived (Q4) areas experienced a 2.91% higher prevalence of PTB. No difference was found for other NDI quartiles and for LBW.

The results of multivariate random effects logistic regression models are shown in **Table 6.5**. In the models for non-Hispanic whites, mothers living in Q4 (most deprived) areas had 1.22 times and 1.13 times the odds of giving LBW and PTB births, respectively, when compared to mothers living in Q1 (least deprived) areas. However in the analysis for non-Hispanic blacks, no significant differences were found for either LBW or PTB among different neighborhood deprivation areas.

Discussion

In this study, we used the PSM method to examine the difference of prevalence of LBW and PTB between deprived and reference group. Moreover, we ran the analysis using random effects logistic regression models for comparison. The results from two methods were not entirely consistent. For instance, regression models failed to identify the association between NDI and PTB among non-Hispanic blacks, and the LBW prevalence difference was not significant between Q4 and Q1 among non-Hispanic whites from PSM as it was using regression. Compared to regression models, PSM weights the data differently and bases its inference on actual data only. In this study, the distribution of NDI was imbalanced between non-Hispanic whites and blacks. When the covariates were added in the multivariate models, there would be thin data in some categories which would result in inferences based on extrapolation, interpolation, regression smoothing, and imputation more generally (Oakes *et al.*, 2006). The problems appear not solved but amplified in multilevel regression models as we did in this study (Oakes, 2004). PSM method matches subjects with the same probability of having been exposed, and one of them is exposed and the other is not. This is what randomization does, and the observed difference between exposed and non-exposed group is attributed to the exposure alone as in randomized experiments. In this situation, we preferred to use PSM method and trusted the prevalence differences from the method.

A number of studies have demonstrated a positive association between neighborhood deprivation and adverse birth outcomes, however, the results were

inconsistent for different race groups (Elo *et al.*, 2009; Janevic *et al.*, 2010b; Messer *et al.*, 2006c; Messer *et al.*, 2008; O'Campo *et al.*, 2008). Elo et al. found that the association between neighborhood deprivation and SGA did not vary significantly by race (Elo *et al.*, 2009). In Janevic et al.'s study, significant association was reported for PTB among only Hispanic Caribbean and for term LBW among only African women (Janevic *et al.*, 2010b). However, several studies claimed bigger neighborhood effect on PTB among non-Hispanic whites than among non-Hispanic blacks (Messer *et al.*, 2006c; Messer *et al.*, 2008; O'Campo *et al.*, 2008). Most these studies utilized logistic regression models to examine the association between NDI quartiles and adverse birth outcomes. Our results confirmed that the association between neighborhood deprivation and adverse birth outcomes varied by race. As shown in Messer et al.'s study, thin data (reported as less than 100 births) were shown in Q4 (most deprived areas) or Q1 (least deprived areas) quartiles in several study sites due to imbalanced distribution of NDI by race, by which the tests on rate differences could not be performed (Messer *et al.*, 2006c). However, no multivariate analysis was conducted in this study. The situation would be worse if covariate variables were included in the analysis. In a later study by Messer et al, the off-support inferences were examined systematically and they concluded that many of the regression model findings were off-support and based on no actual data (Messer *et al.*, 2010).

To allow comparability with other studies, we created the NDI based on the same eight Census SES variables used in previous studies rather than the

variables explaining the most variance in our study area (Elo *et al.*, 2009; Messer *et al.*, 2006c; O'Campo *et al.*, 2008). If we developed the index based on the variables with the biggest weights for SC state only, we would include “% non-Hispanic black” (loading of 0.27) and “median house value” (loading of 0.26) but exclude “% female head with child” (loading of 0.24) and “household in poverty” (loading of 0.24). The total variance for the first principal component from the PCA analysis would be only 35.0% with these SC-specific variables. In this study, based on the variables by Messer et al. (Messer *et al.*, 2006c), the percentage of explained variance of the first principal component was 61.1%, which meant that the computed NDI in this study account for an acceptable variance in the neighborhood.

The findings are subject to several limitations. Although PSM was preferred for the data pattern in this study, there are some limitations for this method. PSM did not account for unobserved or unobservable characteristics. Rosenbaum has developed a method of sensitivity analysis to assess if one's estimated based on matching is robust to the possible presence of an unobserved confounder (Rosenbaum, 2005). Based on this sensitivity analysis, we yielded the tight confidence bounds around the log odds of differential assignment due to unobserved factors and the very small Hodges-Lehmann point estimates, which indicated that unmeasured confounding was inconsequential. Moreover, the PSM did not incorporate the “clustering” of the neighborhood. However, small within-tract variance was found from multilevel logistic regression models (the ICCs were less than 0.02) in this study. In addition to the limitations

of PSM, there were several limitations on the data. First, we only had the 2000 Census tract number for the mothers in the database. The birth data are closer to 2010, thus using 2000 Census data might cause bias. In addition, we used WIC participation as a substitute of income level, because household income was the only criteria to evaluate WIC eligibility. However, WIC participation was just a dichotomous variable. Moreover, there were approximately 6.4% mothers (N=6,345) without WIC participation information. Excluding those mothers in the regression analysis might cause selection bias, even though we compared the characteristics between those without WIC participation information and the original population and no significant differences were found.

Despite these limitations, this study had several strengths beyond previous studies. In general, because the matching was 1:1 based on the propensity scores, there would be observations which could not be matched. However in our study, the huge sample size allowed to yield 100% matching between deprived and reference groups. The matched pairs were even more than the sample size, because we did the matching with replacement by which the matched observations would be returned to the pool for future potential matching. PSM method is not a new approach (Rosenbaum *et al.*, 1983), but it has only started to be used in social epidemiology and reproductive health research in recent years (Hearst *et al.*, 2008; Johnson *et al.*, 2008; Oakes *et al.*, 2006). However, to our knowledge, no studies to date used PSM method to examine the association between NDI and adverse birth outcomes. In addition, this is the first study on neighborhood deprivation and birth outcomes in South

Carolina where racial disparities on adverse birth outcomes are a serious public health concern.

Conclusion

PSM and logistic regression models generated inconsistent results. PSM results suggested neighborhood deprivation was associated with increased risk of LBW among non-Hispanic whites, and with increased risk of PTB among non-Hispanic blacks. However, logistic regression models with random effects identified the association between neighborhood deprivation and adverse birth outcomes only among non-Hispanic whites. Off-support inference might explain the inconsistency. PSM might be an appropriate approach to avoid off-support inferences. Future research using PSM is encouraged to examine the effect of neighborhood deprivation on birth outcomes.

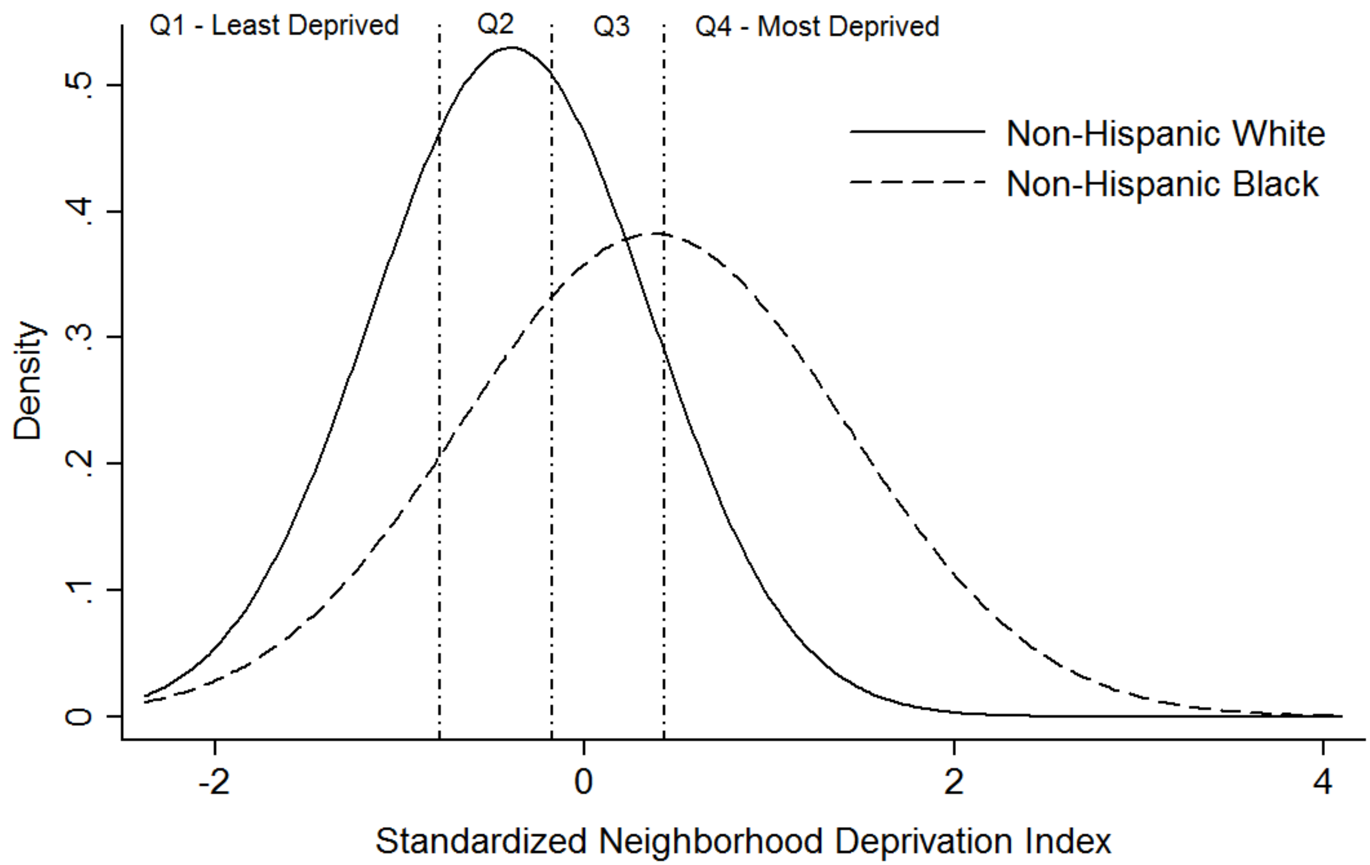

Figure 6.1 Distribution of neighborhood deprivation index by race in South Carolina

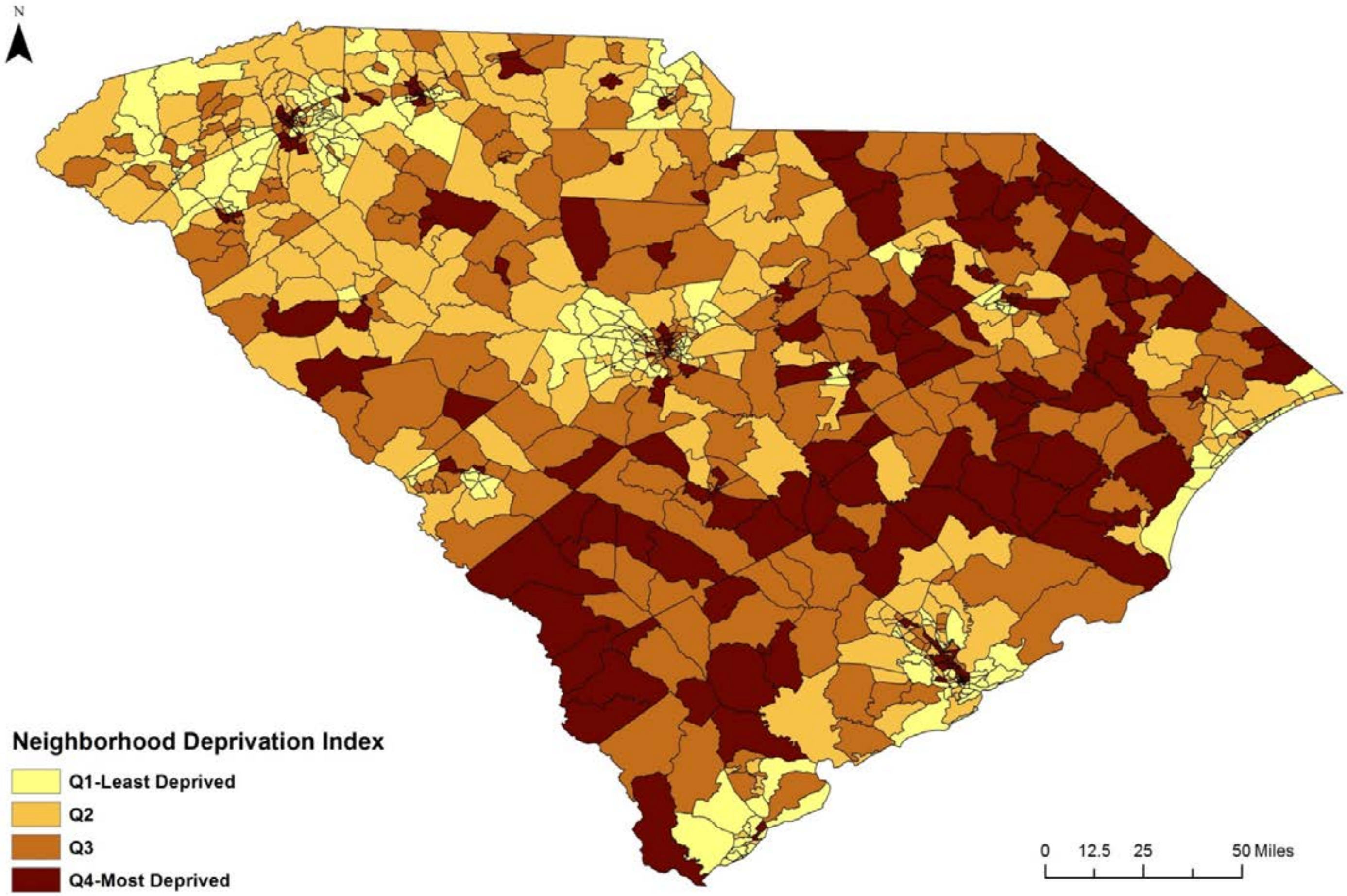

Figure 6.2 Distribution of Neighborhood Deprivation Index in South Carolina (Census tract level)

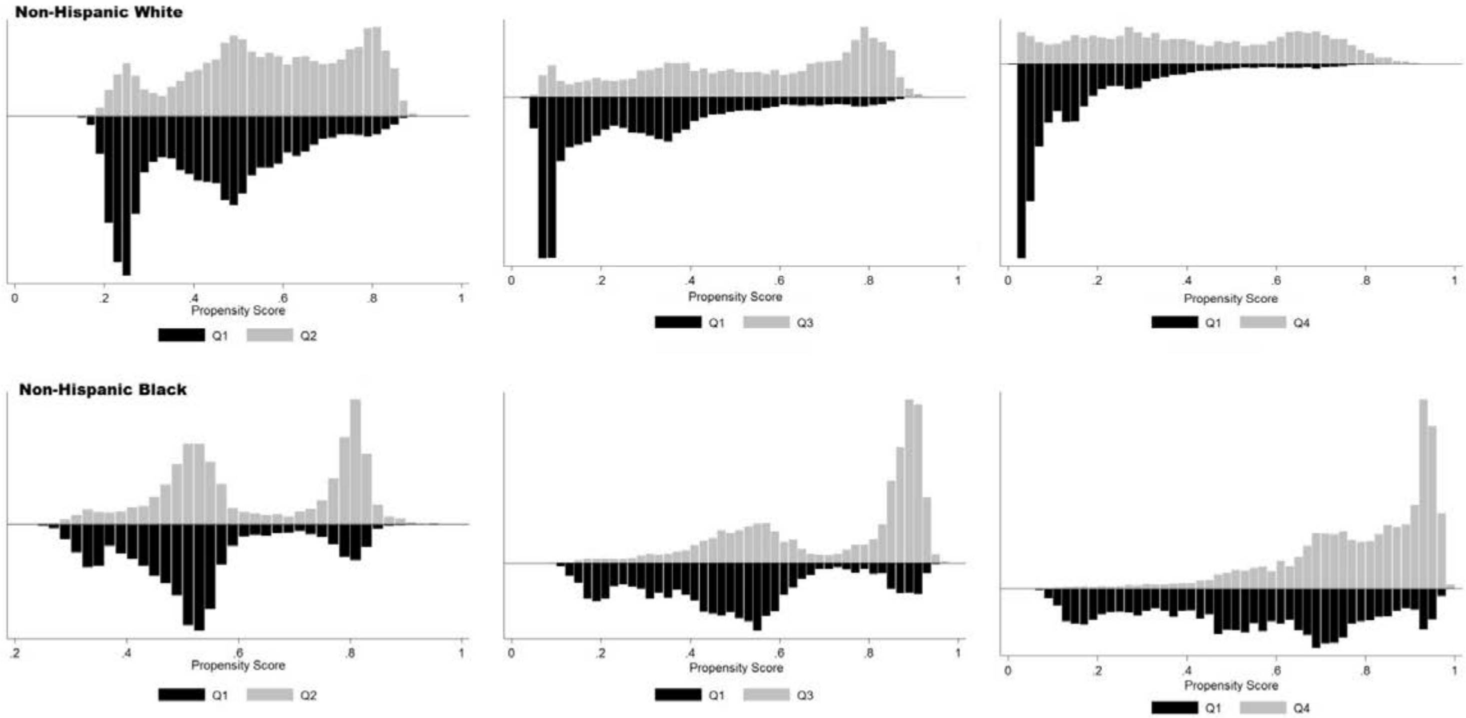

Figure 6.3 Propensity score overlap by level of neighborhood deprivation for non-Hispanic white (upper panel) and black (lower panel)

Table 6.1 Loadings of variables of first principal component from PCA

Variables (N=867 Census Tracts**)**	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**	**PC8**
Education Domain								
% Males and females less than high school	0.37	-0.37	-0.22	0.16	0.00	0.59	0.52	-0.19
Employment Domain								
% Males and females unemployed	0.28	0.70	-0.47	-0.37	-0.23	0.16	0.06	0.07
Housing Domain								
% Crowded housing	0.33	-0.07	0.47	-0.66	0.41	0.22	-0.13	0.03
Occupation Domain								
% Males in management occupations	-0.32	0.55	0.38	0.33	0.34	0.36	0.30	0.10
Poverty Domain								
% Household in poverty	0.39	0.22	-0.11	0.28	0.48	-0.31	-0.12	-0.61
% Female head with child	0.36	0.11	0.49	0.01	-0.40	-0.44	0.52	-0.01
% Households earning <$30,000/year	0.41	-0.05	-0.17	0.28	0.34	-0.18	0.00	0.76
% Households on public assistance	0.37	0.10	0.31	0.38	-0.40	0.35	-0.57	0.00
Eigenvalue	4.89	0.78	0.69	0.50	0.47	0.33	0.23	0.11
Variance, %	61.08	9.73	8.66	6.31	5.86	4.07	2.91	1.38

PCA, principal component analysis; PC, principal component.

Table 6.2 Characteristics of sample by quartiles of neighborhood deprivation index in South Carolina

Variables	**Mean (SD) or Percentage, %**					**P for Trend**
	Q1	**Q2**	**Q3**	**Q4**	**Total**	
Non-Hispanic White	N=21,895	N=21,662	N=12,713	N=6,153	N=62,423	
Mother's Age, y	29.1 (5.7)	26.7 (5.8)*	25.9 (5.7)*	25.5 (5.7)*	27.3 (5.9)	<0.01
Mother's Education						
High school or less	21.3	41.4*	49.0*	55.5*	37.3	<0.01
Some college	29.8	34.1	32.7	29.7	31.9	
Bachelor or above	48.9	24.5	18.4	14.8	30.8	
WIC Participation	23.1	43.9*	52.8*	60.9*	40.2	<0.01
Living in Rural	26.2	52.7*	68.3*	62.3*	47.5	<0.01
Birth Weight, g	3388.2 (492.6)	3348.0 (505.6)*	3322.8 (506.0)*	3290.4 (513.8)*	3351.3 (503.0)	<0.01
Low Birthweight	4.98	6.16*	6.43*	7.56*	5.94	<0.01
Gestational Age, w	38.6 (1.7)	38.5 (1.9)*	38.5 (1.8)*	38.4 (1.9)*	38.5 (1.8)	<0.01
Preterm Birth	7.79	8.51*	8.81*	9.91*	8.46	<0.01
NDI	-1.19 (0.32)	-0.37 (0.19)*	0.23 (0.18)*	1.00 (0.42)*	-0.40 (0.75)	<0.01
Non-Hispanic Black	N=5,303	N=7,482	N=9,362	N=13,886	N=36,033	
Mother's Age, y	26.3 (6.2)	25.1 (5.8)*	24.5 (5.7)*	24.0 (5.5)*	24.7 (5.8)	<0.01
Mother's Education						
High school or less	38.8	49.5*	58.1*	67.4*	57.1	<0.01
Some college	37.8	38.1	34.2	27.8	33.1	
Bachelor or above	23.3	12.4	7.7	4.7	9.8	
WIC Participation	61.1	72.2*	79.6*	82.0*	76.3	<0.01
Living in Rural	17.5	45.5*	61.8*	53.7*	48.8	<0.01
Birth Weight, g	3147.6 (499.5)	3129.0 (495.5)*	3099.9 (493.8)*	3088.1 (490.2)*	3108.4 (494.5)	<0.01
Low Birthweight	11.90	11.84	12.70	12.89	12.48	<0.05
Gestational Age, w	38.1 (2.4)	38.1 (2.4)	38.2 (2.4)	38.1 (2.4)	38.1 (2.4)	0.927
Preterm Birth	12.41	12.64	12.12	12.91	12.57	0.390
NDI	-1.15 (0.28)*	-0.33 (0.19)*	0.27 (0.17)*	1.40 (0.75)*	0.37 (1.04)	<0.01

SD, standard deviation; WIC, women infants children; BMI, body mass index; Q: Neighborhood Deprivation Index quartiles (Q1-less deprived to Q4-more deprived). Q1 was used as the reference group, and all other three groups were compared to the reference. T-test and Chi square were used to compare for continuous and categorical variables, respectively. *: p<0.05.

Table 6.3 Covariates imbalance across Neighborhood Deprivation Index quartiles prior to and after matching by race in all births 2008-2009 in South Carolina

Covariates	Prior to Matching			After Matching			%Bias
	Exposed	Control	%Bias	Exposed	Control	%Bias	Reduction
Non-Hispanic White							
Q2 vs Q1							
Maternal age	26.7	29.1	-42.6	26.7	26.3	5.5	87.2
Some college	34.2	29.8	9.2	34.2	34.9	-1.7	82.1
Bachelor or above	24.5	48.9	-52.3	24.5	24.1	0.8	98.5
WIC participation	43.9	23.1	45.2	43.9	43.3	1.3	97.2
Living in rural	52.7	26.2	56.4	52.7	51.9	1.8	96.8
Overweight	24.8	23.8	2.3	24.8	24.3	1.0	56.7
Obese	25.5	19.2	15.2	25.5	25.4	0.2	98.4
Smoking During Pregnancy	17.5	8.8	25.7	17.5	17.2	0.8	96.9
Prenatal Care in 1^{st} Trimester	22.5	19.1	8.4	22.5	21.5	2.6	69.1
Previous 1 Live Birth	33.7	35.3	-3.4	33.7	33.1	1.1	66.3
Previous 2+ Live Birth	21.8	21.0	1.9	21.8	20.4	3.4	-82.7
Previous Preterm Birth	2.2	2.2	0.1	2.2	1.8	2.7	-2260.9
Infection During Pregnancy	4.2	3.9	1.8	4.2	3.7	2.6	-48.6
Hypertension	2.0	1.7	2.2	2.0	1.4	4.1	-87.8
Gestational Hypertension	5.8	5.4	1.6	5.8	5.1	2.8	-71.7
Diabetes	0.8	0.6	1.5	0.8	0.6	2.2	-54.2
Gestational Diabetes	4.9	4.7	1.2	4.9	4.7	1.0	19.6
Q3 vs Q1							
Maternal age	25.9	29.1	-55.5	25.9	25.6	6.1	89.0
Some college	32.7	29.8	6.2	32.7	33.1	-0.9	85.9
Bachelor or above	18.4	48.9	-68.2	18.4	18.8	-1.0	98.6
WIC participation	52.8	23.1	64.3	52.8	52.4	0.8	98.7
Living in rural	68.3	26.2	93.0	68.3	68.4	-0.3	99.7
Overweight	24.7	23.8	2.2	24.7	24.8	-0.3	88.0
Obese	28.3	19.2	21.5	28.3	27.8	1.2	94.3
Smoking During Pregnancy	19.9	8.8	31.8	19.9	19.0	2.4	92.4
Prenatal Care in 1^{st} Trimester	23.6	19.1	11.1	23.6	22.6	2.5	77.7
Previous 1 Live Birth	33.5	35.3	-3.7	33.5	33.3	0.4	89.8
Previous 2+ Live Birth	23.8	21.0	6.6	23.8	21.4	5.7	14.5
Previous Preterm Birth	2.2	2.2	-0.0	2.2	1.7	3.4	-16728.9
Infection During Pregnancy	5.6	3.9	7.9	5.6	5.9	-1.4	82.2
Hypertension	1.9	1.7	1.6	1.9	1.6	2.0	-27.7
Gestational Hypertension	5.2	5.4	-1.0	5.2	4.9	1.2	-22.2
Diabetes	0.7	0.6	1.0	0.7	0.6	1.9	-87.8
Gestational Diabetes	4.7	4.7	0.2	4.7	4.2	2.2	-1364.2
Q4 vs Q1							
Maternal age	25.5	29.1	-63.4	25.5	25.2	5.3	91.7
Some college	29.7	29.8	-0.3	29.7	30.5	-1.7	-585.0
Bachelor or above	14.8	48.9	-78.6	14.8	14.5	0.7	99.1
WIC participation	60.9	23.1	82.9	60.9	60.1	1.7	97.9
Living in rural	62.3	26.2	78.0	62.3	62.6	-0.7	99.1
Overweight	25.1	23.8	3.2	25.1	25.2	-0.2	93.4
Obese	29.9	19.2	25.1	29.9	29.9	-0.1	99.7
Smoking During Pregnancy	21.7	8.8	36.3	21.7	20.8	2.4	93.5
Prenatal Care in 1^{st} Trimester	25.8	19.1	16.2	25.8	24.8	2.6	84.0
Previous 1 Live Birth	33.0	35.3	-4.8	33.0	32.4	1.4	71.0
Previous 2+ Live Birth	25.3	21.0	10.1	25.3	25.2	0.3	97.5
Previous Preterm Birth	2.2	2.2	0.3	2.2	1.9	1.9	-654.1
Infection During Pregnancy	4.9	3.9	5.2	4.9	4.7	1.3	75.5
Hypertension	2.4	1.7	4.9	2.4	1.8	4.1	17.6
Gestational Hypertension	5.2	5.4	-0.7	5.2	4.5	3.2	-365.6
Diabetes	0.6	0.6	-0.4	0.6	0.6	-0.1	75.4
Gestational Diabetes	4.6	4.7	-0.3	4.6	4.1	2.4	-618.0

Q: Neighborhood Deprivation Index quartiles (Q1-less deprived to Q4-more deprived).

Table 6.3 Covariates imbalance across Neighborhood Deprivation Index quartiles prior to and after matching by race in all births 2008-2009 in South Carolina (cont.)

Covariates	Prior to Matching			After Matching			%Bias
	Exposed	Control	%Bias	Exposed	Control	%Bias	Reduction
Non-Hispanic Black							
Q2 vs Q1							
Maternal age	25.1	26.3	-18.7	25.1	24.8	4.9	73.5
Some college	38.1	37.8	0.5	38.1	39.0	-1.9	-259.0
Bachelor or above	12.4	23.3	-28.8	12.4	12.1	0.9	96.8
WIC participation	72.2	61.1	23.6	72.2	72.2	-0.0	99.9
Living in rural	45.5	17.5	63.1	45.4	45.7	-0.7	98.9
Overweight	26.4	27.5	-2.4	26.4	27.3	-2.1	14.2
Obese	37.5	35.3	4.5	37.5	36.1	2.9	34.8
Smoking During Pregnancy	6.6	5.1	6.6	6.6	6.0	2.7	59.1
Prenatal Care in 1st Trimester	34.0	32.7	2.8	34.0	33.2	1.8	35.6
Previous 1 Live Birth	30.4	30.9	-1.1	30.4	30.9	-1.0	4.1
Previous 2+ Live Birth	27.6	25.6	4.5	27.6	25.8	4.1	9.2
Previous Preterm Birth	3.6	4.0	-1.8	3.6	2.6	5.2	-181.1
Infection During Pregnancy	11.7	10.9	2.4	11.7	11.9	-0.6	73.6
Hypertension	4.0	3.7	1.7	4.0	3.2	4.0	-130.8
Gestational Hypertension	5.6	5.9	-1.7	5.6	5.0	2.2	-31.0
Diabetes	1.3	1.0	2.7	1.3	0.9	3.8	-41.2
Gestational Diabetes	5.2	5.3	-0.6	5.2	4.4	3.3	-449.4
Q3 vs Q1							
Maternal age	24.5	26.3	-29.0	24.5	24.4	1.7	94.0
Some college	34.2	37.8	-7.6	34.2	34.6	-1.0	87.3
Bachelor or above	7.7	23.3	-44.1	7.7	7.0	2.1	95.3
WIC participation	79.6	61.1	41.4	79.6	78.1	3.4	91.7
Living in rural	61.8	17.5	101.4	61.8	62.0	-0.4	99.6
Overweight	26.0	27.5	-3.3	26.0	26.7	-1.5	54.8
Obese	40.1	35.3	9.9	40.1	38.6	3.1	69.0
Smoking During Pregnancy	6.9	5.1	7.5	6.8	7.6	-3.2	56.4
Prenatal Care in 1st Trimester	36.8	32.7	8.7	36.8	37.2	-0.8	91.0
Previous 1 Live Birth	29.6	30.9	-2.9	29.6	31.2	-3.7	-28.7
Previous 2+ Live Birth	29.7	25.6	9.1	29.7	27.7	4.5	51.1
Previous Preterm Birth	3.4	4.0	-2.9	3.4	3.1	1.7	41.8
Infection During Pregnancy	13.4	10.9	7.7	13.4	13.0	1.2	83.7
Hypertension	4.0	3.7	1.7	4.0	3.0	5.1	-190.9
Gestational Hypertension	5.7	5.9	-1.2	5.7	6.7	-4.5	-291.1
Diabetes	1.4	1.0	3.0	1.3	1.0	3.0	0.4
Gestational Diabetes	4.5	5.3	-3.7	4.5	3.9	2.8	24.7
Q4 vs Q1							
Maternal age	24.0	26.3	-37.8	24.0	23.6	7.4	80.4
Some college	27.8	37.8	-21.4	27.8	27.1	1.5	93.1
Bachelor or above	4.7	23.3	-55.6	4.7	4.1	1.8	96.8
WIC participation	82.0	61.1	47.5	82.0	82.9	-2.2	95.4
Living in rural	53.7	17.5	81.4	53.7	52.8	2.0	97.6
Overweight	25.4	27.5	-4.8	25.4	24.7	1.5	69.2
Obese	40.0	35.3	8.8	40.0	38.0	3.2	63.6
Smoking During Pregnancy	7.9	5.1	11.6	7.9	7.1	3.5	69.7
Prenatal Care in 1st Trimester	39.9	32.7	15.1	39.9	40.4	-1.1	93.0
Previous 1 Live Birth	29.3	30.9	-3.5	29.3	31.1	-3.8	-10.6
Previous 2+ Live Birth	33.7	25.6	17.8	33.7	31.3	5.2	70.6
Previous Preterm Birth	3.4	4.0	-3.1	3.4	2.9	2.6	18.1
Infection During Pregnancy	13.8	10.9	8.7	13.8	14.6	-2.4	72.1
Hypertension	4.1	3.7	2.0	4.1	3.5	2.9	-40.8
Gestational Hypertension	5.0	5.9	-4.3	5.0	5.7	-3.2	25.4
Diabetes	1.3	1.0	2.4	1.3	1.6	-3.2	-32.3
Gestational Diabetes	4.1	5.3	-5.7	4.1	3.5	2.9	49.5

Q: Neighborhood Deprivation Index quartiles (Q1-less deprived to Q4-more deprived).

Table 6.4 Difference of prevalence of low birthweight and preterm birth between Neighborhood Deprivation Index quartiles after propensity score matching by race in all births 2008-2009 in South Carolina

	Matched Pairs	**Prevalence in Deprived Group, %**	**Prevalence in Q1, %**	**Prevalence Difference, %**	**Bias-Corrected 95% CI***
Non-Hispanic White					
LBW					
Q2 vs Q1	21,895	6.16	6.14	0.02	-1.04, 0.51
Q3 vs Q1	21,895	6.43	5.84	0.59	-1.02, 1.49
Q4 vs Q1	21,895	7.56	5.55	**2.02**	**0.71, 3.40**
PTB					
Q2 vs Q1	21,895	8.51	8.13	0.38	-0.77, 1.61
Q3 vs Q1	21,895	8.81	8.57	0.24	-1.90, 1.30
Q4 vs Q1	21,895	9.90	8.48	1.42	-0.46, 2.84
Non-Hispanic Black					
LBW					
Q2 vs Q1	7,482	11.85	11.49	0.36	-1.94, 1.93
Q3 vs Q1	9,362	12.70	12.74	-0.03	-2.39, 1.73
Q4 vs Q1	13,886	12.89	11.91	0.98	-1.26, 2.87
PTB					
Q2 vs Q1	7,482	12.65	11.22	1.43	-1.22, 2.87
Q3 vs Q1	9,362	12.11	12.13	-0.02	-2.91, 1.64
Q4 vs Q1	13,886	12.91	10.00	**2.91**	**1.48, 4.92**

Abbreviations: LBW, low birthweight; PTB, preterm birth; CI, confidence interval. Q: Neighborhood Deprivation Index quartiles (Q1-less deprived to Q4-more deprived). *: The bias-corrected 95% CIs were calculated by bootstrap method with 1000 replications.

Table 6.5 The association between Neighborhood Deprivation Index quartiles and low birthweight and preterm birth from random-effect logistic regressions by race in all births 2008-2009 in South Carolina

Variables	**OR (95% CI)**	
	Low Birthweight	**Preterm Birth**
Non-Hispanic White	**N=57,631**	**N=57,608**
NDI		
Q1	1.00	1.00
Q2	1.08 (0.98, 1.20)	1.02 (0.94, 1.12)
Q3	1.09 (0.97, 1.22)	1.03 (0.94, 1.14)
Q4	**1.22 (1.07, 1.40)**	**1.13 (1.01, 1.27)**
Mother's age, y	**1.01 (1.00, 1.02)**	**1.01 (1.01, 1.02)**
Mother's education		
High school or less	1.00	1.00
Some college	**0.72 (0.66, 0.78)**	**0.85 (0.79, 0.91)**
Bachelor or above	**0.50 (0.45, 0.56)**	**0.65 (0.60, 0.72)**
WIC participation	1.02 (0.93, 1.10)	0.95 (0.89, 1.02)
Living in rural	1.04 (0.96, 1.13)	**1.08 (1.01, 1.16)**
Non-Hispanic Black	**N=34,373**	**N=34,356**
NDI		
Q1	1.00	1.00
Q2	1.00 (0.89, 1.13)	1.06 (0.94, 1.20)
Q3	1.06 (0.94, 1.19)	1.01 (0.89, 1.14)
Q4	1.06 (0.95, 1.19)	1.07 (0.96, 1.21)
Mother's age, y	**1.01 (1.01, 1.02)**	**1.03 (1.02, 1.03)**
Mother's education		
High school or less	1.00	1.00
Some college	**0.81 (0.75, 0.87)**	**0.87 (0.81, 0.94)**
Bachelor or above	**0.69 (0.60, 0.78)**	**0.61 (0.54, 0.70)**
WIC participation	**0.80 (0.74, 0.86)**	**0.72 (0.66, 0.77)**
Living in rural	1.03 (0.96, 1.11)	1.00 (0.92, 1.07)

Adjusted variables are maternal age, maternal education, WIC participation, and urbanicity.
CI, confidence interval; OR, odds ratio; WIC, women infants children; Q, quartile. Bolded means $p<0.05$.

CHAPTER 7

Summary

In summary, for **Specific Aim 1**, we found that mothers living in food deserts did not have different birth outcomes compared to those living in high-income and high-food-access areas. Neighborhood income is more important than food access in predicting birth outcomes. For **Specific Aim 2**, the results suggested that accessibility and availability of convenience stores were each associated with adverse birth outcomes. No significant associations were captured for healthy food outlets and limited service restaurants with birth outcomes. For **Specific Aim 3**, the Propensity score matching analyses identified neighborhood deprivation as associated with increased risk of LBW among non-Hispanic whites, and with increased risk of PTB among non-Hispanic blacks. However, logistic regression models identified the association between neighborhood deprivation and adverse birth outcomes only among non-Hispanic whites. PSM might be an appropriate approach to avoid off-support inferences.

Validity of Food Outlet Data

Food outlet data were used to define food desert and compute food access (availability and accessibility of food outlets) in this study. Studies have shown that there are always errors and inaccuracies in food outlet data (Liese *et*

al., 2013; Liese *et al.*, 2010). The common types of inaccuracy in the food outlet data included errors in count, type, and geographic location of the food outlets. In this study, the ground-truthed data were only available for an eight-county study area, thus we used secondary data sources (InfoUSA and DHEC data) for areas outside the eight-county region. Compared to ground-truthed food outlet data, secondary data had more inaccuracies (Liese *et al.*, 2013; Liese *et al.*, 2010). Therefore, bias might be introduced into this study due to the inaccuracies in the food outlet data, especially in areas outside the eight-county region.

Inaccuracy of food outlet data was a type of misclassification bias of exposure, because we used food outlet data to define the exposure of food environment in this study. This misclassification is either differential or non-differential bias depending on the birth outcomes. If the inaccuracies from the data sources are independent of birth outcomes, the bias will be non-differential. The non-differential misclassification bias is most likely toward to null, which means the associations between food environment and birth outcomes are under-estimated. If the inaccuracies are differential on births with or without adverse birth outcome of interest, the bias is differential and the direction of the bias could be either toward to or away from the null. If the food outlet data source tends to overcount the food outlets in the areas where mothers giving the births with adverse birth outcome, the association between food access and birth outcome will be under-estimated and the bias is toward to the null. In another way, if the secondary data source tends to undercount the food outlets in areas where mothers giving the births with adverse birth outcome, the association will

be over-estimated and the bias is away from the null. In Dr. Liese et al.'s study, undercount error of supermarket and grocery store was more likely to be found in less deprived areas for InfoUSA data (Liese *et al.*, 2013). Therefore, the association between food environment and birth outcomes was more likely to be under-estimated in this study.

Quality of Birth Certificate Data

Birth certificate data were used in this study. Birth certificate data are an important resource for researchers, policy makers, and state officials to evaluate the quality of care being delivered to pregnancy women. The quality of birth certificate data is very important and the errors and inaccuracies in the dataset will bias the results in the studies relying on the data. According to the validation studies on birth certificate data, birth certificate data tended to under-report the information for most variables (Clark *et al.*, 1997; Dobie *et al.*, 1998; Reichman *et al.*, 2001). Demographic characteristics, gestational age and method of delivery in the birth certificates showed good quality. Maternal medical and risk factors (including chronic and gestational hypertension, chronic and gestational diabetes), prenatal care, alcohol and tobacco use during pregnancy in birth certificate data were reported a poor to moderate quality. Other variables, such as pregnancy weight, height, weight gain during pregnancy, complications of labor and delivery, abnormal conditions of new born, congenital anomalies, and obstetric procedures, were found with a poor quality (Clark *et al.*, 1997; Dobie *et al.*, 1998; Lydon-Rochelle *et al.*, 2005; Reichman *et al.*, 2001; Reichman *et al.*, 2007).

In this study, the outcome variables, gestational age and birth weight seem to have a good quality in the validation studies. In multivariate models, the covariates were reported to be with good quality except WIC participation which has been found to be underestimated compared to other data sources such as PRAMS. We used some other variables in birth certificate data when computing the propensity score in the **Specific Aim 3**. However, the quality of those variables might not impact the results after matching on propensity scores. Therefore, the results of this study might not be significantly influenced by the quality of birth certificate data.

Food Environment Measures

The measures of food environment could be classified as neighborhood- and individual-level by the study unit, availability, accessibility, and affordability by the dimension of food access, and observation, survey and GIS-based by the method of assessment. Previous studies on food environment and birth outcomes relied only on neighborhood-level availability of food outlets, such as the availability of supermarket within a Census tract and density of food outlets in a Census tract. In this study, we used the USDA food desert as a measure of community food access. Compared to other neighborhood-level measures, food desert evaluated two dimensions of food access, accessibility (access to supermarket) and affordability (neighborhood income). For the first time, we used two individual-level measures to evaluate food environment and its association with birth outcomes. The two measures were distance from mothers' home to the

nearest food outlet and the number of food outlets within 1-mile buffer around mothers' homes.

Although we included measures of food environment in different levels and dimensions, some other measures might be needed to include in future studies on birth outcomes, e.g. perceptions of food environment, shopping behaviors, distance to the 2nd or 3rd nearest food outlet and availability of food outlets within different buffer sizes (Dutko *et al.*, 2013). These measures might capture different characteristics of the food environment.

PSM Method in Birth Outcome Research

The PSM method was introduced by Rosenbaum and Rubin in 1983 (Rosenbaum *et al.*, 1983). It was introduced to research in social epidemiology by Oakes and Johnson using poverty status and infant death as the example (Oakes *et al.*, 2006). In their subsequent studies using the PSM method, they examined the effects of neighborhood poverty and racial residential segregation on infant death (Hearst *et al.*, 2008; Johnson *et al.*, 2008). They found little effects of poverty and racial segregation on death outcomes among non-Hispanic black and American Indian infants. To date, PSM methods were not widely used in studies of neighborhood and birth outcomes. Most studies on neighborhood characteristics and birth outcomes applied traditional regression models by controlling covariate variables to avoiding confounding effects. However in these studies, the distribution of neighborhood characteristics and birth outcomes were usually imbalanced by race or other factors such as urbanicity. When the covariates were controlled in the model, the inferences in some subgroups might

be based on off-support (no actual) data due to limited sample size in the subgroups (Messer *et al.*, 2010). The off-support inferences might cause bias. The PSM method is an appropriate alternative to avoid off-support inference. After the exposure groups were matched by propensity score, the exposure groups have been balanced on all relevant and available covariates. In this way, we reduce the observable bias while maintaining the support of the data. In this study, the distribution of NDI was extremely imbalanced between non-Hispanic white and black women. For instance, there was limited number of non-Hispanic black women in the least deprived quartile of NDI. After the covariates were added in the regression models, the inference on this subgroup might rely on off-support data. Therefore, PSM is an appropriate approach in the research of neighborhood context and birth outcomes.

Food Environment and Gestational Hypertension

In the dissertation proposal, I proposed to examine the association between food environment and gestational hypertension using the same food outlet and birth certificate data. The analyses were similar with those in **Chapter 4 & 5** but considering gestational hypertension as the outcome variable. The results were totally opposite compared to current literature. We were confident with our analysis procedure but not with the quality of the gestational hypertension variable from the birth certificate data. Previous validation studies showed that maternal risk factor variables including gestational hypertension variable had a poor quality. A recent validation study showed that this variable

might be not valid and reliable from SC DHEC (via personal conversation with Dr. Jihong Liu and DHEC staffs). Therefore, I decided not to include the findings on gestational hypertension as a chapter in the dissertation. However, I would discuss the background, research gap, preliminary findings on this topic in this section. I will also communicate with SC DHEC to valid the gestational hypertension variable and continue the potential analysis. When I am confident with the quality of this outcome variable, I will try to publish the findings.

Hypertensive disorders of pregnancy, usually including gestational hypertension and preeclampsia, are the most common complications associated with pregnancy. Hypertensive disorders of pregnancy affected 5% to 10% of all pregnancies in the United States (Wagner *et al.*, 2007). Although the outcome for most mothers and babies are good and the disorders usually recover after the delivery (e.g. preeclampsia), hypertensive disorders remain the leading cause of mortality and morbidity during pregnancy (Chang *et al.*, 2003; Kuklina *et al.*, 2009; Wagner *et al.*, 2007).

Although hypertensive disorders of pregnancy are the major causes of maternal and fetal morbidity and mortality; however, the mechanisms are still not well understood. Taking preeclampsia for example, various theories have been raised to explain the pathogenesis of preeclampsia, such as oxidative stress, inflammatory response, systematic vascular resistance, platelet aggregation, activation of coagulation systems, and endothelial dysfunction. Based on previous evidence, these underlying mechanisms were not mutually exclusive, but rather likely interactive (Redman *et al.*, 2005; Sibai *et al.*, 2005; Xu *et al.*,

2009). All the genetic and environmental risk factors that may affect these pathogenic mechanism pathways may be responsible for the development of preeclampsia. These risk factors may include medical maternal status, demographic factors, health behaviors, nutritional status et al. (Xu *et al.*, 2009). Consumptions of energy and several dietary substances have been identified to be the risk factors of preeclampsia. These factors may include dietary pattern (Brantsaeter *et al.*, 2009), vegetables (Brantsaeter *et al.*, 2009; Longo-Mbenza *et al.*, 2008), vitamins (Haugen *et al.*, 2009; Klemmensen *et al.*, 2009), fatty acids (Chavarro *et al.*, 2011; Olafsdottir *et al.*, 2006), probiotic food (Brantsaeter *et al.*, 2011), homocysteine and folic acid (Patrick *et al.*, 2004).

Environmental and social neighborhood factors were examined to explain the effects on hypertensive disorders of pregnancy in recent studies. However, the evidence on neighborhood and hypertensive disorders of pregnancy is still limited and the results are inconsistent (Agyemang *et al.*, 2009; Clausen *et al.*, 2006; Vinikoor-Imler *et al.*, 2012; Vinikoor-Imler *et al.*, 2011). In addition, several studies examined the effect of food environment on hypertension in adults (Dubowitz *et al.*, 2012; Li *et al.*, 2009; Morland *et al.*, 2006; Mujahid *et al.*, 2008). Most of the studies found that residents of neighborhoods with better availability of healthy foods, worse access and less density of fast food outlets, and better availability of grocery stores/supermarkets were less likely to be hypertensive (Dubowitz *et al.*, 2012; Li *et al.*, 2009; Mujahid *et al.*, 2008). However, the results were inconsistent in a study that the association for hypertension may depend on the types of food outlets in the neighborhood (presence of supermarkets

decreased and presence of grocery and convenience stores increased the risk of hypertension) (Morland *et al.*, 2006). Food environment may be related to hypertensive disorders of pregnancy due to its effects on dietary intake, nutrition status, health behaviors and obesity, however to date, no studies were conducted to understand the relationship between built food environment and hypertensive disorders of pregnancy. In this study, we aimed to examine the association between food environment (USDA food desert, accessibility and availability of food outlets) and gestational hypertension.

According to the results, the prevalence of gestational hypertension was 5.43% in South Carolina. The mothers living in areas with low neighborhood income were less likely to experience gestational hypertension comparing mothers living in areas with high neighborhood income (**Table 7.1**). The results were inconsistent with previous studies on neighborhood characteristics and gestational hypertension (Agyemang *et al.*, 2009; Clausen *et al.*, 2006; Vinikoor-Imler *et al.*, 2012; Vinikoor-Imler *et al.*, 2011). For food access measures, we did not find any significant associations with gestational hypertension. In the multivariate models, we found that mothers smoking during pregnancy and mothers with first prenatal care beginning after 1st trimester or with no prenatal cares were less likely to experience gestational hypertension compared to those no smoking and having prenatal care within 1st trimester. No significant difference was found between non-Hispanic white and black women. These results were also inconsistent with previous studies. Maternal age, obesity, previous preterm birth, infection during pregnancy, and chronic and gestational diabetes showed

harmful effects, and number of previous live births showed protective effects on gestational hypertension. These results were consistent with previous findings.

The distance to the nearest food outlet and number of food outlets within 1 mile buffer were compared between mothers with and without gestational hypertension and significant differences were found in several measures (**Table 7.2**). However, in multivariate models, larger number of grocery stores within 1 mile buffer was associated with lower risk of gestational hypertension (**Figure 7.1**). No significant associations were found for measures of other types of food outlet.

Because most results were not consistent with previous studies, I believed the validation effort was needed for gestational hypertension variable in birth certificate data. In the birth certificate dataset requested from SC DHEC, approximately 3% of the mothers did not have information on gestational hypertension. About 10% of the mothers had missing information on one of the variables included in the models. According to the big sample size in this study, the missing data might not be a problem. We have compared the characteristics. However, these missing data might bias the results if the mothers with missing data were more likely to have gestational hypertension. Based on this dataset, the prevalence of gestational hypertension among mothers with missing data on any of the covariates was approximately 15.5% compared to 5.3% among those without missing data. The big gap of prevalence might be an interpretation of the inconsistent results in this study. Future follow up with this topic is needed to

understand if the inconsistent results were due to poor data quality or true effects.

Limitation and Strengths

There are several limitations of this study worth noting. First, we are unable to control shopping behaviors of households in the present study. Food access will affect the shopping behaviors; however, we do not really know what and where they shop food. Second, we will not incorporate information about public transportation in the analysis. There is only one urban county and the public transportation in this urban county is not sophisticated as other metropolitan areas. Controlling for urban and rural area may compensate for this limitation. Third, the food environment database does not include the farmers or flea markets. There are an increasing number of farmer markets in South Carolina. Lack of information on these markets will bias to the study. Fourth, edge effect is always a limitation for geographic analysis. We added a 10 miles buffer around the edge of our study area and included the food outlets in the buffer area to our master food outlet database. These added food outlets are from commercial and agency databases. Even though the commercial and agencies databases have found not to have a good validity as the ground-truth database, they are the best sources we can find to make up the absence. Fifth, we only include the births born in South Carolina from 2008-2009. We will exclude the births outside the state. For the mothers giving birth in South Carolina, they may not be exposed to the food environment around their home address if they recently changed address. In a study based on linked data

between South Carolina birth certificate and Medicaid data from 1996 to 2001, among mothers in the cohort, 22% moved once, 2% moved twice and 0.1% moved more than twice during pregnancy (Zhen *et al.*, 2008). However, families eligible in Medicaid are usually low-income families which are more likely to live in rent homes and move more frequently. The frequency of movement among study population in this study is expected to be lower than that in above study. At last, only Census 2000 tract number was in the birth data, so we could not link the births to Census 2010 data. The data year 2008-2009 were more close to 2010. It is more accurate to use Census 2010 rather than Census 2000. In this study, the food outlet data were from 2008 to 2009, which was matched with the birth data. However, we did not know the impact of boundary change on our results from Census 2000 to Census 2010, even though the changes were thought to be little.

There are also several strengths in present study. First, the study area covers the entire state of South Carolina. All births from 2008-2009 were included in the analysis. The analysis will show a great power with such big sample size. Second, the food outlet dataset in this study is validated and reliable ground-truthed database from a field census. The ground-truthed data have much fewer errors than other secondary food outlet data sources (Liese *et al.*, 2013; Liese *et al.*, 2010). Third, this study was the first study to examine the association between accessibility and affordability of food environment and birth outcomes, the association between individual-level food access measures and birth outcomes, and it was the first study to use PSM methods to examine the

association between neighborhood deprivation and adverse birth outcomes. The findings of this study added to current limited literatures. Fourth, the racial disparities on birth outcomes were serious in South Carolina and the high proportion of non-Hispanic blacks allowed South Carolina to be a perfect place to study racial disparities on health.

Summary of the Findings

There are two dimensions in the definition of food desert, neighborhood income and food access. According to the results in present study, decreased neighborhood income was associated with decreased birth weight; however, poor food access was associated with increased birth weight. Mothers living in USDA food desert areas were not found with adverse birth outcomes comparing those living in high-income and high-food access areas. As the two dimensions of food desert, neighborhood income is more important to predict adverse birth outcomes than food access; however, these associations could be explained mainly by race difference. Interventions should be placed on mothers living in low-income areas. Future research using individual-level food access measures was encouraged to understand the association between food environment and birth outcomes.

Both accessibility and availability of convenience stores showed a harmful association with birth outcomes. No significant associations were captured for healthy food outlets and limited service restaurants. To limit access to unhealthy foods seemed to be more important than to improve access to healthy food when improving birth outcomes. Future investigations with more measures of food

accessibility, availability, and affordability were encouraged to our understanding of the effects of built food environment on birth outcomes. Spatial analysis might be needed to explore the correlation of various types of food outlets and its impact on birth outcomes.

Neighborhood deprivation could partially explain the racial disparities in birth outcomes. PSM results suggested the neighborhood deprivation was associated with increased risks of LBW among non-Hispanic whites, and increased risks of PTB among non-Hispanic blacks. Typical logistic regression models identified the association between neighborhood deprivation and adverse birth outcomes only among non-Hispanic whites. Off-support inference might explain the inconsistency. Future studies need to understand the difference between PSM and traditional regression methods on the association between neighborhood and birth outcomes. Re-investigation efforts might be needed for previous studies on this topic using PSM rather than off-support inference methods.

Racial Disparities

The racial disparities were found in both neighborhood characteristics and birth outcomes. For instance, approximately 60% of the population was non-Hispanic blacks in low-income areas, whereas it dropped to 25% in high-income areas. Neighborhood deprivation was higher in non-Hispanic blacks than non-Hispanic whites. For birth outcomes, the overall prevalence of LBW and PTB was

5.9% and 8.5% for non-Hispanic whites, and 12.5% and 12.7% for non-Hispanic blacks.

In the analyses of the associations between food environment and birth outcomes in **Chapter 4** (food desert and birth outcomes) and **Chapter 5** (availability and accessibility of food outlets and birth outcomes), the associations were not differentiated between non-Hispanic whites and non-Hispanic blacks. The built food environment might not explain the racial disparities in birth outcomes. When it came to **Chapter 6** (neighborhood deprivation and birth outcomes), the results were differentiated by race. Based on PSM method, neighborhood deprivation was associated with LBW among non-Hispanic whites, and with PTB among non-Hispanic blacks.

Implications and Future Directions

Neighborhood income was more important than community food access in predicting birth outcomes. The researchers and policy makers should pay more attention to women living in areas with low neighborhood income to improve their birth outcomes. Accessibility and availability of healthy food outlets were not associated with birth outcomes, whereas good accessibility and availability of unhealthy food outlets were associated with poor birth outcomes. More attention should be placed on limiting unhealthy food access rather than improving healthy food access to improve birth outcomes. No racial difference was found in the associations between food environment and birth outcomes. The different birth outcomes between high food access and low food access areas could be mainly

explained by different composition of race groups in the areas. Neighborhood deprivation might partially explain the racial disparities on adverse birth outcomes between non-Hispanic white and black women. More efforts should be placed on deprived areas to minimize the racial gap of birth outcomes.

Future studies with more measures evaluating food environment were needed, including measures collected by surveys (perceptions of food environment and shopping behaviors) and store audit, and the GIS-based measures with different buffer sizes and with distances to 2^{nd} or 3^{rd} nearest food outlet. Studies of the effects of neighborhood characteristics and built food environment on other pregnancy/birth outcomes are needed, including gestational hypertension and gestational diabetes mellitus. Studies examining food environment and diet quality and nutrition intake are needed among women before and during pregnancy. These studies will enhance our understanding of the influence of food environment on pregnancy/birth outcomes. Previous studies on neighborhood characteristics and birth outcomes are encouraged to be revisited, using PSM methods to overcome potential flaws due to off-support data inferences.

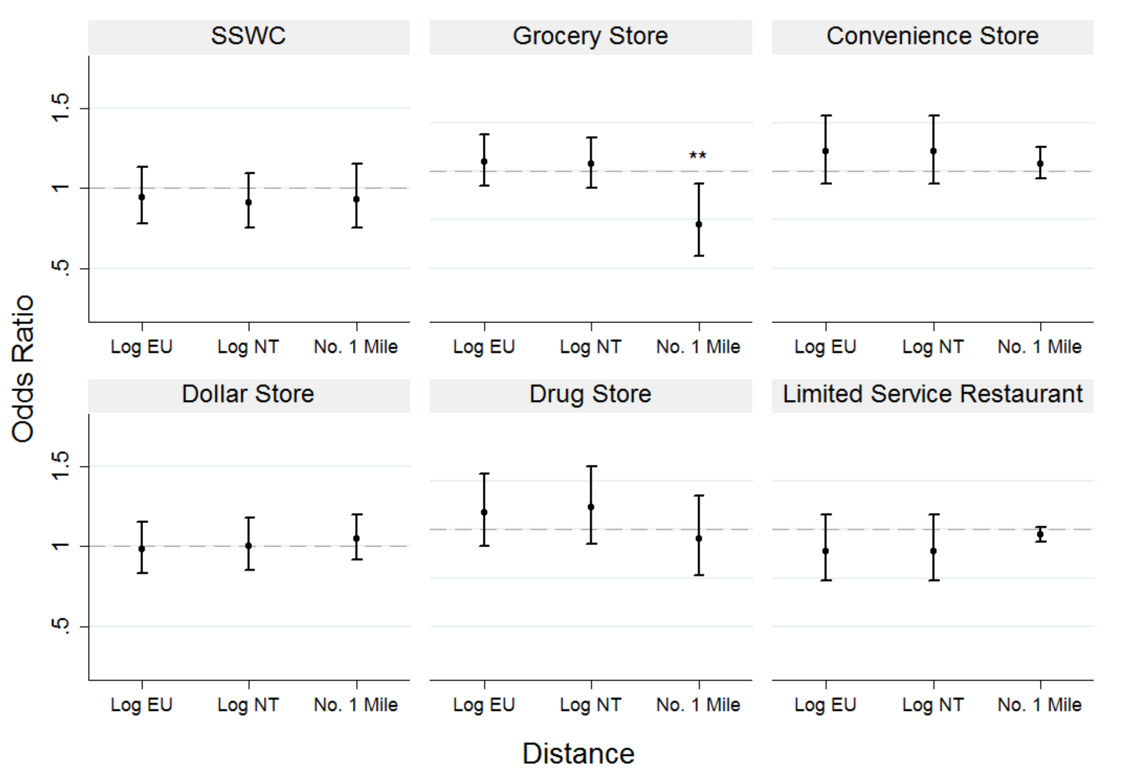

Figure 7.1 Logistic regression between distance to nearest food outlet or number of food outlet in 1 mile and gestational hypertension in eight-county area in South Carolina (N=15,171)

Table 7.1 The association between matrix of income and food access and gestational hypertension in South Carolina

	OR (95% CI)		
	Unadjusted	Model 1	Model 2
Food Desert Dimensions			
HI + HA	1.00	1.00	1.00
LI + HA	**0.82 (0.71, 0.93)**	**0.78 (0.68, 0.90)**	**0.80 (0.70, 0.93)**
HI + LA	0.99 (0.88, 1.11)	0.97 (0.86, 1.10)	1.01 (0.89, 1.14)
LI + LA (Food Desert)	0.95 (0.81, 1.11)	0.92 (0.78, 1.08)	0.96 (0.82, 1.14)
Mother's Age, y		**1.02 (1.01, 1.02)**	**1.03 (1.02, 1.03)**
Female Birth		0.96 (0.91, 1.01)	0.97 (0.91, 1.03)
African American		**1.14 (1.06, 1.22)**	1.03 (0.96, 1.11)
Mother's Education			
High school or less		1.00	1.00
Some college		**1.11 (1.04, 1.19)**	0.96 (0.90, 1.03)
Bachelor or above		0.95 (0.87, 1.04)	**0.77 (0.70, 0.85)**
WIC Participation		1.05 (0.98, 1.13)	0.95 (0.88, 1.02)
Obesity			
Normal			1.00
Overweight			**1.67 (1.54, 1.81)**
Obese			**2.71 (2.52, 2.91)**
Smoking During Pregnancy			**0.88 (0.79, 0.97)**
Prenatal Care After >1st Trimester			**0.91 (0.85, 0.98)**
Previous Live Birth			
0			1.00
1			**0.48 (0.45, 0.52)**
2 or more			**0.43 (0.39, 0.47)**
Previous Preterm Birth			**1.26 (1.06, 1.51)**
Infection During Pregnancy			**1.17 (1.05, 1.30)**
Gestational DM			**1.91 (1.72, 2.11)**
Diabetes Mellitus			**1.71 (1.37, 2.13)**

Adjusted variables are maternal age, gender, race/ethnicity, maternal education, WIC participation in Model 1; maternal age, gender, race/ethnicity, maternal education, WIC participation, mother's obesity, smoking during pregnancy, prenatal care begin, previous live birth, previous preterm birth, infection during pregnancy, chronic diabetes mellitus, gestational diabetes mellitus in Model 2. Abbreviations: CI, confidence interval; OR, odds ratio; HI, high income; LI, low income; HA, high access; LA, low access. For birth weight and gestational age, the models are random-effect linear regression models; for low birthweight and preterm birth, the models are random-effect logistic regression models. Bolded means p<0.05.

Table 7.2 Distance to the nearest food outlet and number of food outlet in 1 mile buffer by gestational hypertension in eight-county area in South Carolina

Food Access Variables	Non-GHTN	HTN	All
Sample Size	**14,664**	**623**	**15,786**
SSWC			
Euclidean Mean, m	3750 (4040)	3762 (3737)	3791 (4018)
Network Mean, m	4754 (4752)	4791 (4494)	4799 (4729)
Number Within 1 Mile, n	0.27 (0.59)	0.22 (0.49)**	0.26 (0.58)
Grocery Store			
Euclidean Mean, m	5644 (4965)	5936 (5050)	5878 (5212)
Network Mean, m	7232 (6146)	7451 (6045)	7488 (6378)
Number Within 1 Mile, n	0.21 (0.68)	0.13 (0.45)**	0.20 (0.66)
Convenience Store			
Euclidean Mean, m	1925 (2082)	2042 (2207)	1946 (2082)
Network Mean, m	2557 (2634)	2653 (2674)	2581 (2629)
Number Within 1 Mile, n	1.62 (2.21)	1.40 (1.95)**	1.58 (2.19)
Dollar Store			
Euclidean Mean, m	3565 (3866)	3994 (4632)*	4002 (4916)
Network Mean, m	4570 (4661)	5018 (5403)*	5060 (5768)
Number Within 1 Mile, n	0.40 (0.88)	0.35 (0.86)	0.39 (0.87)
Drug Store and Pharmacy			
Euclidean Mean, m	4995 (6143)	5330 (6529)	5061 (6146)
Network Mean, m	6091 (6980)	6427 (7333)	6166 (6977)
Number Within 1 Mile, n	0.36 (0.73)	0.29 (0.68)*	0.35 (0.72)
Limited Service Restaurant			
Euclidean Mean, m	2601 (2966)	2614 (2788)	2613 (2948)
Network Mean, m	3392 (3594)	3371 (3349)	3402 (3570)
Number Within 1 Mile, n	2.26 (4.62)	1.77 (3.64)**	2.19 (4.53)
Healthy Outlet			
Euclidean Mean, m	2963 (3141)	3016 (2842)	2997 (3118)
Network Mean, m	3866 (3812)	3916 (3503)	3903 (3788)
Number Within 1 Mile, n	0.49 (0.97)	0.35 (0.70)**	0.47 (0.95)
Unhealthy Outlet			
Euclidean Mean, m	2963 (3141)	3016 (2842)	2997 (3118)
Network Mean, m	2242 (2364)	2312 (2311)	2262 (2357)
Number Within 1 Mile, n	4.64 (7.30)	3.81 (6.03)**	4.51 (7.18)

*: p<0.05; **: p<0.01. SSWC, supermarket, supercenter, and warehouse club; GHT, gestational hypertension.

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APPENDIX A

Sample of South Carolina Birth Certificate Questionnaire

(2004-Present)

STATE OF SOUTH CAROLINA
DEPARTMENT OF HEALTH AND ENVIRONMENTAL CONTROL

CERTIFICATE OF LIVE BIRTH

139 -

BIRTH NUMBER

CHILD

1. CHILD'S NAME (First, Middle, Last, Suffix)
2. TIME OF BIRTH (24HR)
3. SEX
4. DATE OF BIRTH (Mo/Day/Yr)
5. FACILITY NAME (If not institution, give street and number)
6. CITY, TOWN, OR LOCATION OF BIRTH
7. COUNTY OF BIRTH

MOTHER

8a. MOTHER'S CURRENT LEGAL NAME (First, Middle, Last, Suffix)
8b. DATE OF BIRTH (Mo/Day/Yr)
8c. MOTHER'S NAME PRIOR TO FIRST MARRIAGE (First, Middle, Last, Suffix)
8d. BIRTHPLACE (State, Territory, or Foreign Country)
9a. RESIDENCE OF MOTHER - STATE
9b. COUNTY
9c. CITY, TOWN, OR LOCATION
9d. STREET AND NUMBER
9e. APT. NO.
9f. ZIP CODE
9g. INSIDE CITY LIMITS? ☐ Yes ☐ No

FATHER

10a. FATHER'S CURRENT LEGAL NAME (First, Middle, Last, Suffix)
10b. DATE OF BIRTH (Mo/Day/Yr)
10c. BIRTHPLACE (State, Territory, or Foreign Country)

CERTIFIER

11. CERTIFIER'S NAME

TITLE ☐ MD ☐ DO ☐ HOSPITAL ADMIN. ☐ CNM/CM ☐ OTHER MIDWIFE
☐ OTHER (Specify) ____________

12. DATE CERTIFIED ___/___/___ MM DD YYYY
13. DATE FILED BY REGISTRAR ___/___/___ MM DD YYYY

INFORMATION FOR ADMINISTRATIVE USE

MOTHER

14. MOTHER'S MAILING ADDRESS ☐ Same as residence, or: State
City, Town, or Location:
Street & Number:
Apartment No.:
Zip Code:

15. MOTHER MARRIED? (At birth, conception, or any time between)
☐ Yes ☐ No
IF NO, HAS PATERNITY ACKNOWLEDGMENT BEEN SIGNED IN THE HOSPITAL?
☐ Yes ☐ No

16. SOCIAL SECURITY NUMBER REQUESTED FOR CHILD?
☐ Yes ☐ No

17. FACILITY ID (NPI)

18. MOTHER'S SOCIAL SECURITY NUMBER:
19. FATHER'S SOCIAL SECURITY NUMBER:

INFORMATION FOR MEDICAL AND HEALTH PURPOSES ONLY

MOTHER

MOTHER'S MEDICAL RECORD NO.
____
____

20. MOTHER'S EDUCATION (Check the box that best describes the highest degree or level of school completed at the time of delivery)
☐ 8th grade or less
☐ 9th - 12th grade, no diploma
☐ High school graduate or GED completed
☐ Some college credit, but no degree
☐ Associate degree (e.g., AA, AS)
☐ Bachelor's degree (e.g., BA, AB, BS)
☐ Master's degree (e.g., MA, MS, MEng, MEd, MSW, MBA)
☐ Doctorate (e.g., PhD, EdD) or Professional degree (e.g., MD, DDS, DVM, LLB, JD)

21. MOTHER OF HISPANIC ORIGIN? (Check the box that best describes whether the mother is Spanish/Hispanic/Latina. Check the "No" box if mother is not Spanish/Hispanic/Latina)
☐ No, not Spanish/Hispanic/Latina
☐ Yes, Mexican, Mexican American, Chicana
☐ Yes, Puerto Rican
☐ Yes, Cuban
☐ Yes, other Spanish/Hispanic/Latina
(Specify) ____________

22. MOTHER'S RACE (Check one or more races to indicate what the mother considers herself to be)
☐ White
☐ Black or African American
☐ American Indian or Alaska Native
(Name of the enrolled or principal tribe) ____________
☐ Asian Indian
☐ Chinese
☐ Filipino
☐ Japanese
☐ Korean
☐ Vietnamese
☐ Other Asian (Specify) ____________
☐ Native Hawaiian
☐ Guamanian or Chamorro
☐ Samoan
☐ Other Pacific Islander (Specify) ____________
☐ Other
(Specify) ____________

FATHER

23. FATHER'S EDUCATION (Check the box that best describes the highest degree or level of school completed at the time of delivery)
☐ 8th grade or less
☐ 9th - 12th grade, no diploma
☐ High school graduate or GED completed
☐ Some college credit, but no degree
☐ Associate degree (e.g., AA, AS)
☐ Bachelor's degree (e.g., BA, AB, BS)
☐ Master's degree (e.g., MA, MS, MEng, MEd, MSW, MBA)
☐ Doctorate (e.g., PhD, EdD) or Professional degree (e.g., MD, DDS, DVM, LLB, JD)

24. FATHER OF HISPANIC ORIGIN? (Check the box that best describes whether the father is Spanish/Hispanic/Latino. Check the "No" box if father is not Spanish/Hispanic/Latino)
☐ No, not Spanish/Hispanic/Latino
☐ Yes, Mexican, Mexican American, Chicano
☐ Yes, Puerto Rican
☐ Yes, Cuban
☐ Yes, other Spanish/Hispanic/Latino
(Specify) ____________

25. FATHER'S RACE (Check one or more races to indicate what the father considers himself to be)
☐ White
☐ Black or African American
☐ American Indian or Alaska Native
(Name of the enrolled or principal tribe) ____________
☐ Asian Indian
☐ Chinese
☐ Filipino
☐ Japanese
☐ Korean
☐ Vietnamese
☐ Other Asian (Specify) ____________
☐ Native Hawaiian
☐ Guamanian or Chamorro
☐ Samoan
☐ Other Pacific Islander (Specify) ____________
☐ Other
(Specify) ____________

STATE OFFICE USE ONLY

26. PLACE WHERE BIRTH OCCURRED (Check one)
☐ Hospital
☐ Freestanding birthing center
☐ Home birth. Planned to deliver at home? ☐ Yes ☐ No
☐ Clinic/Doctor's office
☐ Other (Specify) ____________

27. ATTENDANT'S NAME, TITLE, AND NPI
NAME ____________
NPI ____________
TITLE ☐ MD ☐ DO ☐ CNM/CM ☐ OTHER MIDWIFE
☐ Other (Specify) ____________

28. MOTHER TRANSFERRED FOR MATERNAL MEDICAL OR FETAL INDICATIONS FOR DELIVERY?
☐ Yes ☐ No
IF YES, ENTER NAME OF FACILITY MOTHER TRANSFERRED FROM:
____

DHEC 609 Rev. 7/2003

COMPLETE REVERSE SIDE

MOTHER

29a. DATE OF FIRST PRENATAL CARE VISIT
___/___/___ MM DD YYYY ☐ No Prenatal Care

29b. DATE OF LAST PRENATAL CARE VISIT
___/___/___ MM DD YYYY

30. TOTAL NUMBER OF PRENATAL VISITS FOR THIS PREGNANCY
________ (If none, enter "0".)

31. MOTHER'S HEIGHT
________ (feet/inches)

32. MOTHER'S PREPREGNANCY WEIGHT
________ (pounds)

33. MOTHER'S WEIGHT AT DELIVERY
________ (pounds)

34. DID MOTHER GET WIC FOOD FOR HERSELF DURING THIS PREGNANCY? ☐ Yes ☐ No

35. NUMBER OF PREVIOUS LIVE BIRTHS (Do not include this child)
____

35a. Now Living
Number ____
☐ None

35b. Now Dead
Number ____
☐ None

36. NUMBER OF OTHER PREGNANCY OUTCOMES
(Spontaneous or induced losses or ectopic pregnancies)
Number ________
☐ None

37. CIGARETTE SMOKING BEFORE AND DURING PREGNANCY
For each time period, enter either the number of cigarettes or the number of packs of cigarettes smoked. IF NONE, ENTER "0".
Average number of cigarettes or packs of cigarettes smoked per day

	Number of cigarettes		Number of packs
Three months before pregnancy	____	OR	____
First three months of pregnancy	____	OR	____
Second three months of pregnancy	____	OR	____
Last three months of pregnancy	____	OR	____

38. PRINCIPAL SOURCE OF PAYMENT FOR THIS DELIVERY
☐ Private Insurance
☐ Medicaid
☐ Self-pay
☐ Other (Specify)
____

35c. DATE OF LAST LIVE BIRTH
___/___ MM YYYY

36a. DATE OF LAST OTHER PREGNANCY OUTCOME
___/___ MM YYYY

39. DATE LAST NORMAL MENSES BEGAN
___/___/___ MM DD YYYY

40. MOTHER'S MEDICAL RECORD NUMBER

MEDICAL AND HEALTH INFORMATION

41. RISK FACTORS IN THIS PREGNANCY (Check all that apply)
Diabetes
☐ Prepregnancy (Diagnosis prior to this pregnancy)
☐ Gestational (Diagnosis in this pregnancy)
Hypertension
☐ Prepregnancy (Chronic)
☐ Gestational (PIH, preeclampsia, eclampsia)
☐ Previous preterm birth
☐ Other previous poor pregnancy outcome (Includes perinatal death, small-for-gestational age/intrauterine growth restricted birth)
☐ Vaginal bleeding during this pregnancy prior to the onset of labor
☐ Pregnancy resulted from infertility treatment
☐ Mother had a previous cesarean delivery
If yes, how many ________
☐ None of the above

42. INFECTIONS PRESENT AND/OR TREATED DURING THIS PREGNANCY (Check all that apply)
☐ Gonorrhea
☐ Syphilis
☐ Herpes Simplex Virus (HSV)
☐ Chlamydia
☐ Hepatitis B
☐ Hepatitis C
☐ None of the above

43. OBSTETRIC PROCEDURES (Check all that apply)
☐ Cervical cerclage
☐ Tocolysis
External cephalic version
☐ Successful
☐ Failed
☐ None of the above

44. ONSET OF LABOR (Check all that apply)
☐ Premature Rupture of the Membranes (prolonged, ≥12 hrs.)
☐ Precipitous Labor (<3 hrs.)
☐ Prolonged Labor (≥ 20 hrs.)
☐ None of the above

45. CHARACTERISTICS OF LABOR AND DELIVERY (Check all that apply)
☐ Induction of labor
☐ Augmentation of labor
☐ Non-vertex presentation
☐ Steroids (glucocorticoids) for fetal lung maturation received by the mother prior to delivery
☐ Antibiotics received by the mother during labor
☐ Clinical chorioamnionitis diagnosed during labor or maternal temperature ≥ 38°C (100.4°F)
☐ Moderate/heavy meconium staining of the amniotic fluid
☐ Fetal intolerance of labor such that one or more of the following actions was taken: in-utero resuscitative measures, further fetal assessment, or operative delivery
☐ Epidural or spinal anesthesia during labor
☐ None of the above

46. METHOD OF DELIVERY
A. Was delivery with forceps attempted but unsuccessful?
☐ Yes ☐ No
B. Was delivery with vacuum extraction attempted but unsuccessful?
☐ Yes ☐ No
C. Fetal presentation at birth
☐ Cephalic
☐ Breech
☐ Other
D. Final route and method of delivery (Check one)
☐ Vaginal/Spontaneous
☐ Vaginal/Forceps
☐ Vaginal/Vacuum
☐ Cesarean
If Cesarean, was a trial of labor attempted?
☐ Yes
☐ No

47. MATERNAL MORBIDITY (Check all that apply) (Complications associated with labor and delivery)
☐ Maternal transfusion
☐ Third or fourth degree perineal laceration
☐ Ruptured uterus
☐ Unplanned hysterectomy
☐ Admission to intensive care unit
☐ Unplanned operating room procedure following delivery
☐ None of the above

NEWBORN INFORMATION

NEWBORN

48. NEWBORN MEDICAL RECORD NUMBER:

49. BIRTHWEIGHT (grams preferred, specify unit)
____
☐ grams ☐ lb/oz

50. OBSTETRIC ESTIMATE OF GESTATION:
________ (completed weeks)

51. APGAR SCORE:
Score at 5 minutes: ________
If 5 minute score is less than 6,
Score at 10 minutes: ________

52. PLURALITY - Single, Twin, Triplet, etc.
(Specify) ________

53. IF NOT SINGLE BIRTH - Born First, Second, Third, etc. (Specify) ________

54. ABNORMAL CONDITIONS OF THE NEWBORN (Check all that apply)
☐ Assisted ventilation required immediately following delivery
☐ Assisted ventilation required for more than six hours
☐ NICU admission
☐ Newborn given surfactant replacement therapy
☐ Antibiotics received by the newborn for suspected neonatal sepsis
☐ Seizure or serious neurologic dysfunction
☐ Significant birth injury (skeletal fracture(s), peripheral nerve injury, and/or soft tissue/solid organ hemorrhage which requires intervention)
☐ None of the above

55. CONGENITAL ANOMALIES OF THE NEWBORN (Check all that apply)
☐ Anencephaly
☐ Meningomyelocele/Spina bifida
☐ Cyanotic congenital heart disease
☐ Congenital diaphragmatic hernia
☐ Omphalocele
☐ Gastroschisis
☐ Limb reduction defect (excluding congenital amputation and dwarfing syndromes)
☐ Cleft Lip with or without Cleft Palate
☐ Cleft Palate alone
☐ Down Syndrome
☐ Karyotype confirmed
☐ Karyotype pending
☐ Suspected chromosomal disorder
☐ Karyotype confirmed
☐ Karyotype pending
☐ Hypospadias
☐ None of the anomalies listed above

56. WAS INFANT TRANSFERRED WITHIN 24 HOURS OF DELIVERY? ☐ Yes ☐ No
IF YES, NAME OF FACILITY INFANT TRANSFERRED TO ________

57. IS INFANT LIVING AT TIME OF REPORT?
☐ Yes ☐ No ☐ Infant transferred, status unknown

58. IS INFANT BEING BREASTFED?
☐ Yes ☐ No

59. WHAT PROPHYLACTIC USED IN EYES? (Specify)
TIME USED (24-hour clock)

APPENDIX B

Exemption Letter from the Institution Review Board at University of South Carolina

UNIVERSITY OF SOUTH CAROLINA

OFFICE OF RESEARCH COMPLIANCE

April 23, 2012

Ms. Xiaoguang Ma
Arnold School of Public Health
Epidemiology and Biostatistics
921 Assembly Street
Columbia, SC 29208

Re: **Pro00016362**
Study Title: *Food Environment and Adverse Birth Outcomes in South Carolina*

Dear Ms. Ma:

In accordance with 45 CFR 46.102 the project referenced above is exempt from Human Research Subject Regulations and further oversight by the Institutional Review Board (IRB) is not required. This exemption is based on the determination that the proposed activity does not meet the regulatory definition of human subjects.

The Office of Research Compliance is an administrative office that supports the USC Institutional Review Board. If you have questions, please contact Arlene McWhorter at arlenem@sc.edu or (803) 777-7095.

Sincerely,

Thomas A. Coggins
Director

cc: Angela Liese

University of South Carolina-Columbia, South Carolina – 803/777-7095 – Fax 803/576-5589

APPENDIX C

Birth Certificate Data Release Agreement from South Carolina

Department of Health and Environmental Control

Max SOUTH CAROLINA DEPARTMENT OF HEALTH AND ENVIRONMENTAL CONTROL
2600 Bull Street
Columbia, South Carolina 29201

Release Agreement Number RES110112A

I. **AUTHORIZATION FOR RELEASE OF CONFIDENTIAL DATA FOR RESEARCH PURPOSES:**

1. RESEARCH INVESTIGATORS: Xiaoguang Ma, Angela Liese (chair of the committee), Jihong Liu (committee member), James Hardin (committee member), and Guang Zhao (committee member)

2. PROJECT/STUDY TITLE: Food Environment and Adverse Birth Outcomes and Hypertensive disorders of pregnancy in South Carolina

3. NATURE OF PROJECT:

Specific Aim 1: To investigate the association between food desert dimensions (low-income and low-access) and adverse birth outcomes in whole South Carolina State, and to evaluate the racial difference on the associations.

Specific Aim 2: To examine the association between neighborhood food access and adverse birth outcomes in live births in eight-county region in South Carolina, and to identify potential racial difference on the associations.

Specific Aim 3: To investigate the association between food desert dimensions (low-income and low-access) and hypertensive disorders of pregnancy in whole South Carolina State, and to evaluate the racial difference on the associations.

Specific Aim 4: To examine the association between neighborhood food access and hypertensive disorders of pregnancy in live births in eight-county region in South Carolina, and to identify potential racial difference on the associations.

4. RECORDS INVOLVED: Birth

5. VARIABLES INVOLVED: Mother: Age, County of residence, Education, Race - option 1, Race - option 2, Month prenatal care began, Total number of prenatal care visits, BMI, Prepregnancy weight, Weight at delivery,WIC participation, Number of previous live births, Number of previous other pregnancy outcomes (includes fetal deaths and abortions), Smoking prior to pregnancy, Smoking during pregnancy, Risk factors in this pregnancy, Onset of Labor, Characteristics of labor and delivery, Method of delivery

Children: Year of Birth, Sex, Birthweight, Obstetric estimate of gestation, Apgar score at 5 min, Apgar score at 10 min, Plurality, Abnormal conditions of the newborn, Breastfeeding

6. ACTION PLANNED: Calculate variables (Network distance to nearest outlet,

Euclidean distance to nearest outlet, number of outlets within 1 mile buffer) and Census Tract 2000.

7. SPECIAL CONDITIONS (For Office use Only): All information which may permit identification of an individual will be held confidentially, will be used only by persons engaged in and for the purposes of this specific research, and will not be released to others for any other purpose. There will be **no follow-back** contact with the relatives of individuals mentioned on these certificates. The identities of study subjects will be lost in the pool of data to be studied and will not be specified in any publication or report. These records may be utilized for the above authorized purpose only and will be destroyed and/or returned to SC DHEC at the conclusion of this study. SC DHEC is to be given written notification of the destruction of these records.

Authorized by DHEC:

Signature [signature]

Title IRB ADMINISTRATOR

Office of Public Health

Statistics and Information Systems

Date 11/05/2012

Conditions Accepted by Requestors:

Signature [signature]

Title PhD Candidate

Organization USC

Date 11/2/12

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