TRANSGENERATIONAL RISK FOR LOW BIRTH WEIGHT AND PRETERM BIRTH: THE ROLE OF BIOLOGY AND NEIGHBORHOOD FACTORS IN RACIAL DISPARITIES

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ABSTRACT

The purpose of this dissertation research is to ascertain the impact of biological factors as well as social and economic environmental factors on the risk of low birth weight (LBW) and preterm birth (PTB) among infants of non-Hispanic (NH) white and NH black mothers, under the hypothesis that intergenerational factors could be explanatory variables in the perpetuated trend in racial/ethnic disparities in birth outcomes. Three separate research studies were performed. The first is a systematic review and meta-analysis of studies reporting the association between LBW/PTB and neighborhood disadvantage, where the results demonstrate that there is a statistically significant higher odds of LBW and PTB among mothers resident in the most disadvantaged neighborhoods relative to those in the least disadvantaged neighborhoods. This relationship was found only when race-stratified, rather than race-adjusted, models were performed. The second and third studies use a transgenerational dataset of births in Allegheny County, Pennsylvania with birth records of infants born in the years 2009-2011 to mothers who were also born in the County in the years 1979-1998. The second study focuses on the role of mothers' birth weight (MBW) along with social and economic contextual factors on infant risk of LBW; while the third study focuses on the role of mothers' gestational age (MGA) coupled with social and economic contextual factors on infant risk of PTB. This research makes significant unique contributions to this field of public health research by examining both biological and neighborhood context factors as predictors of PTB and LBW in multivariate and multilevel models. Even more important is the novel examination of the subcategories of birth weight and gestational age, which led to results suggesting differing roles of biology and neighborhood context among these subcategories. LBW and PTB are of public health significance because they increase an infant's risk of death in the first year of life, developmental disabilities, and chronic diseases in adulthood. The healthcare costs related to treatment of a prematurely born infant costs the United States billions of dollars a year and can be associated with billions more decades later when chronic diseases develop in adulthood.

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PREFACE

It took time and dedication to select what would be my research specialty. It was ambitious and would involve more than I could even conceptualize at the time. But I enjoy this area of research and immediately got excited about the questions I could tackle, and the projects that I could implement later in my career as an independent researcher. My academic advisor and dissertation chair, Dr. Jessie Burke was my biggest supporter. She encouraged me along the way and helped me resolve issues that arose numerous times in the process of developing the dataset that forms the basis of this dissertation. She was also a voice of reason. In her wisdom she knew the ‘politics’ that were involved in working with external agencies and she also knew when to reel in the typical doctoral student tendency of developing an ever expanding and complex research study. I couldn’t have asked for a more supportive, personable, and genuine advisor and I am honored to have received her mentorship. I also owe my completion of this dissertation to the department chair Dr. Steve Albert who was willing to step in as dissertation chair for the last six months of my program while Dr. Burke was away on sabbatical leave. I feel exceptionally fortunate to have had him step in with such commitment to my work. I didn’t miss a beat. I also learned a lot about how to market my expertise to academicians and convey the novelty of my work and I am very grateful for that. I know my career will reap the rewards of those life lessons.

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1.0 INTRODUCTION

The purpose of this dissertation research is to ascertain the impact of biological factors as well as social and economic neighborhood factors on the risk of low birth weight and preterm birth among infants of non-Hispanic white and non-Hispanic black mothers, under the hypothesis that intergenerational biological and environmental factors could be explanatory variables in the perpetuated trend in racial/ethnic disparities in birth outcomes.

The Introduction (Chapter One) presents the case for the public health significance of low birth weight, preterm birth, and racial/ethnicity disparities therein, through the summarization of current incidence statistics, risk factors, and etiology. The Methodology (Chapter Two) follows, with a description of the Allegheny County, Pennsylvania transgenerational birth file created, a description of covariate operationalization and coding schemes, and the analysis performed to study the transgenerational risk for low birth weight and preterm birth as a result of biology and social/economic residential context. Chapter Three is a manuscript of a systematic literature review and meta-analysis synthesizing the body of literature on the association between social/economic residential context and preterm birth/low birth weight in the United States. Chapter Four is a manuscript on the relationship between infant low birth weight and maternal birth weight examined using multilevel binary and multinomial logistic regression, with intent to determine whether generational individual-level and neighborhood-level factors explain the racial disparity in low birth weight. Chapter Five is the third manuscript and looks at the relationship between infant preterm birth and maternal gestational age examined using single-level binary and multinomial logistic regression, with intent to determine whether generational individual-level and neighborhood-level factors explain the racial disparity in preterm birth. Chapter Six brings together the main findings from the three studies, highlighting the statistically significant and non-significant results per the research questions presented and hypotheses made below. The final section, Chapter Seven, provides a conclusion and statements of future research and recommendations for public health practice.

The three aims of this research, corresponding with the three studies conducted, are as follows:

1. Systematic literature review and meta-analysis of the literature on neighborhood social and economic context and the adverse birth outcomes of low birth weight and preterm birth
2. Examination of the impact of maternal birth weight and intergenerational neighborhood social and economic context on infants' risk of low birth weight.
    a. Hypothesis I: A mother of lower birth weight will tend to have an infant of low birth weight, even after controlling for socio-demographic factors.
    b. Hypothesis II: The association between infant low birth weight and maternal birth weight will differ for non-Hispanic white and non-Hispanic black mothers.
    c. Hypothesis III: The relationship between mothers' birth weight and infant low birth weight is mediated by maternal health and obstetric factors such as pre-pregnancy BMI, weight gain during pregnancy, gestational/chronic diabetes mellitus, gestational/chronic hypertension, and vaginal bleeding.
    d. Hypothesis IV: There is a significant contextual effect of mothers' neighborhood characteristics which explains the variation in low birth weight rates across neighborhoods.
    e. Hypothesis V: There is a significant additive contextual effect of maternal grandmothers' neighborhood characteristics which explains the variation in low birth weight rates across neighborhoods.
3. Examination of the impact of maternal length of gestation and intergenerational neighborhood social and economic context on infants' risk of preterm birth
    a. Hypothesis I: A mother of shorter gestational age will tend to have a preterm infant, even after controlling for socio-demographic factors.

b. Hypothesis II: The association between infant preterm birth and maternal gestational age will differ for non-Hispanic white and non-Hispanic black mothers.

c. Hypothesis III: The relationship between mothers' gestational age and infant preterm birth is mediated by maternal health and obstetric factors such as pre-pregnancy BMI, weight gain during pregnancy, gestational/chronic diabetes mellitus, gestational/chronic hypertension, and vaginal bleeding.

d. Hypothesis IV: Mothers' neighborhood characteristics are significantly associated with infant risk for preterm birth.

e. Hypothesis V: Maternal grandmothers' neighborhood characteristics are, in addition to mothers' neighborhood characteristics, significantly associated with infant risk for preterm birth.

1.1 PUBLIC HEALTH SIGNIFICANCE

Low birth weight (LBW) "is defined by the size of the infant at birth, regardless of gestational age" and an infant weighing less than 2,500 grams at birth is considered to be of LBW (Iams & Romero, 2007). Among the almost 4 million live births reported in the United States in 2013, approximately 317,000 infants were born with LBW, which is about 8% of all births. Among non-Hispanic (NH) whites and Hispanics the LBW rate was 7% and 7.1%, respectively, while it was 13.1% for NH blacks (Hamilton, Martin, Osterman, & Curtin, 2014); this can be juxtaposed with 7% for whites and 13.1% for non-whites in 1962 (Lunde, Okada, & Rosenberg, 1964). Despite slight increases and decreases, over time, in the rates of LBW in the United States the racial/ethnic disparity has remained largely unaffected.

The primary cause of LBW is preterm birth (Paneth, 1995), which is birth after 20 weeks of gestation but prior to 37 completed weeks. Worldwide the preterm birth (PTB) rate is about 11%. Although, as one might have suspected, the majority of these births are in the developing nations of sub-Saharan

Africa and South Asia (almost 13%) the United States does not fare much better at 11%, compared with almost 9% in other developed countries (Blencowe et al., 2012). Not only does the United States fare poorly on the international stage, disparities exist within the country such that 16.5% of infants born to NH black mothers are born prematurely – a rate higher than the average of sub-Saharan African and South Asian countries – in contrast to 10.3% and 11.6% for infants of NH white and Hispanic mothers (Hamilton et al., 2014). Although a moderate decline in PTB and LBW rates has been noted since 2006 in the United States, PTB and LBW rates have generally been on an upward trend over the last couple of decades despite advancement in knowledge of risk factors and interventions implemented. It is believed that an increase in induced deliveries, as well as more multiple births as a result of assisted reproductive technologies, can explain a large part of this trend (Goldenberg & McClure, 2010). The majority of PTBs are late PTBs (that is, 34-36 weeks completed gestation) and the decline in PTB rates since 2006 has been primarily in this group of infants while early PTBs (less than 34 weeks completed gestation) have remained relatively unchanged (Martin, Hamilton, Ventura, Osterman, & Mathews, 2013; Martin et al., 2012).

In 2010, the most recent year for which linked birth/death data are available, the risk of death in the first year of life for those born with LBW was about 24 times higher than the rate for non-LBW infants; however, very LBW infants were at highest risk—more than 100 times the rate of non-LBW infants (Mathews & MacDorman, 2013b). An infant’s gestational age and weight at birth are both risks for infant morbidity and mortality and are related to each other yet distinct (Martin et al., 2013). In 2010, about two-thirds of infants that died in their first year of life were born prematurely. Prematurity, and associated conditions, are responsible for about 35% of infant mortality rates nationally, the largest single cause of death, and account for about half of the racial/ethnic infant mortality disparity documented between NH white and NH black infants. The preponderance of deaths were the result of early PTBs rather than late PTBs, with the risk of death decreasing the closer the infant is to term (Mathews & MacDorman, 2013a, 2013b). The risk of death for infants of NH black mothers compared with NH white and Hispanic mothers is more than double. The leading five causes of infant mortality are congenital malformations, disorders related to short gestation and LBW, Sudden Infant Death Syndrome, maternal complications of pregnancy, and unintentional injuries. Together these account for 57% of infant deaths nationally. The rank order of these five leading causes of infant death varies by race/ethnic group, with congenital malformations as number one for NH whites and Hispanics, and disorders of short gestation and LBW the leading cause for NH black. For infants born to NH black women, infant mortality as a result of short gestation and LBW is in excess of three times the rate of NH white women (Hoyert & Xu, 2012; Mathews & MacDorman, 2013b).

In addition to the burden of mortality associated with PTB and LBW are medical expenditures associated with morbidity which, for both mother and prematurely born infant, amount to almost $65,000 per infant – 4 times the cost for an infant born without complications. The overwhelming majority of these costs (90%) are covered by health plans and include the costs of inpatient and outpatient visits and prescriptions (Thomas Reuters, 2008). The economic and social burdens of premature births are substantial, costing the United States healthcare system at least $26 billion per annum (CDC - Reproductive Health). Infants born prematurely are at higher risk of morbidity, including neurodevelopmental and sensorineural disabilities, and more likely to experience adulthood chronic diseases such as “coronary heart disease, stroke, hypertension, and type II diabetes mellitus” (Goldenberg & McClure, 2010).

The higher prevalence of PTB and LBW among infants born to NH black women than to NH white or Hispanic in the United States has fueled the continued disparity in infant morbidity and mortality for decades (Paneth, 1995) but the reasons for higher rates of prematurity and lower birth weight are not fully understood. To compound the issue, the etiology of PTB and LBW has not been fully comprehended (Goldenberg & McClure, 2010).

1.2 RISK FACTORS AND GROUPS AT RISK

1.2.1 Socio-demographic characteristics and maternal behaviors

Research has historically focused much attention on only maternal health behaviors and characteristics as predictors of the incidence of PTB and LBW and as the reasons for racial/ethnic disparities in rates of these adverse birth outcomes. Alcohol and tobacco use during pregnancy, the adequate use of prenatal care services, maternal age, maternal marital status, and socioeconomic position are the factors typically included in analyses. Some researchers have found these risk factors to account for the entire race/ethnic disparity (Lieberman, Ryan, Monson, & Schoenbaum, 1987) while others have not (R. J. David & Collins, 1997).

Women who deliver infants with LBW and PTB are more likely to be non-white, older, hypertensive, primiparous, have high parity, have a short inter-pregnancy interval, have lower educational attainment, be unmarried, drink alcohol and smoke tobacco during pregnancy, receive inadequate or late prenatal care (Ahern, Pickett, Selvin, & Abrams, 2003; Ellen, 2000; P. O'Campo, Xue, Wang, & Coughy, 1997), and be of overall low socioeconomic position (Ahern et al., 2003; Auger, Giraud, & Daniel, 2009; J. W. Collins Jr, David, Rankin, & Desireddi, 2009; Gorman, 1999; P. O'Campo et al., 1997). We know that NH black and Hispanic mothers are more likely to be of lower socioeconomic position (Pickett, Ahern, Selvin, & Abrams, 2002; Reagan & Salsberry, 2005a, 2005b), younger, multiparous, not have a high school degree, to have short inter-pregnancy intervals, and less likely to receive timely prenatal care (Buka, Brennan, Rich-Edwards, Raudenbush, & Earls, 2003; Mason, Messer, Laraia, & Mendola, 2009; Messer, Oakes, & Mason, 2010; Reagan & Salsberry, 2005a).

It is interesting that there exist disparities by race/ethnicity and nativity for the impact of particular behaviors or measures of socioeconomic position on risk for adverse birth outcomes. For example, smoking has been identified as a risk factor for PTB but the odds ratio for PTB for women who smoked during pregnancy is higher for NH black women than it is for NH white (Ahern et al., 2003; Masi, Hawkley, Piotrowski, & Pickett, 2007). The protective effect of receiving adequate prenatal care is diminished for NH black and Hispanic mothers compared to NH white (Masi et al., 2007), as well as mothers living in poor social and economic environments compared to those in wealthier contexts (P. O'Campo et al., 1997). Additionally, the protective effect of higher socioeconomic position or social/economic support as measured by higher educational attainment or being married are weaker for NH black and Hispanic women (M. R. Kramer, Cooper, Drews-Botsch, Waller, & Hogue, 2010; Masi et al., 2007). The reasons for the differential impact of these factors has been stated but not explained in the literature.

Maternal individual-level risk factors account for a small amount of the variance in adverse birth outcomes (Buka et al., 2003; English et al., 2003) and this is one of the reasons for the interest in the role of other factors, including residential context, as explanatory variables. The study of social context as a covariate in the explanation of adverse births outcomes has increased over the years (Geronimus, 1986) and allows for the study of "the important role that the residential environment plays in shaping the psychosocial and physiological factors that lead to poor birth outcomes" (J. F. Bell, Zimmerman, Almgren, Mayer, & Huebner, 2006).

1.2.2 Maternal residential environment

Mothers who reside in poor economic environments are more likely to be of lower socioeconomic position (Luo, Wilkins, & Kramer, 2006), to be recent immigrants to the country, to experience maternal morbidity during pregnancy – diabetes mellitus, preeclampsia, eclampsia, abnormal glucose tolerance, and so on (Urquia, Frank, Glazier, & Moineddin, 2007), and engage in risky behaviors such as substance use during pregnancy and receiving inadequate prenatal care (Fang, Madhavan, & Alderman, 1999; Reagan & Salsberry, 2005a). Living in a neighborhood with a poor economic environment (Ahern et al., 2003; P. O'Campo et al., 1997), a high proportion with low educational attainment, and a high proportion of black residents is associated with a higher risk for PTB, LBW, and risky behaviors, such as smoking during pregnancy (Nkansah-Amankra, 2010; Pickett et al., 2002) compared to women residing in more economically advantaged and predominantly white neighborhoods.

Articles reporting on the study of neighborhood and social context on health have demonstrated that white and black populations live in distinctly different contexts (J. W. Collins Jr, Herman, & David, 1997; Pickett et al., 2002). NH black mothers are more likely than NH white mothers to live in neighborhoods with a higher proportion of black residents, fewer high school graduates, more people in a working class occupation (rather than a professional occupation), more unemployed males, more people living below the poverty level, and lower median income (P. O'Campo et al., 1997; Pickett et al., 2002). Research in certain counties in the United States has found the near absence of poor white neighborhoods and wealthy black neighborhoods (Messer et al., 2010). Not only is there a low probability of shared neighborhood experiences between these two groups but there is also very little overlap in frequency distributions of adverse birth outcomes, such that cities with the lowest rate of early PTB to black women still find that this rate is worse than that of infants born to white women in cities reporting the highest rate of early PTB for whites (M. R. Kramer & Hogue, 2008).

1.2.3 Parental birth outcomes

“It has long been known that [maternal birth weight has] an influence on the” birth weight of infants (Alberman, Emanuel, Filakti, & Evans, 1992), but the influence of maternal gestational age on PTB is less known (Magnus, Bakketeig, & Skjaerven, 1993). Maternal and paternal birth weight (BW) have a positive and significant independent relationship with the BW of their offspring. And although some researchers would argue for the lesser role of paternal factors (Alberman et al., 1992) others have found an impact of similar magnitude as maternal factors (Conley & Bennett, 2000; Klebanoff, Mednick, Schulsinger, Secher, & Shiono, 1998). The mother-infant correlation in BW has been found to range from $r = 0.15$ to $r = 0.25$, but more research is needed to determine the father-infant correlation (Magnus et al., 1993) because less research has incorporated the paternal factors.

Although there is a high recurrence of PTB among siblings, researchers have found the intergenerational transmission of gestational age to be low between mother and offspring (Magnus et al., 1993). Some have found maternal gestational age (GA) to have a significant independent but negative relationship with infant BW, and paternal GA to be suggestive of a negative association but not statistically significant (Alberman et al., 1992). Others have found that mothers born preterm are more likely to give birth to infants at risk of being born preterm as well; with the data suggesting a stronger association for nulliparous women, as well as for the generational transmission of spontaneous PTBs, specifically, compared to medically indicated PTBs (Bhattacharya et al., 2010). Some researcher have found mothers who were born preterm more likely than those born at term to give birth to an infant of higher BW, controlling for maternal BW, suggesting fetal programming of the mother such that offspring have higher BW than was achieved by the mother (Magnus et al., 1993). However, as is clear from the disparate, and somewhat inconsistent findings, much more research is needed in this area.

The low heritability of GA suggests the minimal role of genetics in the relationship between mother and infant GA; however, despite the higher heritability of BW there remains a significant fraction of infant BW variation unexplained by maternal BW (Magnus et al., 1993). A heritability study utilizing grandparent fixed effects models concluded that there exists “a biological (genetic) component to the intergenerational transmission of birth weight and that [it] contributes significantly to the race difference in risk of LBW,” although the actual strength of this factor may be controversial (Conley & Bennett, 2000). Despite hypotheses that higher LBW rates in black populations are the result of higher biological inheritance this may not be the case. In fact, some propose that biological inheritance may be lower in blacks than whites, and that rather the generational social, cultural, and behavioral factors may be more significant for blacks than whites (Conley & Bennett, 2000). Conley & Bennett say “it appears as though there may be significant genetic-environmental interactions at work such that the social and political conditions under which African Americans suffer suppresses the expression of genetic propensities or generates ‘extra’ low birth weight, resulting in the lower observed intergenerational correlation” (Conley & Bennett, 2000).

Research has found that statistical models that include individual socioeconomic measures along with parental LBW substantially reduce the racial disparity in infant LBW, although it still remains. For example, higher family income is protective for infants who are at high risk of being born with lower BW because their parents were LBW (Conley & Bennett, 2001). It is the belief of some that it is the "health status of previous generations—more than current social conditions—that explains the lion's share of race differences in the current generation's birth outcomes" (Conley & Bennett, 2000).

1.2.4 Intergenerational birth outcomes and residential environment

The birth outcome of the mother as well as the neighborhood context into which the mother was born have been found to have independent and significant impacts on the birth outcomes of her infant. Infants born to women who were themselves of LBW are at increased risk of being born preterm or with LBW, regardless of the mother's race, and independent of neighborhood context across the woman's life. Women who were born with LBW are approximately twice as likely as their non-LBW counterparts to deliver a LBW infant (Chapman & Gray, 2014; J. W. Collins Jr, Wambach, David, & Rankin, 2009). Although rarely studied, the level of deprivation in the neighborhood into which the mother was born is an independent risk factor for the LBW status of her infant. Among women who were not born with LBW, neighborhood poverty plays a larger role in the risk of infant PTB and LBW for NH black than NH white women – approximately 10% and 25% for PTB and LBW, respectively, for NH black, and approximately 2% and 3% for NH white women (J. Collins Jr, K. Rankin, & R. David, 2011). The birth of the NH black mother into an affluent neighborhood, despite the affluence of the neighborhood in which she resides during adulthood has modest, yet stable, protective effects for her infant (J. W. Collins Jr, David, et al., 2009). NH black women born into poverty and who live in poverty in adulthood (lifelong impoverishment) have the highest risk of delivering a preterm infant, compared with women who experience upward economic mobility in adulthood. This is likely due, in part, to lower risk characteristics among those who experience upward economic mobility – they are more likely to be married, to have lower parity, to be older, less likely to smoke during pregnancy, and more likely to have received adequate prenatal care (J. W. Collins Jr, K. M. Rankin, & R. J. David, 2011).

"Most studies highlight differences in individual risk attributes rather than [attempt] to explain the genesis of the disparities" (J. F. Bell et al., 2006), but taking a transgenerational perspective may get us closer to a root cause. We can see from the literature summarized above that the exclusion of parental birth outcomes and generational social and economic context in the examination of infant birth outcomes paints an incomplete picture of the determinants of health and disparities.

1.3 ETIOLOGY OF PRETERM BIRTH

Because disorders of prematurity play such a large role in infant mortality this paper will not focus specifically on the etiology of intrauterine growth retardation, which is the other cause of LBW. PTB has near-term consequences for infants as well as long-term effects in adulthood. Neurological, pulmonary and ophthalmic disorders are associated with PTB (WHO, 2002). The majority of PTBs (70%) are spontaneous PTBs while the remainder are induced, whether medically indicated (intentionally induced by a medical professional) or iatrogenic (inadvertently induced by a medical professional). Preterm labor (PTL) and preterm premature rupture of membranes (PPROM) are together considered to initiate the four causes of spontaneous PTB discussed below (see Table 1)—of note is that the relative contribution of either PTL or PPROM varies by race/ethnicity (Goldenberg & McClure, 2010).

Table 1. The causes of spontaneous preterm birth

Cause	*Mechanism*
Maternal and/or fetal stress	Mediated by corticotropin-releasing hormone; triggering contractions
Decidual-amnion-chorion inflammation	Exaggerated response of the immune system leading to the withdrawal of progesterone; triggering contractions
Placental abruption or decidual hemorrhage	Leads to early delivery
Mechanical stretching	Excessive amniotic fluid, multifetal gestation, and fetal movement; triggering contractions

The relationship between maternal and/or fetal stress and spontaneous PTB appears to be mediated by corticotropin-releasing hormone (CRH) which increases the production of cortisol. A positive feedback loop exists in that the production of CRH in the placenta and reproductive tract is enhanced by cortisol. CRH through the stimulation of other chemicals triggers contractions. The increase in cortisol levels may also affect other chemicals thus encouraging changes in the woman's cervix and premature rupture of the amniotic sac. Stress-induced PTB is more common in nulliparous women with anxiety or depression (Hodgson & Lockwood, 2010).

The second cause is decidual-amnion-chorion inflammation. Systemic inflammation and inflammation localized to the reproductive tract have both been associated with spontaneous PTB. Genital tract inflammations are common causes of very early PTB. In particular bacterial vaginosis (BV) has been implicated in spontaneous PTB (Hillier et al., 1995) and its presence creates an environment for the over-growth of other bacteria in the genital tract. Since the bacteria are typically of low virulence the bacteria themselves are not believed to cause PTB but rather the maternal/fetal inflammatory response to the infection. The exaggerated response of the immune system leading to the withdrawal of progesterone can lead to PTB by triggering contractions. The maternal/fetal inflammatory response may explain higher rates of PTB in certain ethnic groups as this "may reflect a genetically determined, exaggerated inflammatory response" (Hodgson & Lockwood, 2010). Genetic predisposition could place one at increased risk – "T2 allele of the TNFα [tumor necrosis factor alpha] gene causes increased expression of TNFα and confers an increased risk of [PPROM] in African-American women. Moreover, African-American mothers harboring both this polymorphism and BV are at even greater risk of PTB" (Hodgson & Lockwood, 2010). Other polymorphisms have been associated with decreased risk (interleukin-6 – 174 promoter) and increased risk (Asp299Gly and Thr399Ile for TLR-4) of PTB among women of European decent. There is also evidence suggesting the role of certain fetal genotypes in the risk of PPROM in African Americans. Gene-environment interactions may be demonstrated through polymorphisms in drug metabolizing genes in women who smoke cigarettes, for example (Hodgson & Lockwood, 2010).

The third cause of PTB is placental abruption or decidual hemorrhage. Placental abruption involves partial or complete separation of the placenta from the uterine wall while the fetus is in utero, leading to early delivery. Decidual hemorrhage presents clinically as vaginal bleeding and is associated with increased risk of PPROM and PTL. Abruption-associated PTB is more common in "older, married, parous, college-educated" women (Hodgson & Lockwood, 2010).

The fourth cause is pathological mechanical stretching of the uterus. Stretching is a normal part of parturition and is the result of fetal growth. Prior to term, progesterone prevents increases in levels of contraction-associated proteins, which would otherwise be induced by the stretching. The withdrawal of progesterone, typically at term, allows for increases in contraction-associated proteins, thus triggering contractions (Institute of Medicine (US) Committee on Understanding Premature Birth and Assuring Healthy Outcomes, 2007). However, mechanical stretching of muscles also increases their contractility; mechanical stretching as can be the result of excessive amniotic fluid surrounding the fetus, multifetal gestation (Hodgson & Lockwood, 2010) and fetal movement (Hall, 2011).

Although these are the known causes, in the majority of cases a specific cause cannot be determined (Goldenberg & McClure, 2010). These attributable causes often do not explain a substantial portion of the etiologic fraction—that is, "the proportion of [PTB] in a given population that can be attributed to a given risk factor" (WHO, 2002). Research has focused on the identification of factors that are found to be associated with PTB and it is hoped that these risk factors will elucidate the etiology. Important risk factors that have been identified to date include: history of delivering a premature infant, history of spontaneous abortion, "in utero exposure to diethylstilbestrol" (M. S. Kramer, 1987); demographic characteristics such as race, age, marital status and socioeconomic position; pre-pregnancy body mass index and physical activity; characteristics of current pregnancy including plurality, vaginal bleeding, volume of amniotic fluid, and medical conditions; stress; alcohol, tobacco, and substance use during pregnancy; and, infections. "Additional research that defines the mechanisms by which risk factors are related to PTB is crucial" (Goldenberg & McClure, 2010).

1.4 THEORETICAL FRAMEWORK

1.4.1 Social determinants of health perspective

Understanding the social conditions in which groups within the population live is imperative if we hope to address health inequality. In developed countries people are living longer; however, those lower on the social strata are still experiencing high morbidity and mortality and not experiencing all the benefits of advances in public health and medicine. An increasingly powerful body of theory and research argues that social conditions, especially social stratification, play a causal role in a population's exposure to these behavioral, psychological and social risk factors. A better understanding of the mechanisms through which these "fundamental causes" affect health should inform the way in which public health professionals and researchers address substantive issues such as disproportionately poor birth outcomes among minority groups, acknowledging the difficulties of influencing change if the broader social and economic environment remains unchanged. Researchers have customarily focused on the identification of risk factors that would, at least partly, account for the relationship between socioeconomic position and health, but House and his colleagues argue that even if psychosocial factors are involved, the impact of social stratification on health remains highly significant (House et al., 1994). Social stratification is a distal factor in the determination of health, and historically, despite different diseases, both infectious and chronic, and the identified risk factors, socioeconomic stratification remains a fundamental cause of health inequalities (House et al., 1994; Link & Phelan, 1995; Phelan, Link, & Tehranifar, 2010).

The association between socioeconomic position and health has been a consistent finding over many decades (Marmot et al., 1991). This linear relationship, whereby those of higher social class live longer and are less likely to be sick, has been observed in various countries and is receiving increased attention from researchers and policy makers (Carpiano, Link, & Phelan, 2008). Scholars, however, do not necessarily agree on the particular aspect(s) of social class that impact the outcome of interest (Hout, 2008). In fact, it is the belief of some that the "proliferation of various measures of [socioeconomic status (SES)] obscured rather than clarified the possible causal linkages between SES and health" (Duncan, 2005). A few explanations have been put forward for the socioeconomic position-health association and these include:

- The association that has been found is spurious and the result of unaccounted for genetic and biological factors,
- Health determines social position such that the social position-health gradient is the result of selection, and
- Social causation, which argues that social position determines health outcomes (Carpiano et al., 2008).

1.4.2 Fundamental causes of disease

Epidemiologic research typically focuses on the identification of risk factors in order to study the pathways through which disease is caused and thus present an opportunity for prevention intervention. While these pathways are valuable in their ability to explain the social patterning of disease/health, Link and Phelan argue they should not become the sole focus at the expense of fundamental causes which are then considered less significant or simply proxies for more proximate factors that have not been accounted for. Link and Phelan note that the socioeconomic status-health gradient has persisted despite the changes over time of diseases and their identified proximate risk factors. The theoretical framework of the fundamental causes of diseases focuses on the economic processes that determine the distribution of resources in the social structure, rather than the proximate factors which appear to be intervening mechanisms at a particular point in time (Link & Phelan, 1995; Phelan et al., 2010). Socioeconomic status, race (Phelan & Link, 2013), racism, racial residential segregation, and stigma (Hatzenbuehler, Phelan, & Link, 2013) are viewed as processes that determine the distribution of resources in society – "knowledge, money, power, prestige, and beneficial social connections" (Phelan & Link, 2013) are those resources. These resources affect people's ability to maintain good health, avoid risks and mitigate the effect of disease if it were to occur (Carpiano et al., 2008).

Segregation affects access “to social and material resources that promote health and avoid disease;” the concentration of poverty affects collective political power, exposure to environmental hazards, access to health-promoting services, behaviors and social connections (Schulz, Williams, Israel, & Lempert, 2002). Racial residential segregation has been proposed as a fundamental cause of disease (Schulz et al., 2002) and found to be associated with the risk of adverse birth outcomes (Debbink & Bader, 2011). Relatively few articles were found in a review of the literature to be using a measure of segregation, but rather the majority looked only at the percent of black residents in a neighborhood. Some researchers criticize “this approach [for not recognizing] the degree to which neighborhood processes are affected by interconnections across more or less permeable boundaries, greater or lesser physical distance from similar and dissimilar local areas, and differential situations of groups within society (Krivo, R., Calder, & Kwan, 2007). As a result, it is not only of interest what the proportion of majority and minority groups in an areal unit is but also whether these population groups live close to, or far away, from each other, and whether the neighborhoods in which they live are similar or dissimilar in this factor to those surrounding them.

Not much research has considered economic segregation as a fundamental cause of disease, but a similar argument can be presented for its consideration as is presented for racial residential segregation and other fundamental causes. It is commonplace for researchers in the area of birth outcomes to be interested in the economic situation of the neighborhoods into which infants are born; however, very few use a measure other than the proportion of residents in poverty. This approach does not consider how close or far the poor live from the non-poor, or the economic situation of nearby neighborhoods. Racial residential segregation and economic segregation have been found to be distinct from each other in black neighborhoods but are more likely to be one and the same in white neighborhoods (Debbink & Bader, 2011), so these two will be considered as separate neighborhood variables in this research study. The fundamental cause of racial residential segregation will be examined along with economic segregation as two processes that determine the distribution of resources in the social structure. The traditionally used racial composition and poverty percentages will be examined as well. It is hypothesized that these neighborhood characteristics will predict the risk of PTB and LBW when examined in a cross sectional manner, and compound the risk when examined in a manner that accounts for intergenerational factors.

1.4.3 Ecosocial theory

Humans are both social beings and biological organisms and the way in which experiences of inequality are embodied "depends in part on our biological constitution (itself a dynamic interplay between exposure, development, growth, and gene expressions)," while this biological constitution is dependent on history and the social environment (Krieger, 2005). Ecosocial theory embraces both biological and social conditions, but does not consider biology to be inherent or innate, and neither does it consider social conditions to only impact the body through the mind. Both distal and proximal factors simultaneously, rather than consequentially, affect health. A diversity of life experiences and exposures structured by social power dynamics accumulate in our bodies over the life course and are the result of current as well as historical factors (Krieger, 2008; Krieger & Davey Smith, 2004). Although the fundamental social causes of disease perspective is distinct, and potentially discordant, from ecosocial theory, studying the role of social context on adverse birth outcomes with both these theoretical frameworks in mind may help researchers understand why women are exposed to risk or protective factors, the social context in which these individual-level risk factors result in the development of adverse birth outcomes, and the causal pathways through which distal factors such as socioeconomic position, power, and race become embodied to cause disease. It is on the basis of these theories that current maternal socio-demographic, behavioral, health/obstetric factors, and neighborhood social and economic context will be examined along with maternal birth outcomes and historical neighborhood social and economic context.

See Figure 1 for a diagrammatic representation of the theoretical framework to be used. The diagram represents direct and indirect pathways from maternal health and behavioral factors, socio-economic factors (person- and neighborhood-level), and mothers' birth outcomes, to birth outcomes of the infant. Additionally, there are hypothesized pathways from the maternal grandmothers' health and behavioral factors, and socio-economic factors, through the mother or directly to the infant. For this research, we will focus primarily on the pathways marked by the dotted arrows.

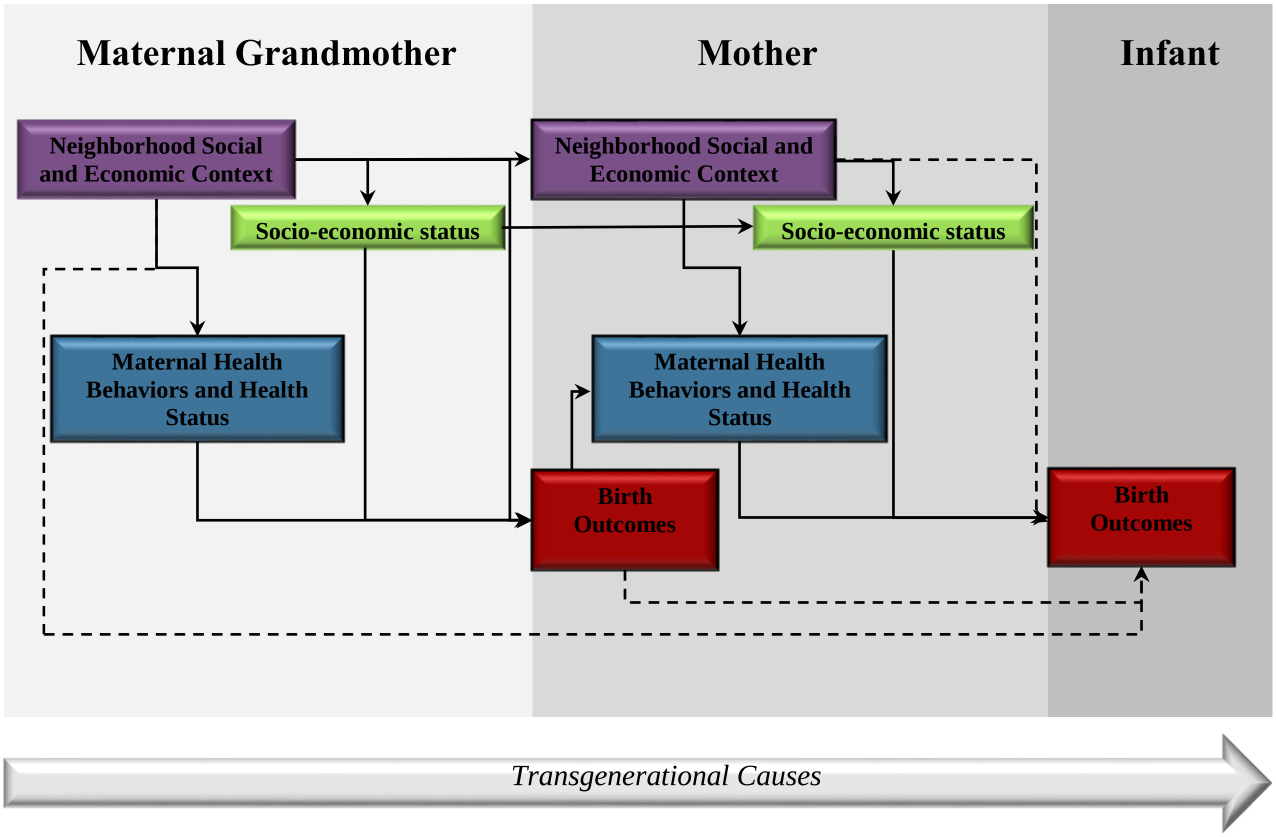

Figure 1. Theoretical framework: transgenerational causes of birth outcomes due to biological factors and social and economic neighborhood context

2.0 METHODOLOGY

2.1 DATA AND INCLUSION/EXCLUSION CRITERIA

The University Of Pittsburgh Graduate School Of Public Health has close ties with the Allegheny County Health Department and frequently joint projects are carried out to further the research interests of academicians at the University and public health practices of the health department. This research team began one such project with the support of the acting health director at the time. Approximately 81% of Allegheny County, Pennsylvania residents are NH white, 13.4% NH black, and the remaining residents are Asian, Hispanic or multi-racial (U.S. Census Bureau, 2010). As a result, this research will focus primarily on NH white and NH black mothers. Allegheny County has experienced similar racial disparities in PTB, LBW, and infant mortality as the national data reflects. For example, the average LBW rate for 2012 was 7.5% – with 12.9% for infants born to black mothers compared with 6.0% for infants born to white mothers (Kimmel & Kokenda, 2013). As a result, gaining an understanding of the causes of perpetuated disparities in PTB and LBW will provide valuable data for public health professions in the county.

Institutional Review Board (IRB) approval was received from the University of Pittsburgh, protocol number PRO13100434, and a data use agreement enacted through the University of Pittsburgh’s Office of Research with the Allegheny County Health Department (ACHD) for access to and use of vital statistics birth records. These data were obtained from the ACHD’s Office of Epidemiology and Biostatistics for first-born singleton infants born in the County in the years 2009-2011, inclusively. These years were selected in order to analyze the most recently available birth records. It was initially intended that 2006-2008 birth records would be included as well; however, this was precluded by the labor-intensive nature of creating this dataset, and the limited resources available at ACHD to assist in this endeavor. Three research assistants were hired with funding obtained through a scholarship awarded by the Behavioral and Community Health Sciences department at the University of Pittsburgh’s Graduate School of Public Health.

From a list of 2009-2011 first-born singleton births in Allegheny County, these research assistants aided the ACHD statistical analyst in the identification of mother's birth records from the years 1979-1998 with Allegheny County as their place of birth. The year 1979 was selected because it is the oldest year for which birth records were available to ACHD in an electronic format that could be read and manipulated by the statistical analyst.

The search strategy involved identifying the mothers' maiden name and date of birth (DOB) from the infants' birth record and using those to search for an infant of that exact name with the same DOB in former years. Due to the potential for misspelled names, when exact matches were not found, the research assistants sorted the data such that the names were in alphabetical order, performed visual searches and made notation of potential matches. With infant and mother's birth file identification numbers compiled by the research assistants, the statistical analyst went through the database and extracted the full birth records for exact matches and linked those records in a Microsoft Excel spreadsheet, that is, pasted the infant and mother birth records on the same row of the spreadsheet. For the potential matches the statistical analyst reviewed the birth records more fully to determine whether it was a feasible match and linked only confirmed matches. A 75% matching rate was obtained, which is less than other transgenerational datasets in the county, although still comparable (Chapman & Gray, 2014; R. David et al., 2010). Once the linking was complete, personally identifiable information was removed, such as names and full addresses. A copy of this de-identified transgenerational spreadsheet was provided to the researchers for analysis.

Each infant birth record and mother's birth record included a census tract code which corresponds to the address provided by the mother during pregnancy. For the purpose of this research the census tract is used as the neighborhood unit of analysis. Census tracts were the smallest geographic unit available on the birth records, others included the ZIP code and municipality designations. Census tracts are fairly homogenous, contain between 1,200 and 8,000 people, and are relatively permanent subdivisions in a county (U. S. Census Bureau). The tract codes appended to the birth record by the ACHD in any given year are those available from the US Census from the most recent decennial census. However, there is typically a delay is the systematic application of new tract codes to the birth records resulting in the first year or two of births in a new decade being assigned census tract codes from the previous decade. Every now and then census tract boundaries and codes change due to increases and decreases in population size. So in order to accommodate these changes, census tracts corresponding to certain birth records were reassigned. Using ArcGIS some original addresses were geocoded and then all 1979-1985 births assigned to 1980 tract codes, 1986-1995 births to 1990 tract codes, 1996-1998 births to 2000 tract codes, and 2009-2011 births to 2010 tract codes. This process of reassignment has been performed by similar studies in this area (R. David et al., 2010).

The University of Pittsburgh's University Center for Social and Urban Research (UCSUR), provided counsel on obtaining census tract-level data for the County for all years required. From the 2010 US Census, tract level information on race, ethnicity, and household income was extracted and linked to the infant's birth record, while the same tract-level information from the US Census Bureau's decennial data from 1980, 1990, and 2000 were linked to the mother's birth record. Social Explorer® was used to obtain tract level information for all decennial time points. From the exported Microsoft Excel spreadsheets from Social Explorer®, the number of NH black, NH white, and total NH residents per tract were extracted and would be used to calculate the percent of NH black residents in each tract. From Social Explorer® the number of households (HH) per income category were exported. Based on the County-wide income distribution and the number of HH in the County, tertiles were calculated for low, middle, and high income with a third of the distribution in each. These income cut-off points were applied to each tract and used to determine the percentage of that tract in each tertile. This information was used to calculate the percentage of the tract in the lowest income tertile. Using Wong's methodology on local spatial segregation, a Geographic Information Service (GIS) expert faculty member provided assistance to the research team in the calculation of racial residential and economic segregation measures. After creating code in R statistical software he used the percentage of NH black residents, percentage of HH in the lowest income tertile, and Census shapefiles for each decennial period and obtained a segregation score for each census tract. (Wong, 2002). These data were merged with the transgenerational birth file. The purpose in merging the census data was to take advantage of the vast amount of data collected by the U.S. Census to provide contextual data that could be important to the determination of birth outcomes. This technique has been used by other researchers in this area (Mason, Kaufman, Emch, Hogan, & Savitz, 2010; P. O'Campo et al., 2008).

The spreadsheet received from the ACHD statistical analyst included 7,213 infant birth records from 2009-2011 successfully linked to their mother's birth records from 1979-1998 in Allegheny County, Pennsylvania. Data collected on Pennsylvania birth records has changed over the decades. As a result, the statistical analyst provided copies of the Birth File Record Formats for the years 1979-1988, 1989-2002, and 2003-current. These Birth File Record Formats were used to obtain data fields, variable descriptions, and coding information used in the original birth files. As part of the data management process, data which had been consistently collected for the mothers' birth records between 1979 and 1998 were identified, and from this list variables selected for analyses. For example, maternal grandmothers' smoking behavior, prenatal care use, and other health and obstetric factors were not consistently and reliably reported in the 1979-1988 and 1989-2002 formats and thus excluded from analyses. Once the list of consistently reported data had been compiled, all the data were coded in a consistent manner in order to be able to then merge the 1979-1998 and 1989-1998 birth records into one dataset. For example, it wasn't uncommon for the coding scheme to have changed over the years and for categorical variables to have expanded or collapsed, the coding of these variables would need to be made uniform prior to merging. The developers of the Illinois Transgenerational Birth File (TGBF) are more than familiar with the complexities involved in the creation of such a linked dataset and their published methods paper provided guidance on the processes involved (R. David et al., 2010). Despite challenges with census tract designations and birth file format changes the variables of primary interest were maintained in the Allegheny County transgenerational dataset and census tract codes used as the neighborhood unit. The Illinois researchers unfortunately could not use census tracts because of the lack of valid tract codes for older years. As a result they used more heterogeneous 'community areas' which included an average of 11 census tracts (R. David et al., 2010).

Applying inclusion/exclusion criteria, birth records of infants with congenital anomalies, whose maternal grandmothers were not black or white, as well as whose mothers were not NH black or NH white, were removed, leaving 7,040 linked birth records. Two datasets were created: one for LBW analyses and another for PTB analyses. For the LBW dataset, infants with birth weight less than 300g were removed, in order to eliminate unrealistically low birth weight for live-born infants, leaving 7,024 linked birth records. Only census tracts with at least 5 births per racial group were retained in the data set; this was applied only to the mothers' neighborhood (2009-2011) resulting in 350 census tracts representing mothers' neighborhoods (M neighborhoods). No minimum births per census tract were required for the maternal grand mothers' neighborhoods (1979-1998); however, the assumption was made that with 578 tracts representing maternal grandmothers' neighborhoods (GM neighborhoods) there was a sufficient number of units that it would not be expected that the census tracts with less than five births would reduce confidence interval accuracy and increase Type I error (B. A. Bell, Morgan, Kromrey, & Ferron, 2010). Birth records could not be missing race/ethnicity, infant birth weight, maternal birth weight, or census tract code. This resulted in a final LBW data set of 6,633 linked records.

Table 2. Low birth weight dataset: Infant births per year (2009-2011) by mother's maternal age

Mother's maternal age	2009	2010	2011	Total
12	0	1	0	1
13	0	3	1	4
14	6	6	8	20
15	14	22	23	59
16	66	58	43	167
17	79	74	92	245
18	175	145	114	434
19	190	177	158	525
20	176	160	174	510
21	167	133	178	478
22	146	122	121	389
23	147	121	115	383
24	147	125	149	421
25	137	114	124	375
26	132	139	175	446
27	161	155	175	491
28	172	161	161	494
29	168	181	202	551
30	93	150	132	375
31	0	65	134	199
32	0	0	65	65
34	0	0	1	1
Total	2,176	2,112	2,345	6,633

The overall percentage of infant LBW (birth weight less than 2,500 grams) was significantly lower for the records maintained in the final dataset (7.49%) when compared with the observations excluded for which we had LBW status (8.31%), $\chi_1^2 = 261.86,\ p < 0.001$. However, the LBW rate of the final dataset is comparable with county-wide LBW rates for infants born in the years 2009-2011 to mothers of similar age to those in the dataset (7.96%)[1]. Table 2 above displays the distribution of infant births by year and mother's age at delivery (maternal age). This is a generally young sample of mothers, but includes a similar age range to the Illinois TGBF (R. David et al., 2010). About 28% of infant births in the final dataset were to NH black mothers which is higher than the county-wide percentage of births to black mothers in this age group, approximately 22%[1]. See Figure 2 for a comparison of LBW rates in the county versus the Allegheny County LBW transgenerational dataset, by race and year.

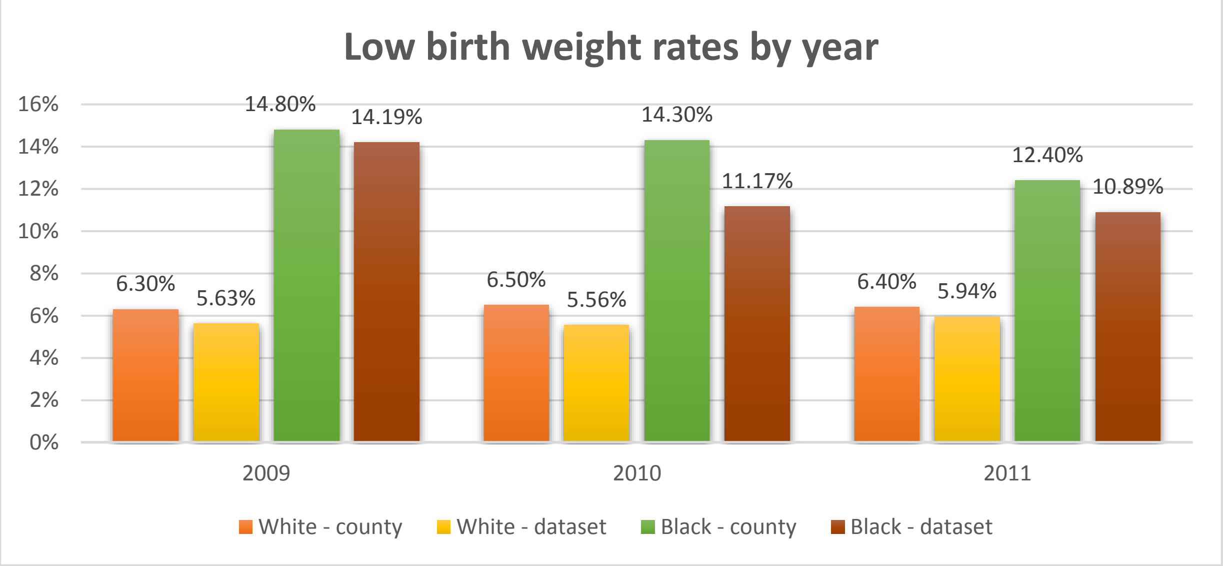

Figure 2. Low birth weight rates in the county (2009-2011) compared with the transgenerational birth file, Allegheny County, PA

For all births in the county for the years 2009-2011, 6.25% of white mothers and 13.69% of black mothers of similar ages to those included in this dataset had LBW infants. These rates are slightly higher than the 5.72% of infants of NH white mothers and 12.06% among infants of NH black mothers in the transgenerational dataset, but overall we can see that the data are comparable, $p = 0.0579$.

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[1] "These data were provided by the Bureau of Health Statistics and Research, Pennsylvania Department of Health. The Department specifically disclaims responsibility for any analyses, interpretations, or conclusions."

The definition of PTB is birth prior to 37 completed weeks of gestation, but after 20 weeks (The American College of Obstetricians and Gynecologists). As a result, for the PTB dataset infants with gestational age less than 20 weeks were removed. After excluding birth records in tracts with less than 5 births per racial group and those missing race/ethnicity, infant gestational age, maternal gestational age, and census tract code, the final data set included 6,592 linked records. In this dataset there were 350 census tracts representing M neighborhoods, and 578 census tracts representing GM neighborhoods. The overall percentage of infant PTB was significantly lower for the records maintained in the final dataset (8.19%) when compared with the observations excluded for which we had PTB status (9.51%), $\chi_1^2 = 695.43, p < 0.001$. No county-wide comparison data were available for the PTB dataset.

2.2 OUTCOME AND PREDICTOR VARIABLES

In this newly created transgenerational birth file, for purposes of distinction, the 2009-2011 birth records are referred to as the infant birth records while the 1979-1998 birth records are referred to as the mothers' birth records. The infant birth records include infant birth outcomes along with maternal and paternal characteristics, while the mothers' birth records include the mothers' birth outcomes and the maternal grandparents' characteristics. See Table 3 for variable names, variable descriptions and the operationalization of the variables.

Table 3. Operationalization of outcome variables and covariates

Variable name	Variable description	Operationalization	Source
Dependent variables – Birth Outcomes			
PTB1	Preterm birth	< 37 completed gestational weeks vs. ≥ 37 weeks at birth, including only births ≥ 20 weeks	2009-2011 birth files
PTB2	Preterm birth	< 34 weeks = Early PTB; 34-36 weeks = Late PTB; ≥37 weeks = term, including only births ≥ 20 weeks	2009-2011 birth files
LBW1	Low birth weight	< 2500 grams in vs. ≥ 2500 grams birth weight, including only births ≥ 500 grams	2009-2011 birth files
LBW2	Low birth weight	<1500 grams = very LBW; 1500-2499 grams = moderate LBW; ≥2500 grams = normal birth weight, including only births ≥ 500 grams	2009-2011 birth files

Independent variables – Main predictors			
MGA	Mothers' length of gestation	Continuous variable	1979-1998 birth files
MBW	Mothers' birth weight	Continuous variable	1979-1998 birth files
MNEIGH_BLK	Percent NH black residents in mothers' neighborhoods	Using counts of NH black residents and total residents per census tract calculate percentage and include as continuous variable	2010 Census data
MSEG_BLK	Racial residential segregation in mothers' neighborhood	Using counts of NH white, NH black, and total residents in the census tract calculate local spatial segregation index[2] and include as continuous variable	2010 Census data
MNEIGH_POV	Percent of poor residents in mothers' neighborhoods	Using county-wide income distribution determine tertiles of income distribution, apply lowest income cut-off to census tracts and determine percentage of households. Calculate percentage and include as continuous variable	2010 Census data
MSEG_POV	Economic segregation in mothers' neighborhood	Using counts of households in lowest income tertile and total households in the census tract calculate local spatial segregation index and include as continuous variable	2010 Census data
GMNEIGH_BLK	Percent black residents in grandmothers' neighborhoods	Using counts of black residents and total residents per census tract calculate percentage and include as continuous variable	1980, 1990, 2000 Census data
GMNEIGH_POV	Percent of poor residents in maternal grandmothers' neighborhoods	Using county-wide income distribution determine tertiles of income distribution, apply lowest income cut-off to census tracts and determine percentage of households. Calculate percentage and include as continuous variable	1980, 1990, 2000 Census data

Independent variables – Socio-demographic factors, Health-related Behaviors and Health Status			
GENDER	Infant sex	Male versus female	2009-2011 birth files
MAGE	Mother's maternal age	Continuous variable	2009-2011 birth files
GMAGE	Grandmother's maternal age	Continuous variable	1979-1998 birth files

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[2] Wong's local spatial segregation index. Written e-mail approval was obtained for the use of this index

Table 3. Operationalization of outcome variables and covariates (continued)

Variable name	Variable description	Operationalization	Source
MEDU_RATIO	Mothers' educational attainment ratio	Continuous variable which is a ratio of educational level attained over expected level of education based on age	2009-2011 birth files
FEDU_RATIO	Fathers' educational attainment ratio	Continuous variable which is a ratio of educational level attained over expected level of education based on age	2009-2011 birth files
MEDUC1	Mothers' categorical educational attainment	< high school, high school diploma/GED, ≥some college	2009-2011 birth files
GMEDU_RATIO	Maternal grandmother's educational attainment	Continuous variable which is a ratio of educational level attained over expected level of education based on age	1979-1998 birth files
MRACE	Mothers' race	NH White vs. NH black	2009-2011 birth files
GMRACE	Grandmother's race	White vs. black	1979-1998 birth files
MMARITAL	Mothers' marital status	Married vs. unmarried	2009-2011 birth files
GMMARITAL	Maternal grandmother's marital status	Married vs. unmarried	1979-1998 birth files
MMEDICAID	Mothers' health insurance	Private or self-pay vs. Medicaid	1979-1998 birth files
PRENAT	Mothers' adequacy of prenatal care	Use APNCU index[3]. Categorical variable: none/inadequate, intermediate, adequate, adequate plus care	2009-2011 birth files
M_SMOK	Mothers' smoking during pregnancy	Yes vs. no. M_SMOKP = prepregnancy smoking, M_SMOK1 = first trimester smoking, M_SMOK2 = second trimester smoking, M_SMOK3 = third trimester smoking	2009-2011 birth files
M_BMI	Mothers' pre-pregnancy body mass index	Categorical variable: < 18.5, 18.5–24.9, 25–29.9, ≥ 30 kg/m^2	2009-2011 birth files
M_GWG	Mothers' adequacy of gestational weight gain	Categorical variable: inadequate, adequate, excessive	2009-2001
MDM_CHR	Mothers' chronic diabetes	Yes vs. no	2009-2011 birth files
MDM_GEST	Mothers' gestational diabetes	Yes vs. no	2009-2011 birth files
MHTN_CHR	Mothers' chronic hypertension	Yes vs. no	2009-2011 birth files
MHTN_GEST	Mothers' gestational hypertension	Yes vs. no	2009-2011 birth files
MVAGBL	Mothers' vaginal bleeding during pregnancy	Yes vs. no	2009-2011 birth files

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[3] Kotelchuk's Adequacy of Prenatal Care Utilization index. Written e-mail approval was obtained for the use of this index

2.2.1 Outcome variables

Of interest are infant risk of low birth weight (LBW1 = 1 if yes, LBW1 = 0 if no) and risk of preterm birth (PTB1 = 1 if yes, PTB1 = 0 if no). Even among LBW and PTB infants, those born smaller and earlier are at higher risk. So very LBW (VLBW), moderate LBW (MLBW), and normal birth weight, are coded LBW2 = 2, LBW2 = 1, LBW2 = 0, respectively; and, EPTB, LPTB, and term birth, coded PTB2 = 2, PTB2 = 1, PTB2 = 0. LBW and PTB used without either a 1 or 2 in front of them, will denote low birth weight and preterm birth more generally, rather than as either a binary or multinomial variable.

2.2.2 Main predictor variables

One of the hypothesized main predictors of LBW and PTB are MBW and MGA, respectively. MBW is included as a continuous variable and multiplied by 100 so that the interpretation of a one-unit change in the variable is equal to a 100 gram change in birth weight. MGA is also included as a continuous variable and a one-unit change in the variable is a one week change.

Neighborhood-level covariates of MNEIGH_BLK, MSEG_BLK, MNEIGH_POV, MSEG_POV, GMNEIGH_BLK, and GMNEIGH_POV, will be included as continuous variables in the analysis. SMOBIL_BLK and SMOBIL_POV variables will be created to examine the impact of social mobility across generations on infant risk of poor birth outcomes. A categorical variable of MNEIGH_BLK and GMNEIGH_BLK will be created with three groups: $0\% \leq \text{low} < 13\%, 13\% \leq \text{medium} < 50\%, \text{and } 50\% \leq \text{high} \leq 100\%$ for mothers and $0\% \leq \text{low} < 12\%, 12\% \leq \text{medium} < 50\%, \text{and } 50\% \leq \text{high} \leq 100\%$ for grandmothers. The reason for slightly different cut-offs points is that the percentage of births to black mothers differed slightly during the time periods and in order to capture this minor change the cut-offs were modified. The variable SMOBIL_BLK with five groups will be created to examine generational social mobility: generational low % black = 5, generational medium % black = 4, generational high % black = 3, moved from lower to higher % black = 2, and moved from higher to lower % black = 1.

A categorical variable of MNEIGH_POV and GMNEIGH_POV will be created with two groups: $0\% \leq \text{low} < 34\%, 34\% \leq \text{high} \leq 100\%$ for both mother and grandmother. If a census tract had the same percentage of households in the lowest income tertile as the overall county this would be 33%, therefore census tracts with < 34% are considered to have low poverty and those above that cut-off considered to have high poverty. The variable SMOBIL_POV with four groups will be created to examine economic mobility: generational low poverty = 4, generational high poverty = 3, low to high poverty =2, high to low poverty = 1. MSEG_BLK, MSEG_POV are created using a local spatial segregation index which is "based upon potential for interaction" between population groups; in this case between NH black (B) and NH white (W) residents for MSEG_BLK, and between low income (L) and high income (H) households for MSEG_POV (Wong, 2002). With b_i and w_i as the population count of NH black and NH white residents, respectively, in each census tract; and, l_i and h_i as the population count of low income and high income HH in the census tract, respectively, the potential interactions between NH blacks and NH whites in census tract *i* is represented by the following formula:

$$S_{i*bw} = 1 - \frac{b_i \sum_j c_{ij} w_j}{b_i \sum_j w_j}$$

where *j* can equal *i*, in order to include *i* tract residents in the calculation; the denominator is the overall potential in the County for interaction between NH blacks and whites without spatial separation due to census tract boundaries; the numerator is the potential for interaction between the groups within *i* tract and the adjacent tracts; and, $c_{ij} = 1$ when census tracts are adjacent to each other and $c_{ij} = 0$ otherwise. The results are standardized and 1 is interpreted to mean perfect segregation, whereby there is no interaction between the two groups, and 0 means no segregation and perfect potential for interaction (Wong, 2002). The same methodology was used for the economic segregation measure which had the following formula:

$$S_{i*lh} = 1 - \frac{l_i \sum_j c_{ij} h_j}{l_i \sum_j h_j}$$

These segregation scores were log transformed and included as continuous variables in the analyses. All continuous neighborhood variables will be explored for nonlinearity in their relationship to the odds of LBW and PTB.

2.2.3 Confounding, mediating, and moderating variables

MAGE, GMAGE, MEDU_RATIO, FEDU_RATIO, GMEDU_RATIO, and GFEDU_RATIO are considered control variables and grand-mean centered for ease of interpretation of output. The following categorical variables were also explored as control variables and coded as follows: MEDUC1 (less than high school = 0, high school = 1, and at least some college = 2); MRACE (NH white = 0, NH black = 1); GMRACE (white = 0, black = 1); MMARITAL and GMMARITAL (married = 0, unmarried = 1); PRENAT (inadequate = 1, intermediate = 2, adequate = 3, adequate plus = 4); M_SMOK (no = 0, yes = 1); M_BMI (underweight = 0, normal = 1, overweight = 2, obese = 3); M_GWG (inadequate = 0, adequate = 1, excessive = 2); MDM_CHR (no = 0, yes = 1); MDM_GEST (no = 0, yes = 1); MHTN_CHR (no = 0, yes = 1); MHTN_GEST (no = 0, yes = 1); MVAGBL (no = 0, yes = 1); GENDER (female = 0, male = 1).

2.3 STATISTICAL ANALYSIS

The following section will provide an overview of the statistical methodology employed in this research in order to address the research questions, and test the hypotheses, mentioned in the Introduction Chapter.

2.3.1 Meta-analysis

Using guidelines established by the Meta-Analysis of Observational Studies in Epidemiology (MOOSE) and Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statements, a systematic literature review and meta-analysis were performed and the manuscript is in Chapter Three. Meta-analyses random effects models were performed to calculate the odds of PTB and LBW among infants of NH black and Hispanic mothers, compared with those of NH white mothers, and to assess the association between PTB and LBW and neighborhood context for infants of NH white and NH black mothers. Egger's regression asymmetry test and the Begg adjusted rank correlation test were used to assess bias.

2.3.2 Multilevel multiple imputation – chained equations

Manuscripts two and three of this research use data from the transgenerational birth file created by the researchers from vital statistics birth records in Allegheny County, Pennsylvania. As is pervasive in health sciences research, vital statistic data commonly have missing data and these partial observations can affect the reliability of the findings, and thus inferences which can be made. The reasons why data in the birth records may be missing vary and it cannot always be determined with certainty whether these data are missing completely at random (MCAR) in which case the complete observations would be representative of the overall sample (J. Carpenter, Goldstein, & Kenward, 2012) and all partial observations could be deleted (listwise deletion). Chi-square tests performed on the bivariate associations between the outcome variables and covariates, for partial observations (at least one missing variable) and complete observations, reveal many statistically significant differences in complete records and partial observations (Appendix A) such that listwise deletion would significantly bias the findings of this research. The assumption is made that the data are missing at random (MAR), which means the covariates in the dataset are believed to explain the missingness of the other covariates; however, MAR cannot be tested directly.

The percentage of incomplete birth records differs by race, with NH blacks more likely to have incomplete records (81.80%) compared with NH whites (57.89%). The variables primary responsible for the high percentages of missing data in the LBW dataset are in Table 4 below, and can reasonably be expected to be the same in the PTB dataset. The issue of partial observations should be addressed through multiple imputation (MI) of the data; MI has become popular, and accepted as the appropriate manner by which to deal with missing data. Because of the hierarchical nature of the dataset, multilevel MI using fully conditional specification (FCS) would be the appropriate approach. FCS "involves specifying a series of univariate models for the conditional distribution of each partially observed variable given the other variables," allowing the analyst to specify the type of regression for each univariate model. The MI process involves:

> '[Filling] in' each missing value with draws from an appropriate distribution, leading to a number *M* of completed datasets. The substantive model can then be fitted to each of the *M* completed datasets, and the results combined across the *M* datasets (Bartlett, Seaman, White, Carpenter, & for the Alzheimer's Disease Neuroimaging, 2014).

Despite the additional complexity involved in accounting for the multilevel aspect of the data, ignoring it could potentially bias inferences (J. Carpenter et al., 2012). MI is further complicated by the presence of non-linear relationships and interactions terms and so it is imperative to identify a statistical package capable of handling all these aspects.

Table 4. Birth record variables with highest percentage of partially observed data

Variable	*% missing*
Mother's adequacy of weight gain	37.40
Mother's pre-pregnancy body mass index	27.02
Father's educational attainment ratio	26.97
Father's age	26.53
Mother's adequacy of prenatal care	14.16
Grandfather's education attainment ratio	7.27
Health insurance	6.97

Few statistical software packages have the capability to perform this type of MI, but MLwiN, in combination with REALCOM-Impute, are designed for this purpose (J. R. Carpenter, Goldstein, & Kenward, 2011) and will be used for this research. However, for purposes of this dissertation research an un-imputed dataset, with both complete and partially observed birth records, will be used. The research team is not as yet familiar with MLwiN and REALCOM-Impute and will take the time to become acquainted with the statistical packages and then re-run all the analyses included in this dissertation prior to submitting the manuscripts for publications. The limitation of keeping both complete and partially observed data is that each statistical test performed has the potential to include a different number of observations (that is, birth records) compared with the prior test. Even though complete listwise deletion was avoided, each test eliminates the observations missing any of the covariates included in that particular test. As such, the results of each test should be interpreted keeping in mind the bias that may be present as a consequence of the dropped observations. The majority of variables in Table 4 are excluded from final analyses either as a result of high collinearity or because they are likely in the causal pathway and excluded to avoid over-adjustment (Schisterman, Cole, & Platt, 2009). Only health insurance is maintained in analyses; and, from Appendix A we know that incomplete records are more likely to be on Medicaid, thus the effect of Medicaid is likely to be underestimated in the results.

2.3.3 Multivariate analysis of low birth weight

For the second study the relationship between infant LBW and MBW was examined along with covariates that may confound, mediate, or moderate that relationship. Along with being interested in this transgenerational risk for LBW the research has a focus on the impact of social and economic neighborhood context on LBW and the effect of generational exposure to disadvantage. Hierarchical generalized linear modeling (HGLM) with a logit link function was performed to model the variation in LBW within a two-level cross-classified structure of 6,633 infants (level 1) within 350 M neighborhoods and 578 GM neighborhoods (level 2).

The binary LBW outcome variable, LBW1, was assumed to follow a Bernoulli distribution $\mathrm{LBW1}_{ij}|\varphi_{ij} \sim Bernoulli(\varphi_{ij})$, with an expected value $E(\mathrm{LBW1}_{ij}|\varphi_{ij}) = \varphi_{ij}$, and variance $Var(\mathrm{LBW1}_{ij}|\varphi_{ij}) = \varphi_{ij}(1-\varphi_{ij})$. With a level-1 link function $\eta_{ij} = \log\left({\varphi_{ij}}/{1-\varphi_{ij}}\right)$ the binomial logistic regression has the following level-1 structural model for our unconditional model

$$\varphi_{ij} = {1}/{1+e^{-\eta_{ij}}}$$

$$\eta_{ij} = \beta_{0j}$$

where φ_{ij} is the probability of LBW1 and η_{ij} the log-odds of LBW1 for each infant i in each j M neighborhood. The level-2 model would be

$$\beta_{0j} = \gamma_{00} + u_{0j}, \qquad u_{0j} \sim N(0, \tau_{00})$$

where u_{0j} is the random effect of M neighborhoods which follows a normal distribution, with a mean of zero and variance of τ_{00}. A cross-classified model was tested in order to examine the effect of both M and GM neighborhood context on infant risk of LBW1. The first step was to run an unconditional model to determine whether there was variability in infant LBW1 across both M neighborhoods and GM neighborhoods. The level-1 structural model was

$$\eta_{ijk} = \beta_{0jk}$$

and the level-2 model

$$\beta_{0jk} = \gamma_{00} + b_{00j} + c_{00k}, \quad b_{00j} \sim N(0, \tau_{b00}), \quad c_{00k} \sim N(0, \tau_{c00})$$

where γ_{00} is the average log-odds of LBW1 of all infants, b_{00j} is the main effect of M neighborhood j, and c_{00k} is the main effect of GM neighborhood k. τ_{b00} is the variance between M neighborhoods in neighborhood-average log odds of infant LBW1, and τ_{c00} is the variance between GM neighborhoods in neighborhood-average log odds of infant LBW1. *i* denotes infants, *j* denotes M neighborhood, and *k* denotes GM neighborhood, where there are $i = 1, \dots, 6{,}633$ infants, $j = 1, \dots, 350$ M neighborhoods, and $k = 1, \dots, 578$ GM neighborhoods. Having found variability in this model, level-1 covariates were included. The conditional level-1 structural model for LBW1 would be as follows

$$\eta_{ijk} = \beta_{0jk} + \beta_{pjk} X'_{pijk}$$

while the level-2 model takes this form

$$\beta_{0jk} = \gamma_{00} + b_{00j} + c_{00k}, \quad b_{00j} \sim N(0, \tau_{b00}), \quad c_{00k} \sim N(0, \tau_{c00})$$

In the multivariate models with individual-level covariates, τ_{c00} could not be estimated so a simpler 2-level model was tested. The first step was to perform HGLM with an unconditional model, one with no predictors, to examine whether there exists sufficient variation across M neighborhoods in LBW1. The intra-class correlation (ICC) was used to test whether there exists M neighborhood-level random effect, and a Chi-square test assessed whether a multilevel model is significantly better than a single-level model. The ICC revealed sufficient variation at level-2 and the next step was to build HGLM conditional models, that is, models with predictors. Level-1 interactions and cross-level interactions were explored. Statistical significance was determined using $p < 0.05$, and the likelihood ratio (LR) test measured an improvement in model fit as covariates are included and excluded from the models. The conditional models' level 1 structural model is:

$$\eta_{ij} = \beta_{0j} + \beta_{pj} X'_{pij}$$

with X'_{pij} representing all $p = 1, \dots, P$ covariates included. The level-2 model is

$$\beta_{0j} = \gamma_{00} + \sum_{s=1}^{S} \gamma_{0s} W_{sj} + u_{0j}, \qquad u_{0j} \sim N(0, \tau_{00})$$

$$\beta_{pj} = \gamma_{p0}, \qquad \text{for } p > 0$$

where W_{sj} represents all $s = 1, \dots, S$ level-2 covariates included in predicting the random intercept. The slopes of all the $p = 1, \dots, P$ covariates in the level-1 model are fixed and do not vary across M neighborhoods. This means that it was assumed that the association between LBW1 and the level-1 covariate (which is the slope) does not vary depending on the M neighborhood.

The nominal outcome variable, LBW2, was assumed to follow a multinomial distribution, with an expected value $E(\mathrm{LBW2}_{mij} | \varphi_{mij}) = \varphi_{mij}$, a variance of $Var(\mathrm{LBW2}_{mij} | \varphi_{mij}) = \varphi_{mij}(1 - \varphi_{mij})$, and covariance of $Cov(\mathrm{LBW2}_{mij}, \mathrm{LBW2}_{m'ij} | \varphi_{mij}, \varphi_{m'ij}) = -\varphi_{mij}\varphi_{m'ij}$. The level-1 sampling model is $\mathrm{LBW2}_{mij} = 1$ if $R_{ij} = m$, $\mathrm{LBW2}_{mij} = 0$ otherwise. R is the response to the LBW2 variable and takes on the value of *m* with a probability of $Prob(R = m) = \varphi_m$, for *m* = 0, 1, and 2, where normal birth weight (0) is the reference category and MLBW = 1 and VLBW = 2. With a multinomial logit link we have a level-1 link function of $\eta_{mij} = \log\left({}^{\varphi_{mij}}/_{\varphi_{Mij}}\right) = \log\left({}^{Prob(R_{ij} = m)}/_{Prob(R_{ij} = M)}\right)$, where M = 3 categories and only M – 1 probabilities need to be specified. In this case we specify the probabilities for

MLBW $Prob(R_{ij} = 1) = \varphi_{1ij}$ and VLBW $Prob(R_{ij} = 2) = \varphi_{2ij}$. Multinomial logistic regression has the following level-1 structural models for MLBW and VLBW

$$\eta_{1ij} = \beta_{0j(1)}$$

$$\eta_{2ij} = \beta_{0j(2)}$$

where η_{1ij} is the log-odds of MLBW and η_{2ij} the log-odds of VLBW. At level-2, the M neighborhood-specific intercepts are allowed to vary across M neighborhoods and the level-2 models are:

$$\beta_{0j(1)} = \gamma_{00(1)} + u_{oj(1)}$$

$$\beta_{0j(2)} = \gamma_{00(2)} + u_{oj(2)}$$

$$\begin{pmatrix} u_{0j(1)} \\ u_{oj(2)} \end{pmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \tau_{00(1)00(1)} & \tau_{00(1)00(2)} \\ \tau_{00(2)00(1)} & \tau_{00(2)00(2)} \end{pmatrix}\right]$$

where the random effect of M neighborhood on MLBW, $u_{oj(1)}$, has a variance of $\tau_{00(1)}$ and the random effect of M neighborhood on VLBW, $u_{oj(2)}$, has a variance of $\tau_{00(2)}$. As with LBW1, level-1 interactions and cross-level interactions will be explored. A $p < 0.05$ will determine statistical significance and the likelihood ratio (LR) test will measure an improvement in model fit as covariates are included and excluded from the models. The level 1 structural models for the conditional models are

$$\eta_{1ij} = \beta_{0j(1)} + \sum_{p=1}^{P1} \beta_{pj(1)} X_{pij}$$

$$\eta_{2ij} = \beta_{0j(2)} + \sum_{p=1}^{P2} \beta_{pj(2)} X_{pij}$$

and the level 2 model has the following form

$$\beta_{0j(m)} = \gamma_{00(m)} + \sum_{s=1}^{S} \gamma_{0s(m)} W_{sj} + u_{0j(m)}$$

$$\beta_{pj(m)} = \gamma_{p0(m)}, \qquad for\, p > 0$$

The variance partition coefficient (VPC) will be calculated to determine the proportion of variance at the neighborhood level conditional on the covariates included in the model. Calculation of the VPC is more complex in logistic regression than in linear regression because there is no "clear distinction between individual level variance and [neighborhood] level variance;" and the neighborhood level variance is on a logistic scale while the individual-level variance is on a probability scale, making them incomparable (Merlo et al., 2006). To address these issues a number of methods to calculating the VPC have been proposed (Goldstein, 2011), including the latent variable method which will be used here. The "unobserved individual variable follows a logistic distribution with individual level variance" of $\pi^2/3$, which is equal to 3.29 (Merlo et al., 2006) and so the VPC formula is

$$^{\tau}/_{(\tau + 3.29)}$$

2.3.4 Multivariate analysis of preterm birth

For the third study the relationship between infant gestational age and MGA was examined along with the covariates that may confound, mediate, or moderate that relationship. A null HGLM (unconditional model), with a logit link function, was used to test whether the data had a hierarchical structure with a two-level cross-classified structure of 6,592 infants (level 1) within 350 M neighborhoods and 578 GM neighborhoods (level 2), in order to determine whether there is any clustering of PTB1 by neighborhoods. The unconditional model indicated no clustering by neighborhood and subsequent analyses were performed using single-level logistic regression.

PTB1, which is a binary response variable, is assumed to follow a Bernoulli distribution, which is a special case of a binomial distribution with an expected value $E(\text{LBW1}_i) = \pi_i$, and variance $Var(\text{LBW1}_i) = \sigma_i^2 = \sigma_i(1 - \pi_i)$, where π_i is the probability that $\text{LBW1} = 1$ and $1 - \pi_i$ is the probability that $\text{LBW1} = 0$, with a logit link function $\eta_i = \text{logit}(\pi_i) = \log(^{\pi_i}/_{1 - \pi_i})$. So the null model is $\eta_i = \beta_0$. The outcome variable, η_i, is the log-odds of PTB1. Binomial logistic regression was appropriate for the analyses of PTB1.

PTB2, which is a nominal response variable, is assumed to follow a multinomial distribution, with M = 3 categories of values 0, 1, and 2 for term birth (reference category), LPTB, and EPTB, respectively. $\pi_{mi} = Prob(\text{PTB}_i = m)$ is the probability that an *i*-th infant is in the M category; and since all categories are mutually exclusive $\sum_{m=1}^{M} \pi_{mi} = 1$ with all probabilities adding up to one. Only two of the parameters need to be included in the multinomial logistic regression. So the null model is $\eta_{mi} = \log\left({}^{\pi_{mi}}/_{\pi_{Mi}}\right) = \beta_{0(m)}$, which is the odds of an infant being in a particular *m* category as opposed to the reference category. The outcome variable η_{1i} is the log-odds of LPTB while η_{2i} is the log-odds of EPTB, compared with normal birth weight.

The next step was to build conditional models which included level-1 covariates and explored interactions between, and non-linear relationships among, these variables. The general equation for PTB1 was as follows

$$\eta_i = \beta_0 + \beta_p X'_{pi},$$

while the equations for PTB2 took the following form

$$\eta_{1i} = \beta_{0(1)} + \sum_{q=1}^{Q1} \beta_{q(1)} X_{qi}$$

$$\eta_{2i} = \beta_{0(2)} + \sum_{q=1}^{Q2} \beta_{q(2)} X_{qi}$$

2.3.5 Mediation models

For the LBW and PTB datasets we performed 1:1:1 mediation models to examine the role of maternal behavioral, and health and obstetric factors in the intergeneration transmission of risk for lower birth weight and gestational age. The mediation model equations are as follows

$$M' = i1 + a\text{X} + e1$$

$$\text{Y}' = i2 + bM + c'\text{X} + e2$$

with *M* representing the maternal health and obstetric factors.

$$Y'' = i3 + cX + e3$$

is the total effect of X (MBW/MGA) on Y (LBW1/PTB1). Using qualitative analysis, that is, visual inspection of effect size changes in indirect pathways among subgroups, we explored the potentially moderating effect of some of the maternal behavioral and neighborhood-level factors on the significant mediating factors in this relationship. Our hypothesis was that lower birth weight of the mother would place her at higher risks for chronic diseases, and thus pregnancy complications, in adulthood. This hypothesis is based on research that has found LBW infants are more likely to develop insulin resistance (D. I. W. Phillips, 1996) and type 2 diabetes (D. J. Barker, Eriksson, Forsen, & Osmond, 2002), develop coronary heart disease (CHD) and experience greater effects of low socioeconomic position on risk of coronary heart disease, suggesting less resilience (D. J. Barker et al., 2002; D. J. Barker, Forsen, Uutela, Osmond, & Eriksson, 2001), and develop hypertension in adulthood (Ligi, Grandvuillemin, Andres, Dignat-George, & Simeoni, 2010). It is believed that fetal programming is responsible for the development of these chronic diseases in adulthood through alterations in “metabolism and hormonal feedback” (D. J. P. Barker, 2012).

The next three sections describe the LBW and PTB datasets by presenting descriptive statistics of the variables of primary interest included in the datasets and assessing the statistical significance of differences between racial groups using Chi-square tests and two-sample t-tests. The sections also present bivariate analyses of the primary outcome variables, reporting the risk of infant LBW/PTB per variable using unadjusted odds ratios.

2.4 DESCRIPTIVE STATISTICS OF DATASET VARIABLES BY RACE

Table 5 through Table 9 displays descriptive statistics of the infant-mother birth records of which 28.25% (N=1,874) are infants of NH black mothers and 71.75% (N=4,759) of NH white mothers.

Table 5. Descriptive statistics for Allegheny County transgenerational birth file – infant variables

	NH white mothers		NH black mothers			
	Mean	*SD*	*Mean*	*SD*	*T-test*	*p-value*
Infant birth weight (grams)	3326.57	547.72	3060.65	624.03	17.10	<0.001
Infant gestational age (weeks)	38.96	2.03	38.57	2.68	6.35	<0.001
	Percent		*Percent*		X^2	*p-value*
Low birth weight infant	5.72		12.06		77.93	<0.001
Very low birth weight	1.01		3.15		84.33	<0.001
Moderate low birth weight	4.71		8.91			
Preterm birth infant	7.37		10.33		15.46	<0.001
Early preterm birth	1.14		2.69		25.54	<0.001
Late preterm birth	6.23		7.64			
Male gender	50.16		50.59		0.10	0.75

Infants of NH black mothers are more likely to be of lower birth weight and gestational age, $p < 0.001$, compared with those of NH white mothers. This corresponds with statistically significant differences in LBW and PTB rates, and even differences in the rates of VLBW and MLBW, and EPTB and LPTB, all at $p < 0.001$. There were no significant differences in the percentage of female/male infants born to NH white or NH black mothers.

Table 6. Descriptive statistics for Allegheny County transgenerational birth file – parent level-1 covariates

	NH white mothers		NH black mothers			
	Mean	*SD*	*Mean*	*SD*	*T-test*	*p-value*
Mothers' birth weight (grams)	3323.72	528.95	3021.97	583.52	20.30	<0.001
Mothers' gestational age (weeks)	39.47	1.72	38.61	2.39	16.42	<0.001
Mothers' education ratio	0.77	0.32	0.43	0.31	38.38	<0.001
Fathers' education ratio	0.80	0.30	0.50	0.33	26.83	<0.001
Mothers' maternal age (years)	24.92	4.12	20.56	3.42	40.59	<0.001
	Percent		*Percent*		X^2	*p-value*
Medicaid mothers	24.16		63.66		861.53	<0.001
Unmarried mothers	48.78		96.37		1.3e+03	<0.001

NH black mothers are more likely to have lower birth weight, gestational age, educational attainment, maternal age, and more likely to be on Medicaid and be unmarried, $p < 0.001$. Rates of Medicaid were similar in this dataset to those reported in the county in years 2009-2011 within the ≤34 year old age group, where 20.68% of white mothers and 62.79% of black mothers were on Medicaid. The statistics on marital status differ by at least 10 percentage points between the dataset and the county rates with 31.73% for white mothers and 86.36% for black mothers in the county.[4]

Table 7. Descriptive statistics for Allegheny County transgenerational birth file – grandparent level-1 covariates

	NH white mothers		NH black mothers			
	Mean	*SD*	*Mean*	*SD*	*T-test*	*p-value*
Grandmothers' maternal age (years)	26.27	4.95	23.58	5.56	19.26	<0.001
Grandmothers' education ratio	0.81	0.11	0.82	0.12	-3.25	0.001
Grandfathers' education ratio	0.82	0.12	0.81	0.10	2.57	0.01
	Percent		*Percent*		X^2	*p-value*
Unmarried grandmothers	17.31		80.36		2.3e+03	<0.001

The maternal grandparents of infants of NH black mothers are also more likely to be younger, less educated and unmarried.

Table 8. Descriptive statistics for Allegheny County transgenerational birth file – parent level-1 mediators

	NH white	NH black		
	Percent	*Percent*	X^2	*p-value*
Smoking mothers	20.32	12.55	53.82	<0.001
Vaginal bleeding	1.87	1.71	0.20	0.656
Pre-pregnancy diabetes	0.44	0.64	1.08	0.300
Gestational diabetes	3.53	2.13	8.62	0.003
Pre-pregnancy hypertension	1.07	1.28	0.53	0.469
Gestational hypertension	5.27	7.04	7.74	0.005
Pre-pregnancy body mass index				
Underweight	5.22	4.55	12.95	0.005
Normal	55.85	51.31		
Overweight	22.06	23.46		
Obese	16.87	20.68		
Gestational weight gain				
Inadequate	15.18	23.07	34.67	<0.001
Adequate	24.69	21.94		
Excessive	60.13	54.99		
Prenatal care use				
Inadequate	4.69	4.68	45.80	<0.001
Intermediate	9.36	3.97		
Adequate	65.26	70.46		
Adequate plus	20.69	20.88		

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[4] "These data were provided by the Bureau of Health Statistics and Research, Pennsylvania Department of Health. The Department specifically disclaims responsibility for any analyses, interpretations or conclusions."

Table 8 includes the health and obstetric factors which will be considered for mediation and moderation. We see that NH white mothers are more likely to smoke during pregnancy and experience gestational diabetes mellitus, while NH black mothers are more likely to experience gestational hypertension. The odds of LBW/PTB as a result of pre-pregnancy BMI, gestational weight gain, and utilization of prenatal care for NH white and NH black mothers will be explored later. With the level-1 (person-level) variables we find a statistically significant difference between races in the majority of descriptive statistics. The rates of smoking during pregnancy in this dataset differ from county-wide data which reports higher rates of smoking during pregnancy for this ≤34 year old age group, with 16.59% for white mothers and 20.36% for black mothers.[5]

Table 9. Descriptive statistics for Allegheny County transgenerational birth file – level-2 covariates

	NH white mothers		NH black mothers			
	Mean	*SD*	*Mean*	*SD*	*T-test*	*p-value*
Mothers' neighborhood % black	0.08	0.12	0.53	0.27	-94.43	<0.001
Mothers' neighborhood % poor	0.24	0.12	0.47	0.16	-64.19	<0.001
Mothers' racial segregation	0.98	0.009	0.99	0.007	-47.98	<0.001
Mothers' economic segregation	0.98	0.000	0.99	0.000	-39.72	<0.001
Grandmothers' neighborhood % black	0.05	0.12	0.62	0.34	-1.0e+02	<0.001
Grandmothers' neighborhood % poor	0.31	0.14	0.60	0.19	-67.28	<0.001
	Percent		*Percent*		X^2	*p-value*
Mothers' neighborhood % black						
Low (0-13%)	81.57		8.00		3.7e+03	<0.001
Medium (14-50%)	16.43		36.45			
High (51-100%)	2.00		55.55			
Mothers' neighborhood % poor						
Low (0-33%)	80.61		21.66		2.0e+03	<0.001
High (34-100%)	19.39		78.34			
Grandmothers' neighborhood % black						
Low (0-12%)	88.74		11.21		4.1e+03	<0.001
Medium (13-50%)	9.75		27.53			
High (51-100%)	1.51		61.26			
Grandmothers' neighborhood % poor						
Low (0-33%)	60.50		9.93		1.4e+03	<0.001
High (34-100%)	39.50		90.07			

We see clearly from Table 9 that the neighborhood contexts in which NH white and NH black mothers live are very different and this is a highly statistically significant finding, $p < 0.001$. The

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[5] "These data were provided by the Bureau of Health Statistics and Research, Pennsylvania Department of Health. The Department specifically disclaims responsibility for any analyses, interpretations or conclusions."

majority of NH black mothers live in neighborhoods with a high percentage of NH blacks and a high percentage of low income households in both generations. The local spatial measures of segregation indicate very high segregation in the county, and despite differences by race, $p < 0.001$, there is a small range of variability (see Appendix B).

2.5 BIVARIATE ANALYSIS OF LOW BIRTH WEIGHT DATASET

Pairwise correlations were performed between all variables in the low birth weight (LBW) dataset (see Appendix C) and the following variables were significantly correlated with LBW1 at $p < 0.05$ for NH white and NH black mothers (Table 10). Some of the variables significantly associated with LBW1 were highly correlated, $r \geq 0.75$, with other variables and these are indicated below. We found that fewer of the variables were correlated with LBW1 for NH blacks, and of particular interest was the absence of a significant association between LBW1 and any neighborhood context factors.

Table 10. Covariates statistically significantly correlated with low birth weight

	NH White		NH Black	
Variables	*p < 0.05*	*Highly correlated (r≥0.75)*	*p < 0.05*	*Highly correlated (r≥0.75)*
MMARITAL	✓	MAGE (*r*=0.7828)		
MHTN_CHR	✓			
MHTN_GEST	✓			
MVAGBL	✓		✓	
M_SMOK	✓		✓	
MMEDICAID	✓		✓	
PRENAT	✓		✓	
M_GWG	✓		✓	
MEDU_RATIO	✓	MAGE (*r*=0.8203)	✓	MAGE (*r*=0.8012), FEDU_RATIO (*r*=0.9816)
FEDU_RATIO	✓	MEDU_RATIO (*r*=0.9690)	✓	MAGE (*r*=0.7939)
MBW	✓		✓	
MAGE	✓			
MNEIGH_BLK	✓			
MNEIGH_POV	✓			
GMMARITAL	✓			
GMNEIGH_POV	✓			

Comparing infants of NH black and white mothers, the odds of being born LBW1 are 2.26 times higher for infants of NH black mothers as for NH white mothers. Comparing mothers born to black and white grandmothers, the odds of them being born LBW1 were 3.35 times higher for blacks than for whites. Mothers who were themselves higher order births, that is, twin or triplet, were 19.62 times more likely to be LBW compared with singleton births. However, comparing mothers who were singleton births and those who were higher order births, there was no statistically significant difference in their odds of delivering a LBW1 infant, $\chi_1^2 = 0.985,\ p = 0.321$. As a result, both singleton and higher order birth mothers are included in the analysis. Table 11 displays unadjusted odds ratios of LBW1 against various level 1 covariates – potential confounders, mediators, and moderators for which there was significant correlation as listed in Table 10. MBW is associated with lower odds of LBW1 for infants of both NH white and NH black mothers; and, Medicaid, mothers' vaginal bleeding during pregnancy, first trimester smoking, inadequate prenatal care, adequate plus prenatal care, and inadequate gestational weight gain are associated with higher odds of LBW for infants of both NH white and NH black mothers, albeit with differing magnitudes of effect.

Table 11. Unadjusted odds ratios of maternal characteristics on infant risk of low birth weight

	NH white		NH black	
	OR	*95% CI*	*OR*	*95% CI*
Mothers' age	0.96**	0.93-0.99	1.03	0.99-1.08
Mothers' birth weight	0.94**	0.92-0.96	0.94**	0.91-0.96
Mothers' education	0.56**	0.39-0.80	1.55*	1.00-2.41
Medicaid	2.02**	1.55-2.63	1.55**	1.13-2.13
Mothers' marital status	1.59**	1.24-2.04	0.90	0.44-1.83
Mothers' pre-pregnancy hypertension	3.13**	1.46-6.73	1.94	0.72-5.25
Mothers' gestational hypertension	2.81**	1.91-4.13	1.42	0.87-2.31
Mothers' vaginal bleeding	3.48**	1.97-6.15	2.48*	1.10-5.60
Mothers' first trimester smoking[6]	2.09**	1.60-2.72	2.14**	1.50-3.05
Adequacy of prenatal care				
Inadequate	2.18*	1.06-4.46	2.29*	1.05-5.01
Intermediate	0.82	0.37-1.82	2.38*	1.03-5.46
Adequate	Ref		Ref	
Adequate plus	9.50**	6.95-12.99	7.59**	5.29-10.89
Gestational weight gain				
Inadequate	2.96**	1.93-4.56	2.31**	1.40-3.81
Adequate	Ref		Ref	
Excessive	0.80	0.53-0.69	0.64	0.39-1.05

* <0.05, ** <0.01

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[6] The variables of smoking pre-pregnancy and or during any of the trimesters are highly correlated, so we included only first trimester smoking

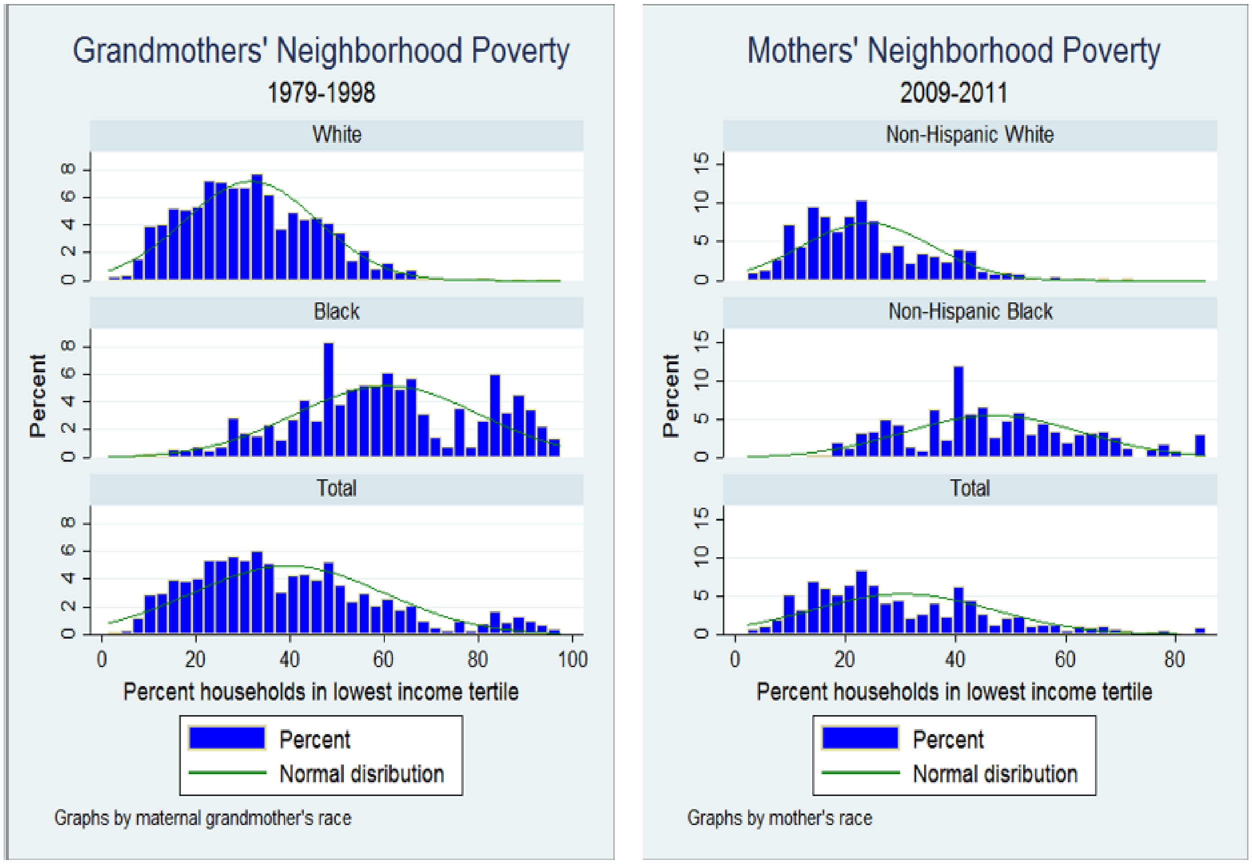
The other variables differ by race in their association with the odds of LBW1. For example, mothers' maternal age, mothers' marital status, and mothers' pre-pregnancy and gestational hypertension, are significant risk factors for NH white mothers only; while having an intermediate level of prenatal care, versus adequate care, is associated with elevated risk for NH black mothers only. Table 12 displays unadjusted odds ratios for level 2 covariates. As discussed in the univariate analysis section, the neighborhood environments of NH white and NH black mothers delivering infants in Allegheny County are very different. Not all neighborhood factors of interest are significantly associated with infant risk of LBW1 in bivariate analysis, and those factors which were significant at $p < 0.05$ are typically significant from one race and not the other.

Table 12. Unadjusted odds ratios of neighborhood characteristics on infant risk of low birth weight

	NH white		NH black	
	OR	*95% CI*	*OR*	*95% CI*
Mothers' neighborhood % black				
Low (0-13%)	Ref		Ref	
Medium (14-50%)	1.53**	1.13-2.05	1.61	0.86-3.04
High (51-100%)	1.43	0.66-3.14	1.64	0.88-3.04
Mothers' racial residential segregation	0.70	0.36-1.37	0.80	0.37-1.73
Mothers' neighborhood low income				
Low (0-33%)	Ref		Ref	
High (34-100%)	1.45*	1.09-1.92	1.53*	1.05-2.22
Mothers' economic segregation	0.75	0.53-1.07	0.86	0.57-1.30
Grandmothers' neighborhood % black				
Low (0-12%)	Ref		Ref	
Medium (13-50%)	1.20	0.82-1.77	1.51	0.87-2.62
High (51-100%)	0.99	0.36-2.74	1.53	0.92-2.56
Grandmothers' neighborhood low income				
Low (0-33%)	Ref		Ref	
High (34-100%)	1.37*	1.07-1.75	1.31	0.79-2.18
Generational social mobility - % black				
Higher to lower % black	1.07	0.67-1.72	1.79	0.41-7.70
Lower to higher % black	1.48*	1.07-2.03	1.56	0.36-6.76
High % black in both generations	-	-	2.17	0.51-9.25
Medium % black in both generations	1.99*	1.12-3.52	2.32	0.53-10.24
Low % black in both generations	Ref		Ref	
Generational social mobility – low income				
Low to high	1.24	0.75-2.03	1.81	0.62-5.31
High to low	1.25	0.93-1.67	1.42	0.53-3.79
High to high	1.74*	1.24-2.44	2.07	0.82-5.21
Low to low	Ref		Ref	

* <0.05, ** <0.01

We used histograms to examine how the neighborhood environments differ between the races in both generations (See Figure 3 through Figure 5). The neighborhoods in which the maternal grandmothers lived had 36.9% of households living in the lowest income tertile (95% CI: 39.1, 40.1). The exposure to neighborhood poverty also differed by race in this generation – 31.7% (95% CI: 31.3, 32.1) for white grandmothers and 60.5% (95% CI: 59.6, 61.4) for black grandmothers. On average, the neighborhoods in which the mothers lived had 30.4% of households living in the lowest income tertile (95% CI: 30.04, 30.84). However, NH white mothers, on average, lived in neighborhoods with less poverty than did NH black mothers – 23.98% (95%CI: 23.64, 24.31) for NH white, and 46.84% (95% CI: 46.12, 47.57) for NH black. See Figure 3.



Grandmothers' Neighborhood Poverty
1979-1998

Mothers' Neighborhood Poverty
2009-2011

Figure 3. Distribution of poverty among grandmothers' and mothers' neighborhoods

The neighborhoods in which the maternal grandmothers lived had 21.15% black residents (95% CI: 20.36, 21.94). However, white grandmothers, on average, lived in neighborhoods with a lower proportion of black residents than did black mothers – 5.13% (95%CI: 4.79, 5.47) for white, and 61.82% (95% CI: 60.28, 63.36) for black. On average, the neighborhoods in which the mothers lived had 20.97% NH black residents (95% CI: 20.32, 21.61). However, NH white mothers, on average, lived in neighborhoods with a lower proportion of NH black residents than did NH black mothers – 8.25% (95%CI: 7.90, 8.59) for NH white, and 53.27% (95% CI: 52.06, 54.47) for NH black. See Figure 4.

Figure 4. Distribution of black residents in grandmothers' and mothers' neighborhoods

Despite log transformation, the distribution of the racial residential segregation index and the economic segregation index are still highly skewed and distributions differ by race (see Figure 5). We can see from all these histograms that the environments in which black and white mothers live are very different and could be a contributing factor to the modest effect of neighborhood context on birth outcomes in bivariate analyses.

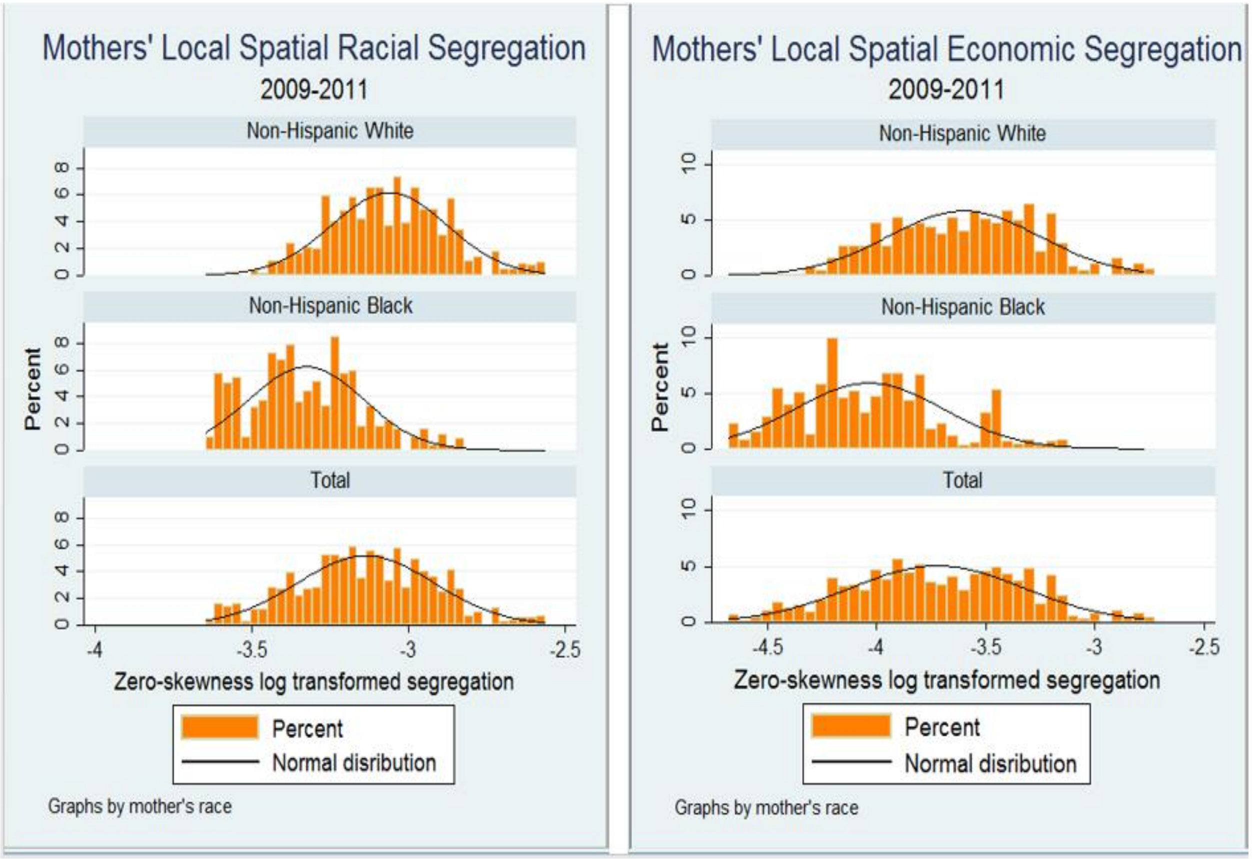


Figure 5. Racial residential segregation and economic segregation of mothers' neighborhood

2.6 BIVARIATE ANALYSIS OF PRETERM BIRTH DATASET

Pairwise correlations were performed between all variables in the PTB dataset (Appendix D) and the following variables were significantly correlated with PTB1 at $p < 0.05$ for NH white and NH black mothers (Table 13). Some of the variables significantly associated with PTB1 were highly correlated, $r \geq 0.75$, with other variables and these are indicated below. Comparing infants of NH black and white mothers, the odds of being born PTB1 are 1.45 times higher for infants of NH black mothers as for NH white mothers. Comparing mothers born to black and white grandmothers, the odds of them being born PTB1 were 3.11 times higher for blacks than for whites. Mothers who were themselves higher order births, that is, twin or triplet, were 10.52 times more likely to be preterm compared with singleton births. However, comparing mothers who were singleton births and those who were higher order births, there was no statistically significant difference in their odds of delivering a PTB1 infant, $\chi_1^2 = 1.455,\ p = 0.228$. As a result, both singleton and higher order birth mothers are included in the analysis. Interestingly, none of the neighborhood context factors were significantly associated with PTB1 for either NH whites or NH blacks.

Table 13. Covariates statistically significantly correlated with preterm birth

	NH White		NH Black	
Variables	*p < 0.05*	*Highly correlated (r≥0.75)*	*p < 0.05*	*Highly correlated (r≥0.75)*
MMARITAL	✓	MAGE (*r*=0.7828)		
MDM_CHR	✓		✓	
MTHN_CHR	✓			
MTHN_GEST	✓		✓	
MVAGBL	✓		✓	
M_SMOK	✓		✓	
MMEDICAID	✓			
PRENAT	✓		✓	
M_GWG	✓		✓	
MEDU_RATIO	✓	MAGE (*r*=0.8203)		
FEDU_RATIO	✓	MEDU_RATIO (*r*=0.9690)	✓	MAGE (*r*=0.7939)
M_BW	✓		✓	
M_GA	✓		✓	
GMMARITAL	✓			
GMEDU_RATIO	✓			
GFEDU_RATIO	✓			

Table 14 displays unadjusted odds ratios for PTB1 against various level 1 covariates – potential confounders, mediators, and moderators. As with LBW1, the odds of PTB1 by each covariate tend to differ by race. MGA is associated with lower odds of PTB1 for infants of both NH white and NH black mothers, as is MBW; and, mothers' pre-pregnancy diabetes mellitus, gestational hypertension, vaginal bleeding during pregnancy, smoking during the first trimester, inadequate prenatal care, adequate plus prenatal care, and inadequate gestational weight gain are associated with higher odds of PTB1 for both NH white and NH black mothers, albeit with differing magnitudes of effect. The other variables differ by race in their association with the odds of PTB1. For example, mothers' educational attainment, Medicaid status, marital status, pre-pregnancy hypertension, and excessive gestational weight gain only have a significant association with odds of PTB1 for NH white mothers. Interestingly, some of the maternal grandparent factors are significantly associated with infant risk of PTB1, including grandmothers' marital status, and grandparents' educational attainment. However, these are also only significant for NH whites. As with LBW1, having an intermediate level of prenatal care, versus adequate care, is associated with elevated risk for NH black mothers only.

Table 14. Unadjusted odds ratios of maternal characteristics on infant risk of preterm birth

	NH white		NH black	
	OR	*95% CI*	*OR*	*95% CI*
Mothers' gestational age	0.94*	0.88-0.99	0.94*	0.89-1.00
Mothers' birth weight	0.98*	0.96-1.00	0.97**	0.94-0.99
Mothers' education	0.66*	0.48-0.92	1.35	0.84-2.17
Medicaid	1.52**	1.19-1.94	1.35	0.96-1.88
Mothers' marital status	1.36**	1.09-1.70	0.71	0.34-1.45
Mothers' pre-pregnancy diabetes	5.10**	1.96-13.22	4.41*	1.32-14.79
Mothers' pre-pregnancy hypertension	3.12**	1.55-6.29	2.45	0.90-6.67
Mothers' gestational hypertension	2.23**	1.54-3.23	2.06**	1.29-3.30
Mothers' vaginal bleeding	3.16**	1.84-5.42	3.52**	1.60-7.71
Mothers' first trimester smoking	1.45**	1.13-1.86	1.76**	1.19-2.60
Adequacy of prenatal care				
Inadequate	6.49**	3.66-11.52	9.05**	3.70-22.15
Intermediate	1.84	0.94-3.61	5.00**	1.61-15.55
Adequate	Ref		Ref	
Adequate plus	21.86**	15.54-30.75	36.99**	21.14-64.74
Gestational weight gain				
Inadequate	1.56*	1.07-2.28	2.10**	1.21-3.63
Adequate	Ref		Ref	
Excessive	0.68*	0.49-0.95	0.84	0.49-1.43
Grandmothers' marital status	1.39*	1.07-1.81	1.06	0.72-1.56
Grandmothers' education	0.35*	0.13-0.95	0.33	0.09-1.17
Grandfathers' education	0.23**	0.09-0.58	1.44	0.30-6.93

* <0.05, ** <0.01

Despite no correlation between PTB1 in Table 13 with any of the neighborhood-level variables we display unadjusted odds ratios for these covariates because neighborhood context is a main predictor to be tested in this research. In Table 15 below we see that essentially none of the neighborhood covariates are significant at $p < 0.05$ and the couple that are the exception are only significant for NH white mothers.

Table 15. Unadjusted odds ratios of neighborhood characteristics on infant risk of preterm birth

	NH white		NH black	
	OR	*95% CI*	*OR*	*95% CI*
Mothers' neighborhood % black				
Low (0-13%)	Ref		Ref	
Medium (14-50%)	1.34*	1.02-1.76	1.07	0.60-1.93
High (51-100%)	1.22	0.59-2.55	1.02	0.58-1.80
Mothers' neighborhood low income				
Low (0-33%)	Ref		Ref	
High (34-100%)	1.11	0.85-1.45	1.13	0.78-1.64
Grandmothers' neighborhood % black				
Low (0-12%)	Ref		Ref	
Medium (13-50%)	1.10	0.77-1.57	0.91	0.52-1.59
High (51-100%)	0.95	0.38-2.36	1.18	0.72-1.93
Grandmothers' neighborhood low income				
Low (0-33%)	Ref		Ref	
High (34-100%)	1.06	0.85-1.32	1.43	0.81-2.53
Generational social mobility - % black				
Higher to lower % black	1.01	0.66-1.55	3.38	0.45-25.35
Lower to higher % black	1.35*	1.01-1.79	2.46	0.32-18.65
High % black in both generations	-		3.24	0.43-24.25
Medium % black in both generations	1.45	0.82-2.55	2.68	0.35-20.81
Low % black in both generations	Ref		Ref	
Generational social mobility – low income				
Low to high	1.07	0.68-1.66	2.59	0.70-9.64
High to low	1.03	0.79-1.33	2.78	0.83-9.29
High to high	1.14	0.82-1.59	2.77	0.86-8.92
Low to low	Ref		Ref	

* <0.05, ** <0.01

3.0 THE EFFECT OF THE SOCIAL AND ECONOMIC NEIGHBORHOOD CONTEXT ON OFFSPRING RISK OF PRETERM BIRTH AND LOW BIRTH WEIGHT: A SYSTEMATIC REVIEW AND META-ANALYSIS OF POPULATION-BASED STUDIES

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3.1 ABSTRACT

The role that neighborhood context plays in the causal pathway of preterm birth (PTB) and low birth weight (LBW) is not fully understood, although its contribution has been considered more in recent years due to the inability of maternal behaviors and characteristics to fully explain the incidence of these adverse birth outcomes. The objective of this review is to systematically examine the relationship between social and economic neighborhood context and PTB and LBW in the United States; and, to identify gaps in knowledge and limitations in study design in this field. PubMed, MEDLINE, EMBASE, CINAHL, PsycINFO, and ProQuest Dissertation and Theses Full Text were used to review articles published in English. Additional articles were obtained from the review of bibliographies of reviewed articles. The search terms used included premature birth, infant low birth weight, and neighborhood. Population-based descriptive, cohort, longitudinal, exploratory, cross-sectional, and causal study designs were included. Using Meta-Analysis of Observational Studies in Epidemiology (MOOSE) and Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statements the articles were reviewed by two reviewers using established inclusion/exclusion criteria, and data were extracted using predefined data extraction tools. Meta-analyses were performed to obtain a summary measure of the odds of PTB and LBW by race/ethnicity, and examine the association between neighborhood context and these adverse birth outcomes. Infants of non-Hispanic (NH) black mothers were approximately twice as likely as NH whites to be born PTB or LBW, while Hispanics were not at increased risk of these outcomes compared to NH whites. Neighborhood disadvantage was associated with a higher odds of adverse birth outcomes in models that ran within-race/ethnicity models but not in those that adjusted for race/ethnicity, with a stronger impact of disadvantage on the birth outcomes of NH whites than NH blacks.

3.2 INTRODUCTION

3.2.1 Rationale

The health of infants is an indicator of the health of a nation. Preterm birth (PTB) and low birth weight (LBW) place an infant at increased risk of morbidity (neurological, pulmonary and ophthalmic disorders) and mortality in the first year of life; as well as increased risk for poor health in adulthood including chronic diseases such as cardiovascular disease (Martin et al., 2013), hypertension, and type II diabetes mellitus (Mathews & MacDorman, 2013a), costing the nation billions of dollars in health care expenditures and lost earnings potential due to premature death or morbidity. In the United States, infants of certain racial/ethnic minority groups are at higher risk of PTB and LBW. However, risky maternal behaviors such as tobacco and alcohol use during pregnancy, inadequate prenatal care, and maternal characteristics such as age at delivery, socioeconomic position, and marital status, have only been found to explain a small proportion of the disparity (R. J. David & Collins, 1997). Researchers have looked to other levels of the socio-ecological model for factors that may impact health. The impact of the neighborhood economic environment has been identified as playing a small role in the risk of adverse birth outcomes in comparison to the impact of maternal characteristics and behaviors (Luo et al., 2006; Masi et al., 2007), others argue for an effect of similar magnitude (Schempf, Strobino, & O'Campo, 2009), yet still other researchers have found no significant association between the deprivation of the neighborhood in which a women resides when she delivers her infant and LBW or PTB, after controlling for maternal covariates (Cubbin et al., 2008). Neighborhood context is examined as a measure of the environment in which the individual lived and any deprivation or stress imposed by the neighborhood is hypothesized to be a risk for the birth outcomes of offspring. The purpose of this study is to combine the findings from various studies that have examined the association between PTB/LBW and neighborhood context.

3.2.2 Objectives

The first objective is to conduct a systematic review of the literature to synthesize the research methodology used to examine the association between neighborhood context and birth outcomes, and racial/ethnic disparities therein. The second objective is to perform a meta-analysis of the odds of PTB and LBW among the racial/ethnic groups, to determine whether the association between the impact of neighborhood disadvantage on PTB and LBW is consistent across studies conducted in this field, by calculating a summary measure and examining the dispersion in a mathematically rigorous manner (Borenstein, Hedges, Higgins, & Rothstein, 2009).

3.3 METHODS

3.3.1 Eligibility criteria

Observational studies of population-based descriptive, cohort, longitudinal, exploratory, cross-sectional, and causal study designs conducted in the U.S. using objective measures of primary or secondary data were included, if published in the English language. No publication date was specified. The population of interest in this literature review included civilian women, both native- and foreign-born, who delivered an infant in the United States. The outcome variables of interest included PTB and LBW as compared with term birth and birth weight of at least 2,500 grams, respectively. PTB is the birth of an infant prior to 37 completed weeks of gestation, while an infant is considered to have low birth weight if he/she weighs less than 2,500 grams at birth. The exposure of interest was the mothers' neighborhood context and the impact it had on the birth outcomes of their infants. Neighborhood or residential context is the conceptual definition of the independent variable while the operationalization of this factor may differ among the studies reviewed. The exposed group was mothers who lived in disadvantaged areas as defined by the researchers, for example high poverty neighborhoods and a comparison group of those who lived in low poverty areas. The time and dose of exposure was as defined in the articles being reviewed. The following exclusion criteria were added after the review had started: 1) studies that were descriptive of the spatial distribution of LBW or PTB in an area, without analysis of covariates of such distribution, 2) studies simply creating an index for the measurement of neighborhood context, 3) studies comparing the appropriateness of various ‘neighborhood’ unit measures, without the analysis of the neighborhood measure on the outcome of interest, 4) studies that looked at a city, Metropolitan Statistical Area, county, or larger, as the geographic unit of interest, and 5) studies where the only neighborhood variable was a measure of pollution.

3.3.2 Search strategy and study selection

Using guidelines established by the Meta-Analysis of Observational Studies in Epidemiology (MOOSE) and Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statements this systematic review and meta-analysis were performed. In PubMed, MEDLINE, EMBASE, CINAHL, PsycINFO, and ProQuest Dissertation and Theses Full Text electronic databases, a search of the literature was conducted to identify studies which evaluated the relationship between neighborhood context, during or before pregnancy, and offspring risk of PTB and LBW. The literature search was limited to articles published in the English language. A doctoral-level researcher (CN) and junior faculty (AH) searched the electronic databases using established search terms and reviewed titles and abstracts against inclusion/exclusion criteria. Full-text articles corresponding to these citations were identified and independently read by two reviewers (CN and AH), and manual searches performed of these articles’ bibliographies. Articles were managed using EndNote X7.1 software. Any discrepancies in inclusion were resolved via discussion. The following search terms were entered in PubMed, MEDLINE, EMBASE, CINAHL, PsycINFO, and ProQuest Dissertation and Theses Full Text – (premature birth/preterm birth or low birth weight) and (neighborhood or residence area/characteristics). A detailed search strategy for each database was designed in consultation with a Public Health Informationist and is presented in Appendix E.

March 20, 2014 was the date of the last search for all databases, but we re-ran the PubMed search August 26, 2014.

3.3.3 Data collection process

The primary reviewer (CN) used data extraction sheets to collect data from each article. This extracted information was managed in Microsoft Excel 2013 and used to create Table 16,
Table 17, and Appendix F, along with providing data to perform the meta-analyses. Attempts were made to contact authors of selected articles for information pertinent to the meta-analysis but not included in the published articles.

3.3.4 Data analysis

Meta-analyses were conducted to calculate the odds of PTB and LBW among infants of NH black and Hispanic mothers, compared with those of NH white mothers, and to assess the association between PTB and LBW and neighborhood context for infants of NH white and NH black mothers. The questions to be answered through the meta-analysis were: 1) what are the odds of PTB and LBW among the racial/ethnic groups, and 2) is the mothers' neighborhood context associated with the infants' risk of PTB and LBW, and are there differences by race in the impact of neighborhood context on birth outcomes? For the first question all studies selected through the systematic review were included assuming they reported birth outcome event rates separately by race, or presented statistics for such a calculation. For the second question studies with similar approaches to analysis and a similar "index of treatment effect" (Borenstein et al., 2009) were included.

Random effects models were performed for all meta-analyses. Heterogeneity was assessed using I^2 between 0% (no observed heterogeneity) and 100% (high heterogeneity). I^2 is used to assess the inconsistency of effect sizes among the studies reviewed, the proportion of the total variance that is true. In the random effects model the summary effect calculated is an approximation of the mean of the effect sizes from the selected studies. Each study is presumed to have its own true effect size and that the studies included in the meta-analysis represent a random sample/distribution of a population of studies from which we would approximate a grand mean. This is in contrast with the fixed effect model which assumes one true effect size which is applicable to all studies and that the summary effect is an approximation of that effect (Borenstein et al., 2009). The studies included in this review were conducted by various researchers unlikely to have performed their research in an identical manner and who selected a diverse population of women for their sample, and because the neighborhood contexts, and therefore the potential impact they could have on birth outcomes, differ across the country, the random effects model was appropriate.

The odds ratio (OR), along with its 95% confidence interval (CI), is the principal summary measure. Studies that reported results as risk ratios (RR) or risk difference (RD) were converted to ORs, if possible. ORs, or data used in the calculation of this statistic, were extracted from studies that reported the fully adjusted model. Intent was to perform meta-regression to examine the extent to which heterogeneity among the studies is a result of the following study-level characteristics: the operationalization of the neighborhood context variable; the scale of the neighborhood variable, i.e. continuous, dichotomous, tertiles, quartiles, or quintiles; the geographic unit used to define the neighborhood; whether or not multilevel modeling was used; and, whether the data was published in a journal article or part of grey literature. In order to avoid increasing Type I error, as a result of running several separate univariate meta-regressions, multiplicity adjustment was made. Within this limited number of studies available for meta-regression, heterogeneity between studies was not explained by these factors. The recommendation is to have 10 studies per covariate used in a meta-regression (Borenstein et al., 2009). This was not the case in any of our meta-regressions and thus the results are not reported as they are likely unreliable. Publication bias was examined via the Egger's regression asymmetry test and Begg adjusted rank correlation test. All statistical analyses were performed with Stata, version 13.1, software (Stata Corporation, College Station, Texas), with the `metan` command.

3.4 RESULTS

3.4.1 Study selection

The search strategy produced a total of 1,314 citations – PubMed (558), MEDLINE and EMBASE (316), CINAHL (107), PsycINFO (262), and ProQuest Dissertations and Theses Full-text (71) on March 20, 2014. From these citations 270 duplicates were removed, leaving 1,044 for title and abstract review. Of these, 932 were removed after application of inclusion/exclusion criteria, leaving a total of 112 citations for full-text review. Two citations, which were conference presentation abstracts, were removed and replaced by one published manuscript identified through a manual search of the databases. Attempts were made to review the full text of the remaining 111 citations. Twenty-two did not meet the criteria – nine had an outcome other than PTB and LBW, six were dissertations published in full-text articles already retrieved in the search, four used the Metropolitan Statistical Area as the neighborhood unit, two were conference abstracts from which the authors had published manuscripts also retrieved in this search, one was hospital-based, one was a commentary, another reported insufficient information, and one dissertation was not publicly accessible; thus leaving 89 studies to be included in the systematic review. With an additional three that were found as a result of reviewing the bibliographies of relevant articles, and an additional one found in the August 26, 2014 re-run of the PubMed search, a total of 93 publications, which correspond to 60 studies, met all inclusion criteria and are included in the systematic review. Thirty six of the 60 were eligible for inclusion in the meta-analysis of the odds of PTB and LBW because they reported sufficient data on rates for NH blacks, NH whites, and Hispanics; 19 of the 60 were eligible for inclusion in the meta-analysis of the association between neighborhood and birth outcomes because they reported data on fully adjusted models wherein the most disadvantaged was compared with the least disadvantaged neighborhood. See Figure 6.

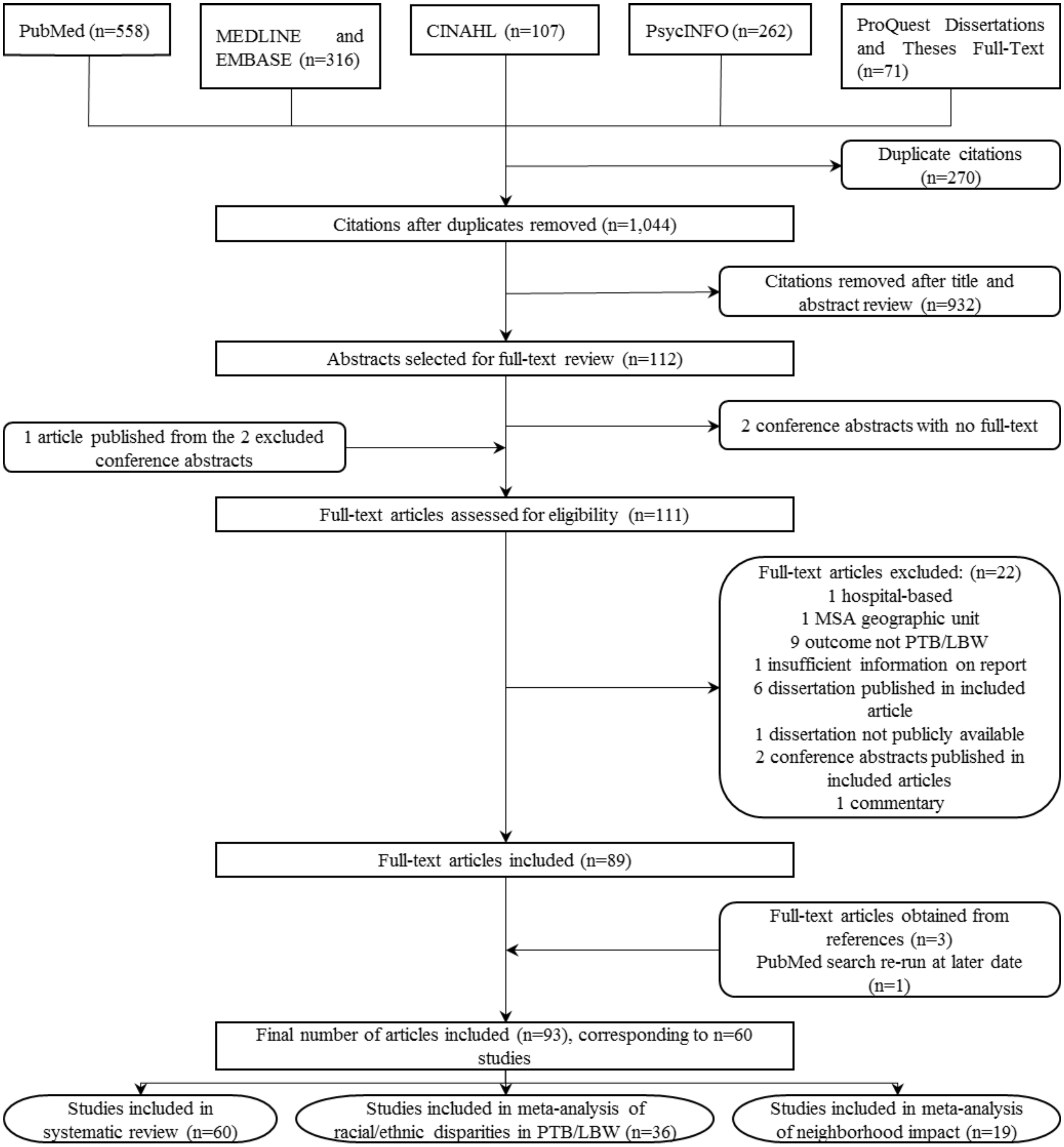

Figure 6. Flow diagram of systematic literature review study selection

3.4.2 Descriptive analysis

Appendix F provides information on the characteristics of the articles included in this review, such as location, sample size, population, inclusion/exclusion criteria, and so on. The use of vital birth records from the health department or the state was the most common source of data for the studies. Individual-level data was typically from the 1990s and early 2000s, and thus the decennial census for years 1990 and 2000 were customarily used for linking census-level data. Most articles included black and white mothers, but not all distinguished between NH and Hispanic ethnicity, or mentioned whether they were native- or foreign-born. The age range of the women at delivery was not typically explicitly mentioned, but the inclusion of women <20, 20-34, and >35 years of age were common categories, suggesting all ages were included. With the exception of a handful of studies, all were clear about their inclusion of only singleton infants in the analysis, with some mentioning live births and fewer excluding infants with congenital anomalies. About a third stated the gestational age and/or birth weight ranges considered plausible.

All 60 studies included in the review were published in English. For 27 of those studies the primary outcome was LBW, 11 studied PTB, and 22 examined both PTB and LBW as the outcome(s) of interest, resulting in 33 studies with PTB data and 49 studies with data on LBW. The majority of studies used cross-sectional data, one used a transgenerational birth file, and a handful utilized cohort data. When multiple articles were published from the same dataset, as determined by author names, study location and birth record years, the most comprehensive article was selected for the analysis of interest. Less than half of the studies used a theoretical framework/theory or mentioned a specific conceptual model. The most commonly stated were the racial residential segregation conceptual model and weathering hypothesis. Some studies used more than one theoretical framework. See Table 16 for frequency statistics of theoretical frameworks or conceptual models used in at least two studies.

Table 16. Systematic literature review study characteristics

	n	%
Theoretical framework or conceptual model	25	41.7
Racial residential segregation	6	24.0
Weathering hypothesis	6	24.0
Author-described conceptual model	5	20.0
Life course health development theory	3	12.0
Segmented assimilation theory	2	8.0
Healthy migrant theory	2	8.0
	n	%
Statistical analysis	60	100.0
Multivariate logistic regression	29	48.3
Accounted for clustering 31% (n=9)		
Multilevel multivariate logistic regression	23	38.3
Stratified analysis by race/ethnicity	21	35.0
Tested interactions	19	31.7
Geographic Information Systems/Spatial analysis	9	15.0
Only descriptive or bivariate analysis	6	10.0
Bayesian multivariate regression	1	1.7
Path analysis	1	1.7

Because of interest in the role of neighborhood context above and beyond individual-level variables, and acknowledging the possibility of residents within a neighborhood being more like each other than like those of other neighborhoods, almost 40% of studies performed multilevel multivariate regression. Almost 50% performed multivariate regression which does not account for the hierarchical nature of the data, although almost a third of those studies attempted to account for the clustering of infants born to mothers living in the same census tract. Some studies used more than one method, particularly those studies from which multiple articles were published. More than a third of studies ran within-race/ethnicity analyses as has been recommended by some researchers (Pearl, Braveman, & Abrams, 2001), based on findings that the effect of risk factors differs by race/ethnicity. The study of the interaction between individual-level and neighborhood-level variables, or even between individual-level variables, was not commonplace, even though such interactions have been found to be significant (Janevic et al., 2010; Rauh, Andrews, & Garfinkel, 2001; Rich-Edwards, Buka, Brennan, & Earls, 2003) and researchers have mentioned the importance of studying such interactions (Auger et al., 2009; M. R. Kramer & Hogue, 2008). A third of studies in this review explored possible interactions among variables. See Table 16.

For the majority of articles, analysis at the neighborhood-level is typically conducted with the use of census tracts as the geographical unit of analysis. The neighborhood predictors used varied, the most common being poverty, deprivation, racial residential segregation or racial composition, and crime. Poverty was operationalized as either median household income or the percentage of the neighborhood population living below the poverty level. Deprivation was customarily measured via the compilation of multiple neighborhood characteristics such as employment, income/poverty, education, housing, and occupations. Some studies used the Neighborhood Deprivation Index (NDI) published by Messer and colleagues (Messer, Laraia, et al., 2006), while others typically used principal component analysis to derive an index with their selected combination of neighborhood characteristics. The rationale for using racial composition in the study of adverse birth outcomes is not customarily stated. Certain researchers have used it as a measure of segregation (Baker & Hellerstedt, 2006; Mason et al., 2009; Messer et al., 2010) while others are clear about their use of the measure as distinct from segregation (Reichman, Teitler, & Hamilton, 2009). These two measures likely capture different aspects of residential life. Additionally, the majority of studies reviewed looked at neighborhood variables linearly and did not test or account for non-linear relationships between individual-level and neighborhood-level variables and PTB or LBW, despite the fact that other researchers have found significant non-linear relationships (Pickett et al., 2002).

See Table 17 for the individual and neighborhood-level covariates included in the analyses. Within the predominant neighborhood-level covariates of poverty, deprivation, segregation/racial composition, crime and income incongruity, we report the number of studies examining PTB and LBW and the covariates included in the analyses. There was no major distinction noted between the covariates likely to be used in the study of LBW and those of PTB. Certain covariates may more appropriately be analyzed as mediators or moderators but were included as confounders in the majority of the studies, with minimal, if any, justification provided other than that these factors have been found to be significantly associated with birth outcomes in other studies. There is a scarcity of articles that include a measure of maternal health as a covariate. When maternal health history is included, very few have anything extensive on the woman's health other than parity and gravidity; it was rare to find history of preterm delivery, pre-pregnancy BMI, adequacy of weight gained during pregnancy, the inter-pregnancy interval, chronic diseases, or whether the delivery was medically indicated included as covariates– confounders or mediators. This is likely due to the preponderant use of vital birth records where access to this kind of information is limited due to missing or unreliably reported data.

Table 17. Individual- and neighborhood-level covariates for low birth weight and preterm birth

	Poverty		*Deprivation*		*Segregation or racial composition*		*Crime*		*Income incongruity*	
	PTB (n=10)	LBW (n=20)	PTB (n=8)	LBW (n=6)	PTB (n=11)	LBW (n=13)	PTB (n=4)	LBW (n=2)	PTB (n=3)	LBW (n=3)
Maternal covariates (%)										
Maternal age	80.0	80.0	87.5	83.3	72.7	69.2	75.0	100.0	100.0	100.0
Maternal education	90.0	80.0	87.5	83.3	90.9	61.5	75.0	100.0	100.0	100.0
Family income	10.0	5.0	12.5	16.7	9.1	15.4			33.3	
Employment	10.0	5.0								
Marital status	70.0	50.0	50.0	66.7	54.5	61.5	75.0	100.0	100.0	100.0
Race/ethnicity	100.0	75.0	50.0	50.0	81.8	69.2	75.0	50.0		33.3
Nativity/birthplace	40.0	20.0	12.5	16.7	36.4	30.8	25.0			
Prenatal care use	60.0	70.0	37.5	16.7	54.5	23.1	50.0	50.0		
Substance use during pregnancy[1]	80.0	60.0	62.5	16.7	54.5	46.2	25.0			
Maternal BW or GA[2]	10.0	10.0	12.5							
Insurance type	30.0	35.0	12.5	33.3	27.3	15.4				
Perceived social factors					9.1	7.7				
Health/obstetric factors	50.0	30.0	50.0		18.2	23.1	25.0		33.3	
Infant covariates (%)										
Infant sex	10.0	10.0	25.0	33.3			25.0			
Parity	60.0	35.0	62.5	66.7	54.5	30.8	50.0	50.0	100.0	100.0
Neighborhood covariates (%)										
Poverty/deprivation					45.5	46.2	75.0	50.0		
Racial/ethnic/immigrant density	10.0	20.0	25.0	33.3		7.7			100.0	66.6
Built environment					18.2	7.7				
Stability		5.0	12.5		9.1	7.7				
Educational level	10.0	5.0			9.1	7.7				
Crime		15.0	12.5							
Rural/urban	20.0	10.0	12.5	16.7		7.7				
Air pollution			12.5							
Inequality	10.0									
Wealth		5.0								

[1] Substance use includes tobacco and/or alcohol use, [2] BW = birth weight and GA = gestational age

There is typically a measure of socioeconomic position—most commonly educational attainment, from the traditional perspective of what factors to use when operationalizing socioeconomic position (Galobardes, Shaw, Lawlor, Lynch, & Davey Smith, 2006); marital status; whether the mother received Medicaid health insurance while pregnant was also commonly adjusted for, assumedly as a measure of poverty and access to care; and, alcohol and substance use during the pregnancy as behavioral risk factors that have biomedical relevance to increased risk for adverse birth outcomes.

For the meta-analysis, PTB and LBW as dichotomous variables, i.e. PTB versus term birth and LBW versus normal birth weight, were used in analyses; for purposes of the literature review, multinomial variables, i.e. early PTB, late PTB and term birth, and very LBW, moderate LBW, and normal birth weight, were included as well. The majority of articles specified their criteria for PTB and LBW as less than 37 weeks of gestation and less than 2,500 grams at birth, respectively. However, very few mentioned, or were specific, about defining PTB as infants born after 20 weeks of gestation but prior to 37 completed weeks; the mention of plausible birth weight ranges was also infrequent. For purposes of the meta-analyses, only data for NH white, NH black, and Hispanic mothers is presented.

3.4.3 Meta-analysis: Preterm birth

From the potential 33 studies from which PTB data could be extracted, 16 reported sufficient information by race/ethnicity for the calculation of ORs. Of the 16 studies one study reported data for 8 cities/counties, with research at each site conducted by independent researchers, and these data are reported separately (thus adding up to 23 ORs). All 23 ORs were used to perform the meta-analysis of the odds of PTB for infants of NH black versus NH white mothers; the results indicate the odds of PTB were higher for infants of NH black mothers versus those of NH white, $\mathrm{OR} = 1.87\ (95\%\ \mathrm{CI}{:}\ 1.73, 2.02)$. Six of the 23 ORs had sufficient data to perform the meta-analysis of the odds of PTB for infants of Hispanic versus NH white mothers. We found no statistically significant difference in the odds of PTB for these infants, $\mathrm{OR} = 1.09\ (95\%\ \mathrm{CI}{:}\ 0.94, 1.27)$. Heterogeneity of the odds of PTB for NH black versus NH white ($I^2 =$

$99.3\%, \chi^2(1, n = 23) = 2958.55, p < 0.001$ and Hispanic versus NH white $(I^2 = 99.2\%, \chi^2(1, n = 6) = 652.06, p < 0.001)$ is high and statistically significant.

Seven of the potential 33 PTB studies report sufficient data for the pooled odds of the association between PTB and neighborhood disadvantage. Three of the seven studies controlled for race/ethnicity and there was no statistically significant increase in odds of PTB for those in the most disadvantaged neighborhoods, $\mathrm{OR} = 1.01$ $(95\%\ \mathrm{CI}: 0.94, 1.09)$. There was no observed heterogeneity among the effect sizes of these three studies $(I^2 = 0.0\%, \chi^2(1, n = 3) = 0.58, p = 0.749)$. However, the odds ratios of studies that performed within-race analyses present different findings.

The summary odds of the effect of neighborhood disadvantage on PTB for infants of NH whites is $\mathrm{OR} = 1.48$ $(95\%\ \mathrm{CI}: 1.25, 1.75)$, with high heterogeneity among the studies $(I^2 = 87.3\%, \chi^2(1, n = 11) = 78.73, p < 0.001)$. Four studies were included in this analysis, but one study included 8 cities/counties resulting in 11 ORs pooled (see Figure 7).

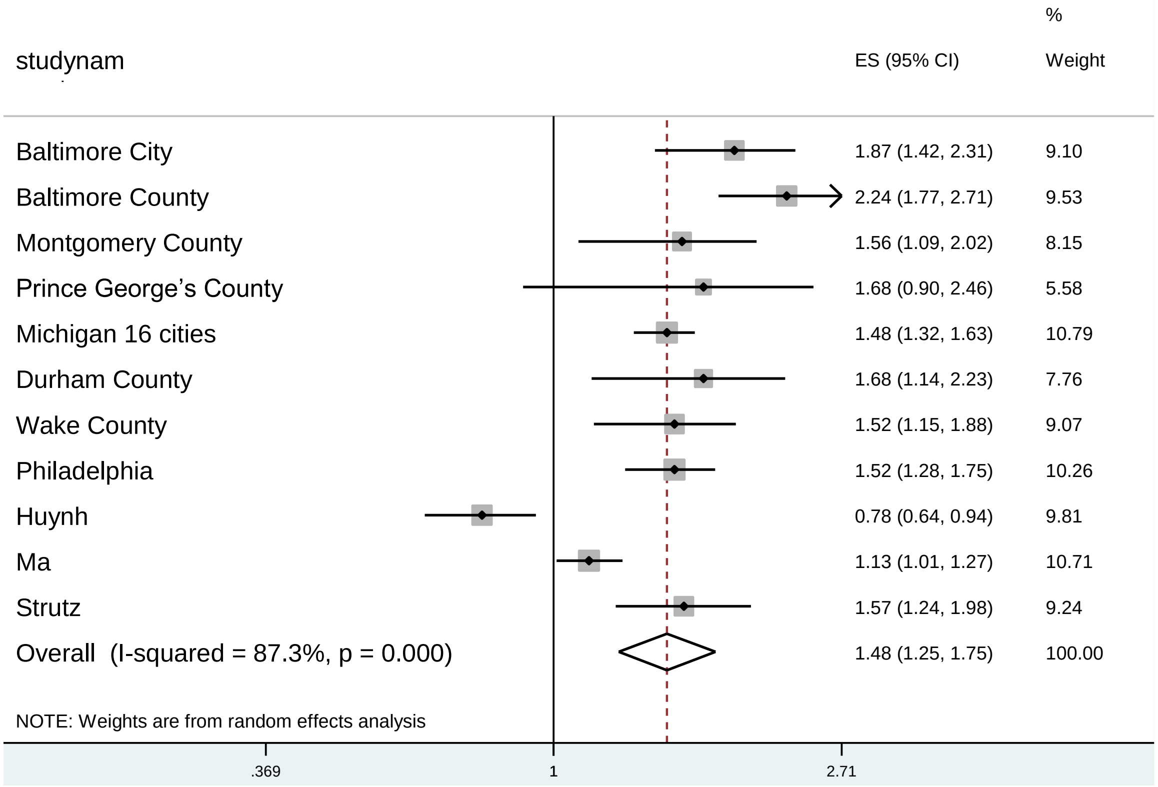

Figure 7. Forest plot for association between preterm birth and neighborhood disadvantage for infants of NH white mothers

The summary odds of the effect of neighborhood disadvantage for infants of NH blacks is $\mathrm{OR} = 1.15$ (95% CI: $1.09, 1.21$), with low heterogeneity among the 10 studies included $(I^2 = 13.3\%, \chi^2(1, n = 10) = 10.38, p = 0.320)$. See Figure 8.

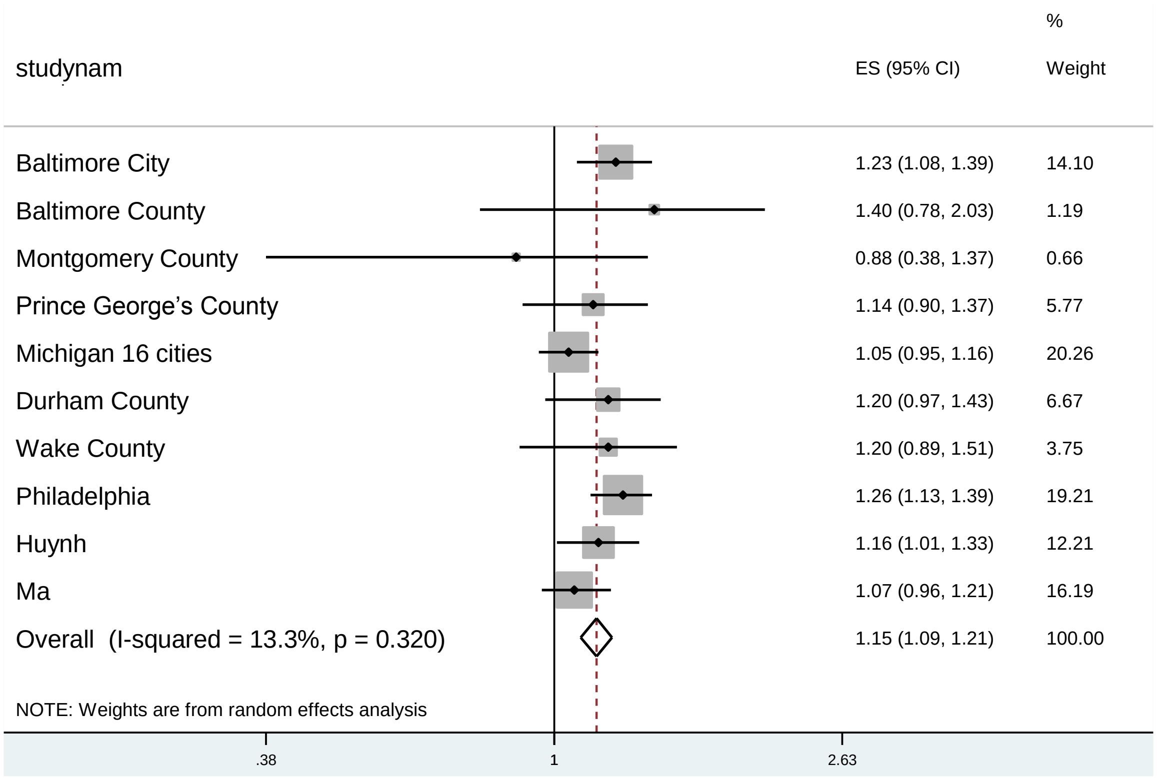

Figure 8. Forest plot for the association between preterm birth and neighborhood disadvantage for infants of NH black mothers

3.4.4 Meta-analysis: Low birth weight

From the potential 49 studies on LBW, 25 reported sufficient data by race/ethnicity for the calculation of a combined OR. Twenty four of these 25 studies were included in the meta-analysis of the odds of LBW for infants of NH black versus NH white mothers; one of the 24 studies reported data for two states and these data were included separately resulting in 25 odds ratios. Infants of NH black mothers were at significantly higher odds of LBW, $\mathrm{OR} = 2.50\ (95\%\ \mathrm{CI}: 2.31, 2.70)$. Nine of the 25 odds ratios were included in the meta-analysis for the odds of LBW for infants of Hispanic versus NH white mothers, and we found them also to be at higher odds of LBW, $\mathrm{OR} = 1.10\ (95\%\ \mathrm{CI}: 1.02, 1.19)$. Heterogeneity was high and statistically significant for the odds of LBW for infants of NH black versus NH white ($I^2 =$

$99.1\%, \chi^2(1, n = 25) = 2538.30, p < 0.001)$ and Hispanic versus NH white $96.9\%, \chi^2(1, n = 9) = 258.77, p < 0.001)$ mothers.

Fourteen of the potential 49 LBW studies report sufficient data for the pooled odds of the association between LBW and neighborhood disadvantage. Eight of the 14 studies controlled for race/ethnicity and the $\text{OR} = 1.02$ $(95\%\ \text{CI}: 1.00, 1.04)$ with high heterogeneity among the studies $I^2 = 81.4\%, \chi^2(1, n = 8) = 37.67, p < 0.001$. Similarly to the corresponding PTB finding above, there is no statistically significant impact of neighborhood disadvantage among studies controlling for race.

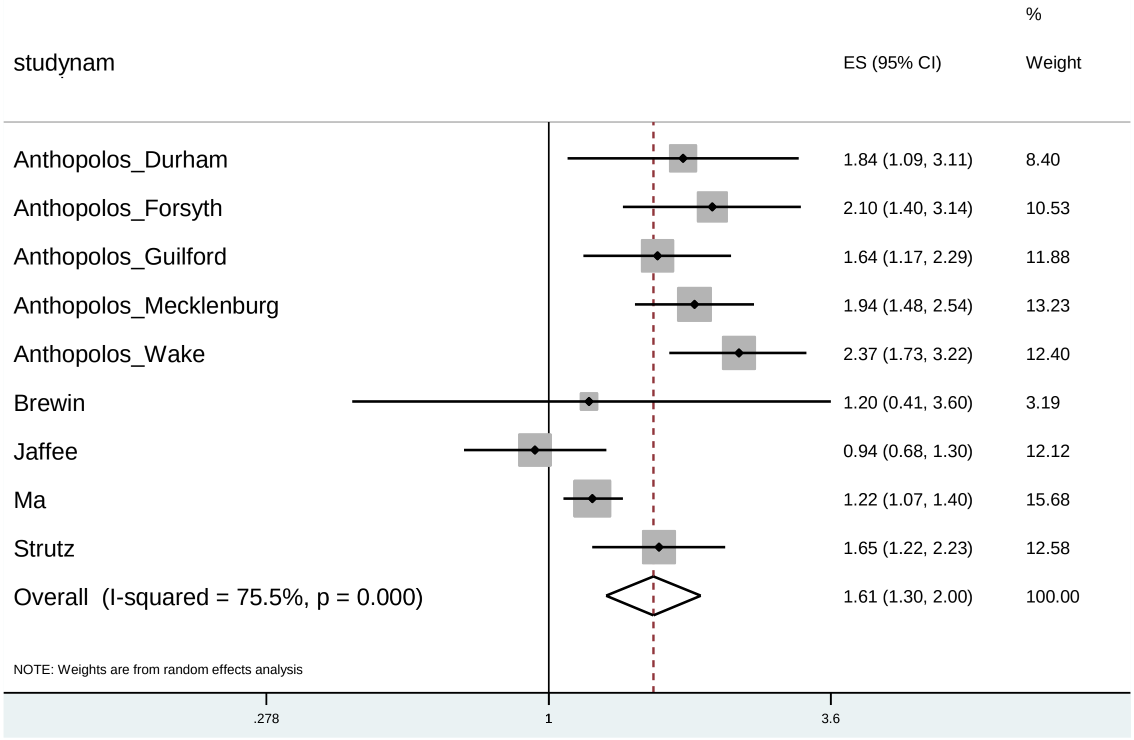

Figure 9. Forest plot for the association between low birth weight and neighborhood disadvantage for infants of NH white mothers

However, when within-race analyses are performed we find that infants of NH white mothers have an odds of $\text{OR} = 1.61$ $(95\%\ \text{CI}: 1.30, 2.00)$ if mothers are exposed to the most disadvantaged neighborhood, and the odds for infants of NH black mothers are $\text{OR} = 1.17$ $(95\%\ \text{CI}: 1.10, 1.25)$. Five studies were pooled in the NH white and NH black analyses, with one study including data from five counties which were included separately, resulting in nine ORs (see Figure 9 and Figure 10). The heterogeneity among the NH white studies was moderate $(I^2 = 75.5\%, \chi^2(1, n = 9) = 32.63, p < 0.001)$, while the heterogeneity among the NH black studies was not statistically significant $(I^2 = 34.4\%, \chi^2(1, n = 9) = 12.19, p = 0.143)$.

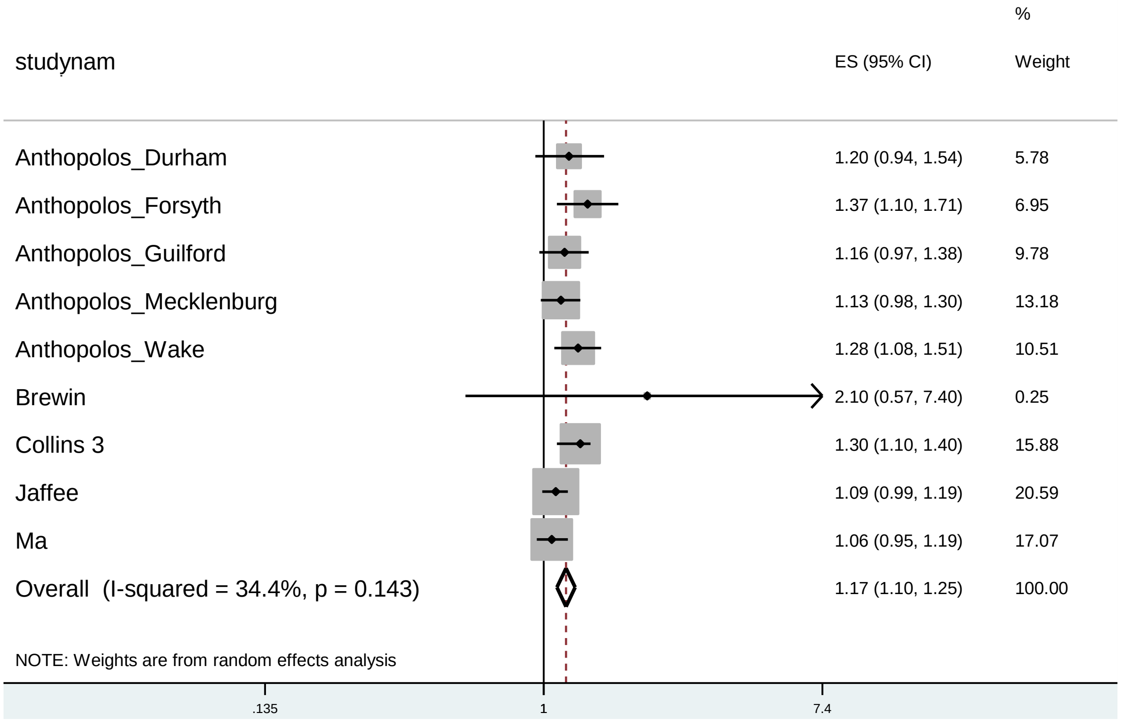

Figure 10. Forest plot for the association between low birth weight and neighborhood disadvantage for infants of NH black mothers

3.4.5 Bias Assessment

Egger's regression asymmetry test resulted in non-significant asymmetry for the meta-analyses performed on the relationship between neighborhood and PTB for race-adjusted models $(p = 0.920)$, NH whites $(p = 0.805)$, and NH blacks $(p = 0.354)$; and between neighborhood and LBW for race-adjusted models $(p = 0.071)$, NH whites $(p = 0.114)$, and NH blacks $(p = 0.227)$. The Begg adjusted rank correlation test was also statistically non-significant $(p > 0.05)$.

3.5 DISCUSSION

3.5.1 Summary

NH black mothers are almost twice as likely to give birth to a premature infant compared with NH white mothers, but Hispanic mothers have similar odds as NH whites. NH black mothers are 2.5 times more likely to have a LBW infant relative to NH white mothers, while Hispanics are 1.1 times more likely than NH whites. Studies that controlled for mothers' race/ethnicity in the statistical model were not likely to find a statistically significant association between PTB/LBW and neighborhood disadvantage. However, studies that perform statistical models separately for each racial/ethnic groups were likely to find that neighborhood is significantly associated with PTB and LBW for infants of both NH white and NH black mothers, albeit with smaller effects for NH blacks. NH white mothers in the most disadvantaged neighborhoods were about 1.5 times and 1.6 times more likely to have PTB and LBW infants, respectively, compared with NH white mothers resident in the least disadvantaged neighborhoods. NH black mothers in the most disadvantaged areas were about 1.2 times more like to have PTB and LBW infants, relative to their counterparts in the least disadvantaged areas. A potential explanation for this difference is the very different neighborhood environments in which NH blacks and NH whites reside. Including race/ethnicity in the model captures aspects of the neighborhood environment such as poverty, crime, racial composition, and deprivation because race is a predictor of where people live in the United States. When performing within-race/ethnicity models, the results represent the relative disadvantage within that group, and because NH blacks are a smaller percentage of the population and more likely to live in disadvantaged areas, the spectrum of exposure to various levels of advantage/disadvantage is likely narrower, resulting is the lower combined ORs and narrower confidence intervals relative to NH white mothers.

A qualitative review of the extracted data reveals the majority of within-race studies of LBW used racial composition as the neighborhood variable, while PTB studies primarily used neighborhood deprivation. As a result, it may be reasonable to assume that the results of the combined ORs apply when those neighborhood variables are used as measures of neighborhood disadvantage. As more studies are conducted in this area, subsequent meta-analyses should be able to determine whether the association between neighborhood disadvantage and birth outcomes vary depending on the operationalization of the variable.

This systematic literature review search strategy retrieved two other meta-analyses on this topic (Metcalfe, Lail, Ghali, & Sauve, 2011; Vos, Posthumus, Bonsel, Steegers, & Denktas, 2014). These were subsequently removed because they did not meet the inclusion criteria, but the identification of these articles permits us to compare findings. We performed a review of the literature specifically to identify additional meta-analyses and did not identify any. Both of these meta-analyses included only studies that controlled for race/ethnicity in their models; that is, they did not include studies that ran within-race/ethnicity analyses. Vos et al. included a random effects model of PTB by neighborhood disadvantage, but all seven studies included in the meta-analysis were of studies conducted outside of the United States, which would not have been included in our meta-analysis, and their findings perhaps not comparable. Metcalfe et al. performed a random effects model of LBW by neighborhood income which included five studies that used multilevel analysis, one of which included data from two states – resulting in six ORs. The summary odds for this association were $\mathrm{OR} = 1.11\ (95\%\ \mathrm{CI}{:}\ 1.02, 1.20)$ which is statistically significant. This can be compared with our meta-analysis which found a summary odds for the association between LBW and neighborhood disadvantage of $1.02\ (95\%\ \mathrm{CI}{:}\ 1.00, 1.04)$. Our analysis included four of the five studies included by Metcalfe et al. (and an additional four others). We contacted the authors to receive clarification on their inclusion of the fifth study (Cubbin et al., 2008) because upon review of that study we found the OR in the report did not compare the most disadvantaged to the least disadvantaged neighborhood (the moderate group was used as a reference category). The authors informed us of the table from which they extracted the data in Cubbin et al.'s report. This revealed their incorrect extraction of data as the income variable was at the individual-level not neighborhood-level. Removing the Cubbin et al. study and rerunning the analysis with just the four remaining studies in Metcalfe et al.'s analysis, we get a summary odds of

$1.08\ (95\%\ \mathrm{CI}: 1.00, 1.17)$ which indicates a statistically non-significant effect of neighborhood income on LBW when controlling for race/ethnicity.

This meta-analysis provides a comprehensive synthesis of the literature, indicating associations between the neighborhood environment of the mother and the risk to offspring of adverse birth outcomes that differ by race/ethnicity when performing within race/ethnicity analyses; but not significant effects of neighborhood environment when controlling for race/ethnicity in the models.

3.5.2 Limitations

The majority of studies included here were cross sectional in nature, thus limiting their ability to distinguish the causal mechanisms underlying the impact of neighborhood context on adverse birth outcomes as compared with just correlations between variables at a particular time point. As a meta-analysis of observational studies, this paper has the inherent bias of not having the ability to assesses the effect of randomly assigned interventions (neighborhood environments are not randomly assigned), and the challenge of summarizing the results of studies with differing study designs (Stroup et al., 2000). Differences found between groups, for example, neighborhood disadvantage groupings, cannot be attributed solely to that grouping criteria as they may be the result of unmeasured factors associated with participation in those groups (Borenstein et al., 2009). For studies that included multiple neighborhood variables the authors arbitrarily selected one, usually the more commonly used measure in order to improve comparability with other studies. The definition of neighborhood disadvantage was not predetermined; although this provides a more comprehensive overview of the operationalization of neighborhood disadvantage in this field, it also has the limitation of potentially comparing different constructs. Most studies in this meta-analysis were from studies using data from east coast cities in the United States. The manner in which the history and politics of the country have determined differences in things such as demographics, and social and economic neighborhood environments, to name a few, could limit the generalizability of these findings.

Publication bias is a limitation of systematic reviews and meta-analyses in that studies with statistically significant findings and higher effect sizes are more likely to be in the published literature and thus included in a meta-analysis. Although not completely addressing this bias, unpublished theses and dissertations were included to capture an element of grey literature. To test the potential for publication bias, Egger's regression asymmetry and Begg adjusted rank correlation tests were run and do not suggest the presence of this bias. Another limitation is language bias. Only articles published in the English language were included, due to the linguistic limitations of the authors. However, the authors were interested in the impact of neighborhood disadvantage on PTB and LBW in the United States. so there is a low probability of articles excluded due to publication language restrictions. Duplication bias is present when studies with statistically significant findings and higher effect sizes are more likely to be published multiple times (Borenstein et al., 2009; Tramer, Reynolds, Moore, & McQuay, 1997) and, therefore, more likely to be selected for inclusion in meta-analysis. In order to address this bias efforts were made to eliminate duplicate studies by reviewing author names, geographic location of birth records and years of birth data as well as contacting authors when determination of duplicate publications could not be made with certainty.

Stata software, version 13.1, uses the DerSimonian and Laird procedure for random effects meta-analysis which is accurate for a large number of studies, that is, greater than 20; however, the accuracy also varies with the heterogeneity (I^2) value (Jackson, Bowden, & Baker, 2010). When there are a small number of studies in a meta-analysis, such as the three or four used in some of the analysis in this study, heterogeneity might not be estimated and using fixed effects models is recommended (Borenstein et al., 2009). Replicating the PTB model (which adjusted for race/ethnicity) with three pooled odds ratios and running both fixed and random effects models produced the same the results, indicating that there was insufficient information to calculate I^2. However, using the DerSimonian and Laird procedure the actual coverage probability of a nominal 95% confidence interval with four studies and low heterogeneity is still close to 95% and so the small number of studies may not be of huge concern in this case.

We have been limited in our ability to truly study the role of neighborhood context on PTB because only a minority of articles make a distinction between whether the birth was medically indicated/iatrogenic or spontaneous. The literature is suggestive of a stronger relationship between neighborhood context and PTB for spontaneous PTBs, rather than medically indicated PTBs (G. S. Phillips, Wise, Rich-Edwards, Stampfer, & Rosenberg, 2009). Since the increase in indicated births over the years is primarily responsible for the increase in PTB and LBW rates, to study the true impact of neighborhood context, researchers need to focus on spontaneous PTB. There is also the possibility that some of the neighborhood context factors impact LBW through PTB while others impact LBW through intrauterine growth retardation (Debbink & Bader, 2011), but it is not common practice for researchers to report these distinctly.

3.5.3 Future research

The inclusion of biomedical covariates as mediators in this causal pathway is largely missing in this area of research. Associations have been found between health and various neighborhood factors but not much has been done to understand how they are connected causally or if they are simply associations capturing unmeasured individual-level factors. This will require more in-depth collection and analysis of a variety of theoretically-founded variables at the biological-, behavioral-, family-, and neighborhood-level (M. R. Kramer et al., 2010; Roberts, 1997; Schempf, Kaufman, Messer, & Mendola, 2011) to allow for a more rigorous and comprehensive study of the complexities involved.

The differential impact of known risk factors on risk of adverse birth outcomes by race/ethnicity has been identified in a number of studies but much work remains in order to understand these effects. This is an area of research that could get us closer to understanding the determinants of racial/ethnic disparities in PTB and LBW (Ahern et al., 2003).

There is high correlation between the birth outcomes of adjacent neighborhoods and this could be as a result of multiple factors, including the social and economic environment of that area (Morenoff, 2003). The use of spatial measures of neighborhood variables may be of great benefit to this area of research

(Mason et al., 2009) as it cannot be assumed that health is affected only within the lines that make up a census block group or census tract. Although some studies using spatial methodology were identified, there remains an opportunity for more research.

There were few articles that examined the effect of generational neighborhood context on infant birth outcomes. The Collins and colleagues articles (J. W. Collins Jr, Wambach, et al., 2009) that did so suggest that the maternal grandmothers' neighborhood environment has an independent effect on birth outcomes, even after accounting for the mothers' neighborhood environment. There is also a possibility of an "epigenetic or primary genetic inheritance pattern" (J. Collins Jr et al., 2011) which could explain the consistency of the relationship between maternal LBW and infant LBW, regardless of the economic environment across the life course of the woman as well as the impact of the mother's neighborhood environment at birth on her infant's birth outcome. The current datasets available for the study of women and birth outcomes and, to some extent, the analytical techniques currently available make it a challenge to conduct research that examines the cumulative exposure of adversity and the intergenerational biological factors that could explain the persistent racial/ethnic disparities in birth outcomes. More research is needed into understanding this etiologic pathway (J. W. Collins Jr, David, et al., 2009).

3.5.4 Conclusions

Studies that control for mothers' race/ethnicity in the statistical model are not likely to find a statistically significant association between PTB/LBW and neighborhood disadvantage. However, studies that perform statistical models separately for each racial/ethnic groups are likely to find that neighborhood disadvantage is significantly associated with higher odds of PTB and LBW for infants of both NH white and NH black mothers, albeit with smaller effects for NH blacks.

3.5.5 Acknowledgements

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4.0 THE TRANSGENERATIONAL RISK FOR LOW BIRTH WEIGHT AMONG NON-HISPANIC BLACK AND WHITE MOTHERS: THE ROLE OF BIOLOGY AND SOCIAL AND ECONOMIC NEIGHBORHOOD CONTEXT

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Manuscript in preparation

4.1 ABSTRACT

Objective: Racial/ethnic disparities in low birth weight (LBW) rates have remained largely unchanged over time. Research has typically focused on maternal health behaviors and characteristics as predictors of LBW and racial/ethnic disparities therein. The objective of this study is to examine the risk of LBW as a result of maternal birth weight (MBW) and generational social and economic neighborhood conditions. *Methods*: Using a transgenerational dataset which includes infant birth records linked to mothers' birth records, hierarchical generalized linear modeling was used to examine LBW and its categories of moderate LBW (MLBW) and very LBW (VLBW). *Results*: MBW is a significant predictor of MLBW, but not VLBW, in multivariate models. The protective effect of higher MBW on the odds of MLBW is dependent on the mothers' maternal age, with an increase in maternal age corresponding with a larger reduction in odds of MLBW at higher MBW. Neighborhood poverty is a significant predictor of VLBW, but not MLBW; living in high poverty neighborhoods increases the relative risk of VLBW by 100%. Racial disparities in VLBW remained in multivariate models. *Conclusions*: More research is needed into

the causal pathway between maternal and infant birth weight; and between neighborhood economic disadvantage and VLBW, which is the group of infants at highest risk for infant mortality.

4.2 INTRODUCTION

In 2013, approximately 317,000 infants in the United States were born with low birth weight (birth weight less than 2,500 grams), which is about 8% of all births. As has been the trend for at least half a century, infants born to non-Hispanic (NH) black mothers are almost twice as likely as those born to NH white mothers to have low birth weight (LBW). Among NH whites and Hispanics the LBW rate is 7% and 7.1%, respectively, while it is 13.1% for NH blacks (Hamilton et al., 2014); this can be juxtaposed with 7% for whites and 13.1% for non-whites in 1962 (Lunde et al., 1964). Despite slight increases and decreases over time in the rates of LBW in the United States the racial/ethnic disparity has remained largely unaffected.

LBW can have negative effects on the health of infants; it increases risk for infant mortality, and can cause long-term effects into adulthood. The primary cause of LBW is preterm birth (Paneth, 1995), but it can also be the result of intrauterine growth retardation. In 2010, about 24,500 infants died in their first year of life – the majority of whom were born prematurely (Mathews & MacDorman, 2013b). Prematurity and associated conditions are responsible for about 35% of infant mortality rates in the country, the largest single cause of death, and account for about half of the racial/ethnic infant mortality disparity documented between NH white and NH black infants (Mathews & MacDorman, 2013a). LBW rates have been on an upward trend over the last couple of decades despite advancement in knowledge of risk factors and interventions implemented. There has been a general rise in LBW in industrialized countries and the United States is ahead of the pack in this regard. The higher prevalence of LBW among infants born to NH black women than to NH white or Hispanic in the United States has fueled the continued disparity in infant morbidity and mortality for decades (Paneth, 1995) but the reasons for higher rates of lower birth weight are not fully understood. To compound the issue, the etiology of LBW has not been fully comprehended

(Goldenberg & McClure, 2010). Research has historically focused much attention on only maternal health behaviors and characteristics as predictors of the incidence of LBW and as the reasons for racial/ethnic disparities. Alcohol and tobacco use during pregnancy, the adequate use of prenatal care services, maternal age, maternal marital status and socioeconomic position are the factors typically included in analyses. However, the study of social context as a covariate in the explanation of adverse births outcomes has increased over the years (Geronimus, 1986) and allows for the study of "the important role that the residential environment plays in shaping the psychosocial and physiological factors that lead to poor birth outcomes" (J. F. Bell et al., 2006).

Researchers have found that both maternal and paternal birth weight have a positive and significant independent relationship with the birth weight of their offspring; although some would argue for the lesser role of paternal factors (Alberman et al., 1992) others have found an impact of similar magnitude as maternal factors (Conley & Bennett, 2000; Klebanoff et al., 1998). A heritability study utilizing grandparent fixed effects models concluded that there exists a biological (genetic) aspect to this intergenerational transmission of LBW risk between parents and offspring and that it could be a contributing factor to the racial disparities in risk of LBW. It is hypothesized that genetic-environmental interactions could be at play; and knowing that African Americans are more likely to be exposed to adverse social and economic conditions, this could generate the excess LBW seen in this population (Conley & Bennett, 2000).

The birth weight of the mother as well as the neighborhood context into which the mother was born have been found to have an independent and significant impact on the birth outcome of her infant. Women who were themselves of LBW are more likely to have LBW infants, regardless of the mother's race, and independent of neighborhood context across the woman's life. Women who were born with LBW are approximately twice as likely to deliver a LBW infant as their non-LBW counterparts (J. W. Collins Jr, Wambach, et al., 2009). Although rarely studied, the level of deprivation in the neighborhood into which the mother was born is an independent risk factor for the LBW status of her infant. The birth of the NH black mother into an affluent neighborhood, despite the affluence of the neighborhood in which she resides during adulthood has modest, yet stable, protective effects for her infant (J. W. Collins Jr, David, et al., 2009).

The health of prior generations may explain better the racial disparities in birth outcomes than do the current social and economic conditions (Conley & Bennett, 2000). We can see from the literature summarized above that the exclusion of the health of prior generations in the examination of birth outcomes paints an incomplete picture of the determinants of health and disparities. As a result, it is the purpose of this study is to examine the risk of LBW in relation to maternal birth weight and generational social and economic neighborhood conditions.

4.3 METHODS

4.3.1 Study population

The University Of Pittsburgh Graduate School Of Public Health has close ties with the Allegheny County Health Department and frequently joint projects are carried out to further the research interests of academicians at the University, and public health practices of the health department. This research team began one such project with the support of the acting health director at the time. A total of 7,213 infant birth records from 2009-2011 were successfully linked to mothers' birth records from 1979-1998 in Allegheny County, Pennsylvania, forming a transgenerational dataset. This study was approved by the Institutional Review Board of the University of Pittsburgh. Excluded were birth records of infants with congenital anomalies, whose maternal grandmothers were not black or white as well as whose mothers were not NH black or NH white, because the majority (94%) of the population in this county self-identify as being a part of these two groups. Infants with birth weight less than 300g were subsequently removed, in order to eliminate unrealistically low birth weight for live-born infants; census tracts with less than 5 births per racial group were removed in the dataset, in order to have sufficient births to examine neighborhood clustering. The latter was applied only to the mothers' neighborhood (2009-2011) resulting in 350 census tracts representing mothers' neighborhoods (M neighborhoods). No minimum births per census tract were required for the 578 maternal grandmothers' (GM) neighborhoods (1979-1998). To be included in this study, birth records had to include race/ethnicity, infant birth weight, maternal birth weight, or census tract code. This resulted in a final LBW dataset of 6,633 linked records. The overall percentage of infant LBW was significantly lower for the records maintained in the final dataset (7.49%) when compared with the excluded observations for which we had LBW status (8.31%), $\chi^2(1, n = 2) = 261.86,\ p < 0.001$. However, the LBW rate of the final dataset is comparable with county-wide LBW rates for infants born in the years 2009-2011 to mothers of similar age to those in the dataset (7.96%)[7].

4.3.2 Study variables

For purposes of distinction, the 2009-2011 birth records are referred to as the infant birth records, while the 1979-1998 birth records are referred to as the mothers' birth records. The infant birth records include infant birth outcomes along with maternal and paternal characteristics, while the mothers' birth records include the mothers' birth outcomes and the maternal grandparents' characteristics. The primary outcome variables are infant risk of LBW, the coding is LBW1 = 1 if yes, LBW1 = 0 if no; and infant risk of very LBW (VLBW) and moderate LBW (MLBW), coded as LBW2 = 2, LBW2 = 1, respectively, and LBW2 = 0 for normal birth weight. VLBW is <1500 grams and MLBW is 1500-2499 grams. LBW used without either a 1 or 2 in front of it, will denote low birth weight generally, rather than as a binary or multinomial variable.

Mothers' birth weight (MBW) and neighborhood characteristics are the main predictors. MBW is included as a continuous variable multiplied by 100 so that the interpretation of a one-unit change in the variable is equal to a 100 gram change in birth weight; and the neighborhood characteristics include neighborhood racial composition and segregation, and neighborhood low income and economic

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[7] "These data were provided by the Bureau of Health Statistics and Research, Pennsylvania Department of Health. The Department specifically disclaims responsibility for any analyses, interpretations or conclusions."

segregation. Included were the following covariates for the mothers: maternal age, race, marital status, Medicaid (versus private/self-pay health insurance) and educational attainment (a ratio of education achieved compared with education expected at maternal age). The following covariates for the maternal grandmothers were also included: maternal age, marital status, and educational attainment. The individual-level factors included were only those significantly correlated with LBW1 in bivariate analysis; all M and GM neighborhood-level factors were tested because they are relevant to the objective of the study. Data on health and obstetric factors such as chronic (pre-pregnancy) hypertension, gestational hypertension, chronic diabetes, gestational diabetes, vaginal bleeding, smoking during first trimester, adequacy of prenatal care utilization, and adequacy of gestational weight gain were available on the birth records. However, these were not included in the multivariate analyses because of concerns with reliability of variables (DiGiuseppe, Aron, Ranbom, Harper, & Rosenthal, 2002), and to avoid over-adjustment in statistical models with variables that could be in the causal pathway (Schisterman et al., 2009).

Neighborhood racial composition was included as a continuous variable (percent of residents in the census tract who are NH black) and as a categorical variable $(0\% \leq \text{low} < 13\%, 13\% \leq \text{medium} < 50\%, \text{and } 50\% \leq \text{high} \leq 100\%)$. 13% of U.S. Census 2010 residents self-identify as NH black, so if a census tract had the same percentage of residents NH black residents as the overall County it would fall in the ‘low’ category. Neighborhood low income was also included as a continuous variable (percent of households in the census tract in the lowest income tertile) and as a categorical variable $(0\% \leq \text{low} < 34\%, 34\% \leq \text{high} \leq 100\%)$. If a census tract had the same percentage of households in the lowest income tertile as the overall County this would be 33%, therefore census tracts with < 34% are considered low poverty and those above that cut-off considered to have high poverty. GM neighborhood racial composition and neighborhood low income were included as a continuous and categorical variable as well, with similar cut-off points. Because of interest in generational disadvantage we created social mobility variables. For neighborhood racial composition: generational low % black, generational medium % black, generational high % black, moved from lower to higher % black, and moved from higher to lower % black; and, for neighborhood low income: generational low poverty, generational high poverty, low to high poverty, high to low poverty. Neighborhood racial and economic segregation measures were calculated using Wong's local spatial segregation index (Wong, 2002). With b_i and w_i as the population count of NH black and NH white residents, respectively, in each census tract the potential interactions between NH blacks and NH whites (racial residential segregation) in census tract *i* is represented by the following formula:

$$S_{i*bw} = 1 - \frac{b_i \sum_j c_{ij} w_j}{b_i \sum_j w_j}$$

The same approach is used for the economic segregation measure. The results are standardized and 1 is interpreted to mean perfect segregation, whereby there is no interaction between the two groups, and 0 means no segregation and perfect potential for interaction. Both measures are log transformed, with intent to eliminate skewness, and included as continuous variables.

4.3.3 Statistical analyses

Hierarchical data structures are common in the fields of the health sciences and require appropriate statistical analysis. For the purpose of this research we examined how neighborhood context, specifically measures of social and economic composition, influence infants' risk of LBW. In this case both the infant (and other person-level characteristics) and the neighborhood are units of analysis, such that we have infants, at level-1, nested within neighborhoods, at level-2. Research into the association between neighborhood context and birth outcomes has not always taken into account the hierarchical data structure and this can be the result of tests indicating multilevel models would not be appropriate or in some cases simply the result of inadequate statistical techniques to handle such a data structure. However, there have been recent advances in this area of statistics that allow public health researchers to utilize such methodology (Raudenbush & Bryk, 2002). We performed hierarchical generalized linear modeling (HGLM) with a logit link function to model the variation in LBW within a two-level data structure, and sought to study the relationship between MBW and infant odds of LBW, and the role of neighborhood disadvantage. We used an HGLM cross-classified model to examine the effect of both M and GM neighborhood on infant risk of LBW1. Examination of the data revealed that the mothers living in each of the 350 M neighborhoods come from as few as one to as many as 58 GM neighborhoods, which suggests little evidence that mothers born into certain neighborhoods were systematically moving to particular M neighborhoods in adulthood. There are between five and 70 infants born into each M neighborhood, with an average of 18.95, and there are between 1 and 92 infants per GM neighborhood, with an average of 11.48. The low number of births corresponding to each GM neighborhood will make precise estimation of GM neighborhood effects difficult. Inferences made about M neighborhoods will be more reliable than those made about GM neighborhoods. We ran an unconditional model to determine whether there was variability in infant LBW1 across both M neighborhood and GM neighborhoods. Analyses for the cross-classified models were performed using SAS, version 9.4, software (SAS Institute Inc., Cary, NC, USA) PROC GLIMMIX command. Having found statistically significant variability in this model, level-1 covariates were included. However, we were unable to estimate between-GM neighborhood variation after including level-1 covariates, due to issues of model convergence.

As a result, we proceeded to test a simpler 2-level model with M neighborhood as the level 2 unit. We assessed the magnitude of variation between M neighborhoods on risk of infant LBW1 and LBW2. Having found sufficient variation, we examined the odds of LBW1 by performing an HGLM random intercept model with MBW. To determine whether within-race models were appropriate we tested the interaction between MBW and race. Finding no statistically significant difference in the impact of MBW on odds of LBW1 by race we opted to run models adjusting for race. We proceeded to run random intercept models with MBW and race, and controlling for potential confounders. We followed a similar model-building approach when examining LBW2, using HGLM multinomial random intercept models. We used Laplace Approximation for both the binomial and multinomial models to approximate the parameter estimates (Rabe-Hesketh & Skrondal, 2002). Statistical analyses of LBW1 were performed using Stata, version 13.1, software (Stata Corporation, College Station, Texas) `xtmelogit` command, while statistical analyses of LBW2 were performed using SAS, version 9.4, software (SAS Institute Inc., Cary, NC, USA) PROC GLIMMIX command. Statistical significance was determined using $p < 0.05$, and the likelihood ratio (LR) test measured an improvement in model fit as covariates are included and excluded from the models.

4.4 RESULTS

4.4.1 Descriptive statistics

In this transgenerational birth file, NH black mothers are significantly more likely to have been of lower birth weight ($M = 3{,}021.97$ grams, $SD = 583.52$) than NH white mothers ($M = 3{,}323.72$ grams, $SD = 528.95$), $p < 0.001$. The overall rate of LBW1 among the mothers was 8.43%; with 5.48% among those born to white mothers and 16.26% among those born to black mothers, $\chi^2(1, n = 2) = 198.60, p < 0.001$, (these would be the infants' grandmothers). This is an odds of LBW1 that is 3.35 times higher for mothers born to black grandmothers than white grandmothers. Infants of NH black mothers were significantly more likely to have lower birth weight as well ($M = 3{,}060.65$ grams, $SD = 624.03$) compared with infants of NH white mothers ($M = 3{,}326.57$ grams, $SD = 547.72$), $p < 0.001$. The overall LBW1 rate among infants was 7.51%; with 5.72% among infants of NH white mothers and 12.06% and those of NH black mothers, $\chi^2(1, n = 2) = 77.93, p < 0.001$. The odds of LBW1 are 2.26 times as high for infants of NH black mothers as for those of NH white mothers.

Overall, 5.89% of infants were born MLBW and 1.61% were born VLBW. Among NH white mothers, 4.71% of infants were MLBW and 1.01% were VLBW; among NH black mothers, 8.91% of infants were MLBW and 3.15% were VLBW. This difference in distribution of LBW2 by race is statistically significant, $\chi^2(1, n = 2) = 84.33, p < 0.001$. The overall relative risk of MLBW relative to normal birth weight is 0.06, while the relative risk of VLBW relative to normal birth weight is 0.02. For NH white mothers infant relative risk of MLBW is 0.05 and for VLBW 0.01, relative to normal birth weight; while for NH black mothers infant relative risk of MLBW is 0.10 and for VLBW 0.04, relative to normal birth weight.

Infants of NH black and NH white mothers were found to differ on a number of level-1 and level-2 factors, including MBW, mothers' educational attainment, mothers' maternal age, maternal grandmothers' maternal age, and grandmothers' educational attainment, all of which were lower among NH blacks. Infants of NH blacks were more likely to live in M and GM neighborhoods with a high percentage of black residents and low income households, have mothers on Medicaid, unmarried mothers, mothers with gestational hypertension, and unmarried maternal grandmothers; infants of NH whites were more likely to have mothers who smoked during pregnancy and mothers with gestational diabetes. The pattern of distribution among the categorical variables of gestational weight gain and prenatal care use were significantly different at $p < 0.05$, meaning they differed by race.

4.4.2 Mothers' birth weight and infant risk of low birth weight

A question of interest in this research is whether the contextual effects of GM neighborhood have an effect on infant risk of LBW alongside M neighborhood factors. The first step was to determine whether there exists a clustering of birth outcomes across both M neighborhoods and GM neighborhoods. In order to examine the components of variance in LBW1 that lie between M neighborhood and between GM neighborhood we tested an unconditional cross-classified model. The variance between M neighborhoods was $\tau_{b00} = 0.105$, while the variance between GM neighborhoods was $\tau_{c00} = 0.155$. The LR test which compares this unconditional cross-classified model to a single-level logistic regression model with no neighborhood effects was $\chi^2(1, n = 3) = 14.89, p < 0.001$ which suggests it is a better fit than a single-level model. We conclude that these $6{,}633$ infants do not act as independent observations, but are clustered in a higher-level cross-classified model. The LR test to compare the cross-classified model with a simpler two-level model with infants clustered within M neighborhoods, $\chi^2(1, n = 2) = 7.91,\ p = 0.005$, confirms that the M neighborhood variance is separately significant, and the LR test comparing the cross-classified model with a simpler two-level model with infants clustered within GM neighborhoods confirms a significant separate variance for GM neighborhood $\chi^2(1, n = 2) = 3.85,\ p = 0.05$. Infants born into the same M neighborhood are more alike than those from different M neighborhoods, and infants whose mothers were born into the same GM neighborhood are more alike those whose mothers were born into different GM neighborhoods.

The M neighborhood-level Variance Partition Coefficient (VPC) for the unconditional cross-classified model is $0.105/(0.105 + 0.155 + 3.29) = 0.0295$, and the GM neighborhood-level VPC is $0.155/(0.155 + 0.105 + 3.29) = 0.0437$. We see that 2.95% of variation in risk of LBW lies between M neighborhoods while 4.37% lies between GM neighborhoods. The VPCs show there is a low degree of clustering in the data, with a combined 7.32% at the M neighborhood and GM neighborhood levels. A caterpillar plot was used to examine the estimate of GM neighborhood effects from the unconditional model (Figure 17 in Appendix G). The estimates of u_j, the random effect of GM neighborhoods, are plotted with 95% confidence intervals and we see that the majority of the 578 GM neighborhoods do not differ significantly from the overall average, at the 5% level. Only 3 out of 578 differ significantly. We added level-1 covariates to the model, beginning with MBW, which we found to be a significant predictor of LBW1. The between-M neighborhood variable is now $\tau_{b00} = 0.082$, while the between-GM neighborhood variance is $\tau_{c00} = 0.092$. Comparing these estimates to the unconditional model reveals that MBW explains $\left(0.082 - 0.105/_{0.105} = -0.22\right)$ 22% of the M neighborhood variance and $\left(0.092 - 0.155/_{0.155} = -41\right)$ 41% of the GM neighborhood variance. We attempted to add all level-1 covariates which were statistically significant in bivariate analysis but the GM neighborhood random effect could not be estimated. As a result we proceeded to test a simpler 2-level model.

Based on our assumption that infants born into the same M neighborhood are more alike than infants born into different M neighborhoods, we fit the unconditional (null) HGLM model for LBW1. The results are in Table 18 below. The interpretation for these unit-specific estimates is as follows: in a M neighborhood with a ‘typical’ LBW1 rate i.e. a neighborhood with no random effect, $u_{0j} = 0$, the expected log-odds of LBW1 are $\hat{\beta}_0 = -2.59, se = 0.06$ which is an odds of LBW1 of $e^{-2.59} = 0.075$, which corresponds to a probability of $1/(1 + e^{[-(-2.59)]} = 0.07$. Assuming u_{0j} is normally distributed we would expect 95% of the M neighborhoods to have a u_{0j} value that lies within two standard deviations, approximately $\pm 2\sqrt{0.144} = \pm 0.759$. Thus we would expect the proportion of infants born with LBW1 to lie between $\left(e^{-2.59-0.759} / 1 + e^{-2.59-0.759}\right) = 0.03$ and $\left(e^{-2.59+0.759} / 1 + e^{-2.59+0.759}\right) = 0.14$ in the middle 95% of M neighborhoods.

Table 18. Low birth weight – Estimates for multilevel random intercept unconditional logistic regression

		Unit-Specific Model for low birth weight			
Fixed Effect	Coefficient	*se*	*exp(b)*	*z*	*p* - value
γ_{00}	-2.59	0.06	0.08	-42.33	<0.001

Random Effect	Variance Component	*se*	χ^2	*p*
u_{0j}	0.14	0.06	6.98	0.004

The intra-class correlation coefficient (ICC), which indicates the variance in LBW1 between M neighborhoods, was $\rho = 0.04$ representing a low clustering effect. LR statistic, based on Laplacian Approximation, tests the null hypothesis that the variance of the random effect $\hat{\sigma}^2_{u0} = 0$. The LR statistic, $\chi^2(1, n = 2) = 6.98, p = 0.004$, presents evidence that there is variation among M neighborhoods in LBW1 rates, which means a multilevel model accounting for clustering is appropriate.

A caterpillar plot was used to examine the estimates of M neighborhood effects from the unconditional model. The estimates of u_j are plotted with 95% confidence intervals and Figure 18 (in Appendix G) shows that none of the 350 M neighborhoods are significantly above or below the average LBW1 rate, at the 5% level. The confidence intervals are large due to small sample sizes within each M neighborhood.

We fit conditional models with level-1 covariates (explanatory variables). We assumed that MBW would predict infant risk of LBW1, and we grand-mean centered this predictor at 3,238.47 grams. The results from fitting a random intercept model (Model 1) are in Table 19.

Table 19. Low birth weight – Estimates of multilevel random intercept binary logistic regression, level-1 covariates

Fixed components	Model 1 β (SE)	Model 2 β (SE)	Model 3 β (SE)	Model 4 β (SE)
Intercept	-2.642 (0.061)**	-3.113 (0.118)**	-3.030 (0.123)**	-3.023 (0.123)**
Mother’s birth weight	-0.076 (0.008)**	-0.060 (0.008)**	-0.059 (0.008)**	-0.063 (0.009)**
Mother’s race		0.348 (0.119)**	0.455 (0.127)**	0.445 (0.127)**
Mother’s maternal age		0.016 (0.224)	0.017 (0.224)	0.008 (0.023)
Mother’ education		0.002 (0.026)	-0.034 (0.031)	-0.028 (0.031)
Medicaid		0.514 (0.117)**	0.504 (0.116)**	0.508 (0.116)**
Mother unmarried		0.277 (0.157)$^{+}$	0.172 (0.164)	0.160 (0.164)
Mother’s race*education			0.070 (0.033)*	0.060 (0.033)$^{+}$
Mother’s birth weight*age				-0.004 (0.002)*
Variance of random components				
$var(u_{0j})$	0.097 (0.060)	0.014 (0.054)	0.012 (0.054)	0.011 (0.054)
Number of observations	6,633	6,157	6,157	6,157

$^{+}$ <0.10 * <0.05 ** <0.01

The intercept estimate $\hat{\beta}_0 = -2.642$ is the estimated log-odds of LBW1 for an infant born to a mother with average MBW, born into a ‘typical’ M neighborhood. This corresponds to an odds of $e^{-2.642} = 0.07$ and $1/(1 + e^{[-(-2.642)]} = 0.066$ predicted probability of LBW1. There is a highly significant, negative effect of MBW $\hat{\gamma}_{10} = -0.076$ so we would expect a one-unit increase in MBW to decrease the odds of infant LBW1 by $e^{-0.076} = 0.93$, a 7% decrease, controlling for M neighborhood differences. In Figure 19 (in Appendix G), we present the predicted relationship between the log-odds of LBW1 and MBW across M neighborhoods. The lines are parallel, which corresponds with our assumption that the effect of MBW is linear and the same in each M neighborhood. To determine whether the effect of MBW differed by race we tested the interaction of race and MBW and it was not statistically significant, $p = 0.748$, indicating no difference by race. Additional level 1 covariates were added to the random intercept model (Model 2) and include mothers’ race, mothers’ maternal age, mothers’ education ratio, health insurance (Medicaid or private/self-pay), and mothers’ marital status (married or unmarried). MBW, mothers’ maternal age, and mothers’ education ratio, all continuous variables, were grand-mean centered. We notice a substantial decrease in the estimate of between-M neighborhood variance with the addition of the explanatory variables in Model 2, suggesting that the distribution of one or more of these covariates differs across M neighborhoods. Using histograms we looked at the distribution of the mean of the continuous variables (MBW, mothers' maternal age, and mothers' education ratio), and proportion of the categorical variables (mothers' race, Medicaid, and mothers' marital status) across M neighborhoods. We see from Figure 20 through Figure 25 (in Appendix G) that there is a large amount of between-M neighborhood variation in the mean/proportion of the covariates, with the exception of the proportion of births in M neighborhoods to NH black mothers. Approximately 250 of the 350 M neighborhoods had less than 5% of their births to NH black mothers, and about 50 M neighborhoods had about 95% of their births to NH black mothers.

Interaction terms were tested between all level-1 covariates (data not shown). The interaction between mothers' race and mothers' education ratio, and between MBW and mothers' maternal age were statistically significant and tested in subsequent models. When both are included in the model (Model 4) only the MBW*maternal age interaction term is signification at $p < 0.05$.

Table 20. Summary of model fit, multilevel binary logistic regression

Complex	*Log likelihood*	*Simpler*	*Log likelihood*	χ^2	*df*	*p value*
Model 1	-1719.176	Unconditional Model	-1764.7562	91.1604	1	< 0.001
Model 2	-1567.5985	Model 1	-1719.176	303.155	5	<0.001
Model 3	-1565.3622	Model 2	-1567.5985	4.4726	1	0.03
Model 4	-1563.3786	Model 3	-1565.3622	3.9672	1	0.046

For Model 4 the intercept estimate of $\hat{\gamma}_{00} = -3.023$ is the log-odds of LBW1 for an infant born to a married NH white mother, not on Medicaid, with average MBW, average educational attainment, average maternal age, and born into a 'typical' M neighborhood. This corresponds to an odds of $e^{-3.023} = 0.049$, which is a predicted probability of ${}^{1}\!/_{1 + e^{[-(-3.023)]}} = 0.046$. Having a mother on Medicaid, rather than private/self-pay insurance, is associated with a higher log-odds, $\hat{\gamma}_{50} = 0.508, \mathrm{z} = 4.38, p < 0.001$, of LBW1; infants are $e^{0.508} = 1.66$ times more likely to have LBW1, holding constant other predictors. NH blacks have higher log-odds of LBW1, $\hat{\gamma}_{20} = 0.445, \mathrm{z} = 3.51, p < 0.001$; compared with NH whites infants of NH black mothers are $e^{0.445} = 1.56$ times more likely to have LBW1, ceteris paribus. The log-odds of LBW1 were not related to mother's marital status.

Next we explored our MBW*maternal age interaction. A one-unit change in MBW yields a change in log-odds of $(\hat{\gamma}_{10} = -0.063) + (1 \times (\hat{\gamma}_{80} = -0.004)) = -0.067$, holding mother's grand-mean centered age = 1 (approximately 24.7 years) and other covariates constant. We would expect a 100 gram increase in MBW to decrease infant odds of LBW1 by $(e^{-0.067} = 0.935)$ 6.5%. However, when holding mother's grand-mean centered age $= -4$ (approximately 19.7 years), and other covariates constant, a one-unit change in MBW yields a change in log-odds of $(\hat{\gamma}_{10} = -0.063) + (-4 \times (\hat{\gamma}_{80} = -0.004)) = -0.047$. We would then expect a 100 gram increase in MBW to decrease infant odds of LBW by $(e^{-0.047} = 0.954)$ 4.6%. This interaction suggests a varying effect of MBW dependent on maternal age, although the main effect of maternal age is not statistically significant. We explored this interaction visually in Figure 11 below.

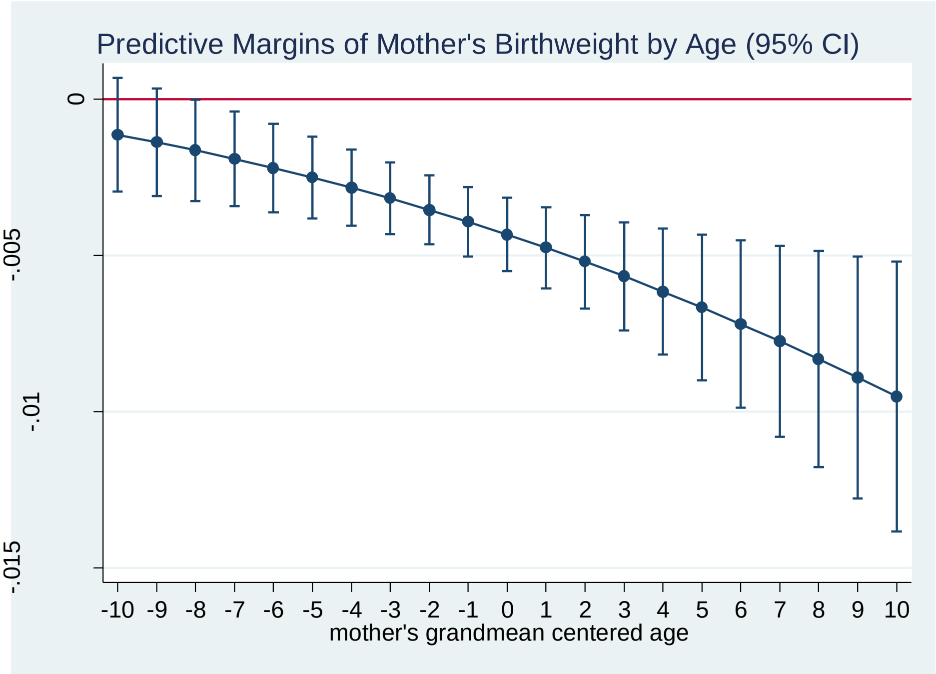

Figure 11. Effects on predictive means of mother's birth weight on infant risk of low birth weight, by mother's age

This plot demonstrates that the effect of an increase in MBW on decreasing LBW1 risk is not significantly different from zero at very low ages, that is, less than approximately 16.7 years, but increases with maternal age such that higher MBW among older mothers reduces infant risk of LBW1 more than it does for younger mothers. For Model 4, the VPC, calculated with the latent variable method (Goldstein, 2011; Merlo et al., 2006), is $0.01/(0.01 + 3.29) = 0.003$ which means 0.3% of the residual variance in the propensity of LBW1 can be attributed to unobserved M neighborhood characteristics. The VPC for the unconditional model in Table 18 was $0.14/(0.14 + 3.29) = 0.04$ which is 4%; a substantial portion of M neighborhood variance has been explained by level-1 covariates and their interactions. After building the level 1 model, we proceeded to test the following characteristics as predictors of the log-odds of LBW1: continuous variables of percentage of households in the lowest income tertile and percentage of residents that are NH black; categorical variables of neighborhood poverty and proportion NH black residents; log transformed local spatial racial residential segregation of black from white residents and local spatial economic segregation of low income from high income households. We explored the continuous variables for any nonlinear relationships with LBW1. See Table 21 for the random intercept model with only M neighborhood-level covariates included, controlling for race.

Table 21. Low birth weight – Estimates of multilevel random intercept binary logistic regression, level-2 covariates

Fixed components	Model 5 β (SE)	Model 6 β (SE)	Model 7 β (SE)
Intercept	-3.082 (0.117)**	-2.922 (0.072)**	-2.634 (1.060)*
Mother's race	0.637 (0.145)**	0.476 *0.142)**	0.753 (0.117)**
Random components			
Mothers' neighborhood black, continuous	-0.195 (0.293)		
Mothers' neighborhood poverty, continuous	1.166 (0.417)**		
Mothers' neighborhood black, categorical			
High		0.253 (0.194)	
Medium		0.273 (0.154)$^+$	
Low		Ref	
Mothers' neighborhood poverty, categorical			
High		0.269 (0.134)*	
Low		Ref	
Racial residential segregation			0.801 (0.731)
Economic segregation			-0.631 (0.390)
Variance of random components			
$var(u_{0j})$	0.016 (0.049)	2.76e-07 (0.001)	0.023 (0.051)
Number of observations	6,633	6,633	6,633

$^+$ <0.10 * <0.05 ** <0.01

Only the continuous and categorical measures of neighborhood poverty were statistically significant. However, once included in a model with all level-1 covariates none of the effects of the M neighborhood variables were statistically significant (data not shown). Model 4 is the final model for the HGLM binary logistic regression analysis.

We thought it interesting that the interaction mothers' race*maternal age was not statistically significant in these models. Based on the weathering hypothesis developed by A. Geronimus (Geronimus, 1996) and tested by other researchers (Love, David, Rankin, & Collins Jr, 2010; Rich-Edwards et al., 2003) we expected to see an increase in infant risk of LBW1 for NH black mothers and a relatively consistent risk of LBW1 for NH white mothers with increasing maternal age. In a process of exploration, we decided to run a HGLM model similar to Model 2 but excluding MBW and including the mothers' race*maternal age interaction. The interaction was significant, $p = 0.042$, and supports the weathering hypothesis. See Figure 12 for a visual representation of this interaction.

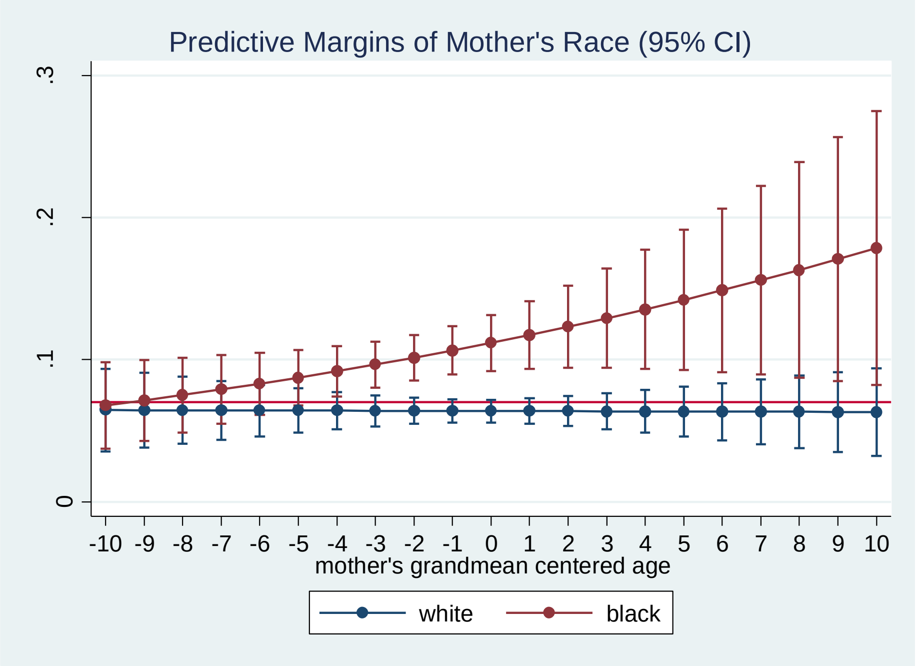

Figure 12. Predictive margins of the effect of mother's race on infant low birth weight by maternal age

Because the interaction represented in Figure 11 (MBW*maternal age) did not differ by mothers' race, and we did not find a significant race*maternal age interaction in our models, it may be reasonable to hypothesize that what appears to be a more rapid degradation of maternal health with increasing age for black mothers, due to a cumulative exposure to social and economic disadvantage, may be partly explained by black mothers having lower birth weights and thus their infants are more likely to experience an increase in the probability of LBW1 regardless of maternal age; and, NH black mothers are more likely to have children at younger ages and therefore less likely to benefit from the protective effect of higher MBW at older maternal ages.

4.4.3 Mothers' birth weight and infant risk of moderate and very low birth weight

We began our analysis of LBW as a multinomial variable by calculating the overall response probabilities in each LBW2 category. This model includes no predictors (unconditional model) and we get the following predicted response probabilities: the probability of MLBW = $\eta_{1ij} = e^{-2.824}/1 + e^{-2.824} + e^{-4.120} = 0.055$, the probability of VLBW = $\eta_{2ij} = e^{-4.120}/1 + e^{-2.824} + e^{-4.120} = 0.015$, and the probability of normal birth weight = $1 - 0.055 - 0.015 = 0.93$. As mentioned in the descriptive statistics section, infants of NH black mothers are more likely than those of NH white mothers to be MLBW or VLBW rather than be of normal birth weight. The relative risk of MLBW rather than normal birth weight was $e^{0.708} = 2.03$ times higher for NH blacks than for NH whites, while the relative risk of VLBW rather than normal birth weight were $e^{1.208} = 3.35$ times higher for NH blacks than NH whites.

The LR statistic tests the null hypothesis that the variance of the M neighborhood random effects for MLBW $\hat{\sigma}^2_{u0j(1)} = 0$ and for VLBW $\hat{\sigma}^2_{u0j(2)} = 0$. The LR statistic, $\chi^2(1, n = 3) = 9, p = 0.011$, presents evidence that there is variation among M neighborhoods in LBW2 rates, which means a multilevel model accounting for clustering is appropriate. We built our conditional models (see Table 22) by first including level-1 covariates (See Table 23 for summary of model fit). As we did in our binary logistic regression, we begin with MBW, in Model 1, which is grand-mean centered at $3{,}238.47$ grams. We find that higher MBW is associated with lower log-odds of MLBW, $\hat{\gamma}_{00(1)} = -0.081, t = -9.50, p < 0.001$, and VLBW, $\hat{\gamma}_{00(2)} = -0.056, t = -3.38, p < 0.001$, relative to normal birth weight. In Figure 27 (in Appendix G), we represent the predicted relationship between the log-odds of MLBW and MBW across M neighborhoods, and in Figure 28 (in Appendix G) the predicted relationship between the log-odds of VLBW and MBW across M neighborhoods. The MBW relationship with MLBW is, for the most part, the same across M neighborhoods, but the curvilinear relationship is suggestive of a quadratic slope. For VLBW the graph suggests that the relationship with MBW has a slight curvilinear relationship, and at lower levels of MBW there appears to be a noticeable difference in the relationship with VLBW across M neighborhoods.

Table 22. Low birth weight - Estimates for multilevel random intercept multinomial logistic regression models, level-1 covariates

Fixed components	Unconditional model β (SE)	Model 1 β (SE)	Model 2 β (SE)	Model 3 β (SE)
For MLBW				
Intercept	-2.810 (0.067)**	-2.878 (0.068)**	-3.264 (0.130)**	-3.227 (0.136)**
Mothers' birth weight		-0.081 (0.001)**	-0.067 (0.009)**	-0.072 (0.009)**
Mothers' race			0.272 (0.133)*	0.297 (0.145)*
Mothers' maternal age			0.015 (0.025)	0.001 (0.026)
Mothers' education ratio			0.003 (0.029)	-0.000 (0.035)
Medicaid			0.449 (0.130)**	0.452 (0.130)**
Mother unmarried			0.224 (0.172)	0.168 (0.180)
Mothers' race*education				0.010 (0.038)
Mothers' birth weight*age				-0.005 (0.002)*
For VLBW				
Intercept	-4.387 (0.184)**	-4.402 (0.182)**	-5.252 (0.314)**	-5.013 (0.318)**
Mothers' birth weight		-0.056 (0.017)**	-0.030 (0.018)$^{+}$	-0.022 (0.020)
Mothers' race			0.636 (0.252)*	1.019 (0.267)**
Mothers' maternal age			0.018 (0.048)	0.030 (0.048)
Mothers' education ratio			0.001 (0.055)	-0.141 (0.068)*
Medicaid			0.742 (0.249)**	0.716 (0.243)**
Mother unmarried			0.530 (0.362)	0.142 (0.376)
Mothers' race*education				0.243 (0.068)**
Mothers' birth weight*age				0.004 (0.004)
Variance of random components				
$var(u_{0j(1)})$	0.108 (0.071)	0.063 (0.067)	0.018 (0.066)	0.020 (0.066)
$var(u_{0j(2)})$	0.703 (0.330)	0.648 (0.320)	0.368 (0.319)	0.352 (0.318)
Number of observations	6,633	6,633	6,157	6,157

$^{+}$ <0.10 * <0.05 ** <0.01

We proceed to test for a quadratic curve in the relationship between the log-odds of LBW2 and MBW in Model 2 and include other level-1 covariates. The MBW^2 logit estimate is statistically significant, but of small effect, and the minimum point of the quadratic curve is extremely high and birth weights above that point are not common. As a results subsequent models do not include the quadratic term. In Model 2, we see NH black mothers and those in Medicaid have higher odds of MLBW (relative to normal birth weight), whereas higher MBW is associated with lower odds of MLBW. The estimate for mothers' race, $\hat{\gamma}_{20(1)} = 0.292, t = 2.04, p = 0.04$, would mean an infant born to a NH black mother relative to an infant born to a NH white mother would be expected to have an increase in relative risk of MLBW relative to normal birth weight by a factor of $e^{0.292} = 1.31$ which is a 31% increase in risk, controlling for all other covariates in the model. The logit estimate, $\hat{\gamma}_{50(1)} = 0.449, t = 3.44, p < 0.001$, suggests that for an infant whose mother was on Medicaid relative to an infant whose mother had private or self-pay health insurance, the relative risk of MLBW to normal birth weight would be expected to increase by a factor of $e^{0.449} = 1.57$, given all other covariates in the model. The MBW logit estimate remains significantly associated with lower odds of MLBW after the inclusion of other covariates, $\hat{\gamma}_{10(1)} = -0.067, t = -7.39, p < 0.001$, and can be interpreted to mean we would expect an increase in MBW to yield a decrease in the relative log-odds of being in the MLBW category versus the normal birth weight category. The relative risk of MLBW relative to normal birth weight would be expected to decrease by a factor of $e^{-0.067} = 0.93$, 7%, for a 100 gram increase in MBW.

In Model 2, NH black mothers and those on Medicaid have higher odds of VLBW (relative to normal birth weight). The estimate for mothers' race, $\hat{\gamma}_{20(2)} = 0.636, t = 2.53, p = 0.01$, would mean an infant born to a NH black mother relative to an infant born to a NH white mother would be expected to have an increase in relative risk of VLBW relative to normal birth weight by a factor of $e^{0.636} = 1.89$ which is a 89% increase in risk, controlling for all other covariates in the model. For mothers on Medicaid, $\hat{\gamma}_{50(2)} = 0.742, t = 2.99, p = 0.003$, relative to those with private/self-pay insurance their infants would have a relative risk of VLBW rather than normal birth weight that would increase by a factor of $e^{0.742} = 2.10$. This is a larger relative risk increase than for MLBW, a 110% increase in risk, ceteris paribus. Interestingly, MBW is no longer a significant predictor of VLBW odds after controlling for other covariates.

For Model 3 we added the interaction terms for MBW*maternal age and mothers' race*education ratio. The logit estimates for MLBW changed only very slightly and the interpretation the interpretation of the results is as follows: NH black mothers are 35% more likely and mothers on Medicaid 57% more likely to have MLBW infants relative to normal birth weight. The logit estimate for the mothers' race*education ratio interaction, $\hat{\gamma}_{70(1)} = 0.010, t = 0.26, p = 0.79$, is not statistically significant which means the effect of mothers' education on odds of MLBW do not differ by mothers' race. However, as in the binary logistic regression model, the logit estimate for the MBW*maternal age interaction is statistically significant, $\hat{\gamma}_{80(1)} = -0.005, t = -2.44, p = 0.01$. A one-unit change in MBW yields a change in log-odds of $\left(\hat{\gamma}_{10(1)} = -0.072\right) + (1 \times \left(\hat{\gamma}_{80(1)} = -0.005\right)) = -0.077$, holding mother's grand-mean centered age = 1 (approximately 24.7 years) and other covariates constant. We would expect a 100 gram increase in MBW to decrease infant odds of LBW1 by $(e^{-0.077} = 0.926)$ 7.4%. However, when holding mother's grand-mean centered age $= -4$ (approximately 19.7 years), and other covariates constant, a one-unit change in MBW yields a change in log-odds of $\left(\hat{\gamma}_{10(1)} = -0.072\right) + (-4 \times \left(\hat{\gamma}_{80(1)} = -0.005\right)) = -0.051$. We would then expect a 100 gram increase in MBW to decrease infant odds of LBW by $(e^{-0.051} = 0.951)$ 4.9%. This interaction demonstrates a varying effect of MBW dependent on maternal age.

For VLBW, the estimate for the interaction term mothers' race*education ratio, $\hat{\gamma}_{70(2)} = 0.243, t = 3.60, p < 0.001$, was statistically significant. For infants of NH black mothers, we would expect at 0.1-unit increase in the education ratio to yield a $\left(0.1 \times \left(\hat{\gamma}_{40(2)} = -0.141\right)\right) + \left(0.1 \times \left(\hat{\gamma}_{70(2)} = 0.243\right)\right) = 0.010$ change in log-odds of VLBW relative to normal birth weight. On the other hand, for infants of NH white mothers we could expect a 0.1-unit increase in the education ratio to yield a change in log-odds of $\left(0.1 \times \left(\hat{\gamma}_{40(2)} = -0.141\right)\right) = -0.014$. A 0.1-unit change in the education ratio corresponds to about 1.5 more years of school for mothers of average age. So for infants of NH black mothers we would expect the risk of VLBW, relative to normal birth weight, to change by a factor of $e^{0.010} = 1.01$ which is a 1% increase, while for infants of NH white mothers we would expect the relative risk ratio to change by a factor of $e^{-0.014} = 0.99$ which is a 1% decrease in relative risk of VLBW compared with normal birth weight. This is a very small effect, but should be explored in additional studies.

Table 23. Summary of model fit, multilevel multinomial logistic regression

Complex	*-2 Log likelihood*	*Simpler*	*-2 Log likelihood*	χ^2	*df*	*p value*
Model 1	3951.43	Unconditional Model	4045.42	93.99	2	<0.001
Model 2	3598.15	Model 1	3951.43	353.28	10	<0.001
Model 3	3579.10	Model 2	3598.15	19.05	2	<0.001
Model 7	3571.15	Model 3	3579.10	7.95	2	0.019

Table 24. Low birth weight - Estimates of multilevel random intercept multinomial logistic regression, level-2 covariates

	Model 4	Model 5	Model 6
	β (SE)	β (SE)	β (SE)
For MLBW			
Fixed components			
Intercept	-3.263 (0.122)**	-3.071 (0.082)**	-3.295 (1.176)**
Mother's race	0.480 (0.163)**	0.387 (0.164)*	0.614 (0.131)**
Random components			
Mothers' neighborhood black, continuous	-0.061 (0.326)		
Mothers' neighborhood poverty, continuous	1.100 (0.456)*		
Mothers' neighborhood black, categorical		0.184 (0.109)$^{+}$	
Mothers' neighborhood poverty, categorical		0.147 (0.145)	
Racial residential segregation			0.555 (0.812)
Economic segregation			-0.552 (0.433)
For VLBW			
Fixed components			
Intercept	-5.054 (0.304)**	-4.905 (0.221)**	-3.151 (2.349)
Mother's race	1.145 (0.295)**	0.833 (0.294)**	1.249 (0.251)**
Random components			
Mothers' neighborhood black, continuous	-0.518 (0.629)		
Mothers' neighborhood poverty, continuous	1.420 (0.954)		
Mothers' neighborhood black, categorical		-0.106 (0.202)	
Mothers' neighborhood poverty, categorical		0.941 (0.290)**	
Racial residential segregation			1.577 (1.608)
Economic segregation			-0.897 (0.862)
Variance of random components			
$var(u_{0j(1)})$	-	0.002 (0.060)	0.009 (0.062)
$var(u_{0j(2)})$	0.419 (0.282)	0.271 (0.267)	0.430 (0.283)
Number of observations	6,633	6,633	6,633

$^{+}$ <0.10 * <0.05 ** <0.01

After building the level 1 model, we proceeded to test the following characteristics as predictors of the log-odds of MLBW and VLBW: percent of households in the lowest income tertile and percent of residents that are black; categorical variables of neighborhood poverty and percent black residents; log transformed local spatial racial residential segregation of black from white residents, and local spatial economic segregation of low income from high income households.

See Table 24 above for multilevel multinomial logistic regression models with M neighborhood-level covariates, controlling for mothers' race at level-1. For MLBW, only the continuous measure of neighborhood poverty was statistically significant. We found that none of the neighborhood factors were significantly associated with infant risk of MLBW in the model including individual-level factors (data not shown). In the final multivariate model (see Table 25), MBW and Medicaid are statistically significant predictors of the relative risk of MLBW relative to normal birth weight. The reduction in odds of MLBW are dependent on maternal age, and being on Medicaid relative to private/self-pay insurance increases the odds of MLBW by 56%.

Table 25. Low birth weight - Estimates for multilevel random intercept multinomial logistic regression, level-1 and level-2 covariates

	Model 7	
	β (SE)	
	MLBW	VLBW
Fixed components		
Intercept	-3.246 (0.138)**	-5.073 (0.327)**
Mothers' birth weight	-0.071 (0.009)**	-0.021 (0.020)
Mothers' race	0.155 (0.186)	0.806 (0.328)*
Mothers' maternal age	0.001 (0.026)	0.034 (0.048)
Mothers' education ratio	0.001 (0.035)	-0.135 (0.068)*
Medicaid	0.445 (0.131)**	0.667 (0.243)**
Mother unmarried	0.158 (0.181)	0.082 (0.375)
Mothers' race*education	0.010 (0.038)	0.239 (0.067)**
Mothers' birth weight*age	-0.005 (0.002)*	0.003 (0.004)
Random components		
Mothers' neighborhood black, categorical	0.137 (0.115)	-0.102 (0.206)
Mothers' neighborhood poverty, categorical	-0.031 (0.156)	0.726 (0.297)*
Variance of random components		
$ar(u_{0j})$	0.017 (0.066)	0.206 (0.317)
Number of observations	6,157	

$^{+}$ <0.10 * <0.05 ** <0.01

For VLBW, only the categorical measure of M neighborhood poverty was statistically significant, and at the 1% level. When included in a model with all level-1 variables, living in a high poverty neighborhood was still significantly associated with the risk of VLBW, relative to normal birth weight. The level-1 logit estimates changed slightly in Model 7 compared with Model 3. The interpretation of the new results are that NH black mothers are 120% more likely, and mothers on Medicaid are 95% more likely, to have VLBW infants relative to normal birth weight. The logit estimate for high neighborhood poverty, $\hat{\gamma}_{02(2)} = 0.726, t = 2.45, p = 0.01$, tells us that for an infant who was born into a high poverty neighborhood, relative to an infant who was born into a low poverty neighborhood, the relative risk of VLBW to normal birth weight would be expected to increase by a factor of $e^{0.726} = 2.07$ given all covariates in the model. This is over a 100% increase in risk. Model 7 is the final model for LBW2 multinomial HGLM logistic regression.

4.4.4 Population attributable risk factor (PARF)

Assuming the relationship between MBW and infant birth weight is truly causal, and that the maternal LBW1 rates in this transgenerational dataset are representative of the County, then 8.67% of all MLBW infants are as a result of maternal LBW1. As a result of racial disparities in LBW, only 3.11% of all MLBW is as a result of maternal LBW1 for infants of NH white mothers, whereas the PARF is 13.3% for infants of NH black mothers.

4.5 DISCUSSION

4.5.1 Summary

In this study, low birth weight was examined both as a binary outcome variable of LBW1, as well as a multinomial outcome variable of LBW2, which included VLBW and MLBW. Both LBW1 and LBW2 had significant clustering at the neighborhood-level and hierarchical generalized linear modeling was used to analyze the data.

Individual-level factors of MBW, mothers' race, maternal age, mothers' education, Medicaid status, mothers' marital status, and interactions among some of these variables explain a substantial portion, approximately 89%, of the variance across neighborhoods in LBW1 rates. In the final multilevel binary logistic regression model we find that MBW, mothers' race, and Medicaid are statistically significant predictors of LBW1, after controlling for the other covariates. The significance of MBW is consistent with other studies that examine the generational transmission of risk for LBW1 (Chapman & Gray, 2014; J. Collins Jr et al., 2011). An increase in MBW reduces infant risk of LBW1, but the size of the reduction in odds is dependent on maternal age. The older the mother the larger the reduction in odds of low birth weight as a result of higher MBW. At very young ages higher MBW is not protective for LBW1. To our knowledge, this is the first study to report a maternal age-dependent relationship between MBW and LBW. As a result of this finding, it is possible that the high rates of LBW1 typically seen in young NH black mothers compared with similar aged NH white mothers (referred to as the weathering hypothesis) could be the result of NH black mothers having lower birth weight to begin with, and therefore more likely to have a LBW1 infant; and, having children at younger ages, thus not benefiting from the protective effect of higher MBW even if they had high birth weight. NH black mothers are 1.6 times more likely than NH white mothers to have LBW1 infants; and, mothers on Medicaid, relative to private/self-pay insurance, are 1.7 times more likely to give birth to an infant of LBW1.

The individual-level factors explained approximately 81% of the variance across mothers' neighborhoods in MLBW rates. In a multivariate model we find MBW, mothers' race, and Medicaid are significant predictors of MLBW. Infants of NH black mothers versus NH white mothers are 35% more likely, and infants of mothers on Medicaid versus private/self-pay insurance 57% more likely, to be MLBW than normal birth weight. Similarly to LBW1, the protective effect of higher MLBW varies with maternal age. Higher MBW reduces the odds of MLBW more than it does for the overall LBW1 category.

The individual-level factors explain about 50% of the variances across mothers' neighborhoods in VLBW rates. Medicaid and mothers' race are significant predictors of VLBW, but MBW is not. NH black mothers versus NH white mothers are 120% more likely, and mothers on Medicaid versus private/self-pay insurance 95% more likely, to have VLBW infants than normal birth weight, and the effect of mothers' educational attainment varies minimally by race.

None of the mothers' neighborhood variables tested in this study were significant predictors of the remaining variance of LBW1, and specifically MLBW, rates across mothers' neighborhoods. However, living in high poverty neighborhoods explains additional variance of VLBW rates across mothers' neighborhoods. The final multivariate model including neighborhood poverty explains 71% of the variance.

There is a significant racial disparity in LBW1 after adjusting for individual-level factors and their interactions, and there remains a significant racial disparity in VLBW rates even after accounting for individual- and neighborhood-level factors. However, the racial disparity in MLBW appears to be explained by the factors included in this study. The racial disparity in LBW1 is likely due to the VLBW category. Despite low percentages of VLBW infants out of all births, this is the group at highest risk for morbidity and mortality, and the category of LBW which has not experienced a substantial decline in rates over time. They are 100 times more likely than non-LBW infants to die during their first year of life (Mathews & MacDorman, 2013b). Conley & Bennett (2000) mentioned that the heritability of low birth weight may be lower among blacks; however, this was not found to be the case in this study.

4.5.2 Limitations and strengths

This study does not include paternal birth weight and thus only partly telling the story of the impact of parental biological factors on infant birth outcomes. We used birth records to obtain variables for our analyses, which do not always have reliably reported data. However, concerns typically arise with the maternal health and obstetric factors and these were not included in the multivariate analyses. Additionally, vital statistics have a high percentage of partially observed birth records. Deleting those records with missing data typically biases the results towards a lower risk sample. However, multivariate imputation is a way to address this issue. There were a low number of births per grandmothers' neighborhood, which could be responsible for the inability to obtain estimates of grandmothers' neighborhood variance in a model with level-1 covariates. Applying the criteria of ≥ 5 births per census tract for both mothers' and grandmothers' neighborhoods could produce different results and allow for exploration of the cross-classified data structure. Another limitation is that the mothers included in the dataset were fairly young; not including mothers within the full spectrum of reproductive age limits the generalizability of our findings.

A major strength of this study is that there are few transgenerational datasets that have been created in the United States (Chapman & Gray, 2014; J. Collins Jr et al., 2011; Emanuel et al., 1999) and doing so allowed the researchers the unique opportunity to add to the body of research examining the generational transmission of risk for LBW as a result of biology, and social and economic neighborhood context factors. Additionally, the focus on the subcategories of LBW (MLBW and VLBW) is a unique contribution to the field and presents the case for varied causal pathways for each, whereas looking at just LBW1, which is commonly done, would not expose these important differences. We were conservative in the inclusion of covariates in an attempt not to over-adjust our statistical models with factors that may be intermediate to the factors we intended to study.

4.5.3 Future research

There is need for research that examines the joint contribution of maternal and paternal birth weight in the transmission of risk for infant low birth weight. Including additional individual-level factors such as income and wealth would allow for a more accurate assessment of the impact of socio-economic status. There is a need for datasets which include information on the birth record as well as medical records; this will allow for the examination of biomedical covariates as mediators in this causal pathway between parental birth weight and/or neighborhood social and economic factors – this is largely missing in this area of research.

5.0 THE TRANSGENERATIONAL RISK FOR PRETERM BIRTH AMONG NON-HISPANIC BLACK AND WHITE MOTHERS: THE ROLE OF BIOLOGY AND GENERATIONAL SOCIAL AND ECONOMIC NEIGHBORHOOD CONTEXT

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5.1 ABSTRACT

Objectives: Racial/ethnic disparities in preterm birth (PTB) rates have persisted over time. Research has historically focused on maternal health behaviors and characteristics as predictors of PTB and racial/ethnic disparities. The objective of this study is to examine the risk of PTB as a result of maternal gestational age (MGA) and generational social and economic neighborhood conditions. *Methods*: Using a transgenerational dataset which includes infant birth records linked to mothers' birth records, logistic regression was used to model the risk of PTB, as well as its subgroups of late PTB (LPTB) and early PTB (EPTB). *Results*: MGA is a significant predictor of LPTB, but not EPTB, in multivariate models. Longer MGA reduces the odds of LPTB relative to term birth. Neighborhood poverty is a significant predictors of EPTB, but not LPTB; generational exposure to high neighborhood poverty increased the odds of EPTB relative to term birth by over 200%. Racial disparities in PTB were fully explained by the factors examined. *Conclusions*: More research is needed into the causal pathway between maternal and infant gestational age; and between generational neighborhood economic disadvantage and EPTB.

5.2 INTRODUCTION

In 2013 approximately 450,000 infants were born prematurely (before 37 completed weeks of gestation), this is 11.4% of all births (Hamilton et al., 2014). Worldwide the preterm birth (PTB) rate is about 11%. Although, as one might have suspected, the majority of these births are in the developing nations of sub-Saharan Africa and South Asia (almost 13%) the United States does not fare much better when compared with about a 9% PTB rate in other developed countries (Blencowe et al., 2012). Not only does the United States fare poorly on the international stage, disparities exist within the country such that 16.5% of infants born to non-Hispanic (NH) black mothers are born prematurely – a rate higher than the average of sub-Saharan African and South Asian countries – in contrast to 10.3% and 11.6% for infants of NH white and Hispanic mothers (Hamilton et al., 2014). Prematurity, and associated conditions, are responsible for about 35% of infant mortality rates nationally, the largest single cause of death, and account for about half of the racial/ethnic infant mortality disparity documented between NH white and NH black infants (Mathews & MacDorman, 2013a). In Allegheny County, Pennsylvania, the geographic location of focus for this research, prematurity and its associated conditions account for 60% of infant deaths, and the five leading causes of death mentioned above are responsible for 80% of infant deaths in the County (R. Voorhees, personal communication, November 26, 2014). PTB has near-term consequences for infants as well as long-term effects into adulthood. Neurological, pulmonary and ophthalmic disorders are associated with PTB (WHO, 2002). The majority of PTBs (70%) are spontaneous PTBs while the remainder are induced, whether medically indicated (intentionally induced by a medical professional) or iatrogenic (inadvertently induced by a medical professional).

Preterm labor (PTL) and preterm premature rupture of membranes (PPROM) are together considered to initiate the four causes of spontaneous PTB. Maternal and/or fetal stress, decidual-amnion-chorion inflammation, abruption-associated PTB, and mechanical stretching of the uterus are the causes of spontaneous PTB. Although these are the known causes, the majority of the time a specific cause cannot be determined (Goldenberg & McClure, 2010).

Research has historically focused much attention on only maternal health behaviors and characteristics as predictors of the incidence of PTB and as the reasons for racial/ethnic disparities. Important risk factors that have been identified to date include: history of delivering a premature infant, history of spontaneous abortion, “in utero exposure to diethylstilbestrol” (M. S. Kramer, 1987); demographic characteristics such as race, age, marital status and socioeconomic position; pre-pregnancy body mass index and physical activity; characteristics of current pregnancy including plurality, vaginal bleeding, volume of amniotic fluid, and medical conditions; stress; alcohol, tobacco, and substance use during pregnancy; and, infections. “Additional research that defines the mechanisms by which risk factors are related to PTB is crucial” (Goldenberg & McClure, 2010).

The study of social context as a covariate in the explanation of adverse births outcomes has increased over the years (Geronimus, 1986) and allows for the study of “the important role that the residential environment plays in shaping the psychosocial and physiological factors that lead to poor birth outcomes” (J. F. Bell et al., 2006). Mothers who reside in poor economic environments are more likely to be of lower socioeconomic position (Luo et al., 2006), to be recent immigrants to the country, to experience maternal morbidity during pregnancy (Urquia et al., 2007), and engage in risky behaviors such as substance use during pregnancy and receiving inadequate prenatal care (Fang et al., 1999; Reagan & Salsberry, 2005a). Living in a neighborhood with a poor economic environment (Ahern et al., 2003; P. O'Campo et al., 1997), a high proportion of low educational attainment, and a high proportion of black residents is associated with a higher prevalence of PTB and risky behaviors, such as smoking during pregnancy (Nkansah-Amankra, 2010; Pickett et al., 2002) compared to women residing in more economically advantaged and predominantly white neighborhoods.

The birth outcome of the mother as well as the neighborhood context into which the mother was born have been found to have an independent and significant impact on the birth outcome of her infant. The birth of the NH black mother into an affluent neighborhood, despite the affluence of the neighborhood in which she resides during adulthood has modest, yet stable, protective effects for her infant (J. W. Collins Jr, David, et al., 2009). NH black women born into poverty and who live in poverty in adulthood (lifelong impoverishment) have the highest risk of delivering a preterm infant, compared with women who experience upward economic mobility in adulthood. This is likely due, in part, to lower risk characteristics among those who experience upward economic mobility – they are more likely to be married, to have lower parity, to be older, less likely to smoke during pregnancy, and more likely to have received adequate prenatal care (J. W. Collins Jr et al., 2011).

Although there is a high recurrence of PTB among siblings, researchers have found the intergenerational transmission of PTB to be low between mother and offspring (Klebanoff, Schulsinger, Mednick, & Secher, 1997; Magnus et al., 1993). Some have found maternal gestational age to have a significant independent but negative relationship with infant birth weight, and paternal gestational age to be suggestive of a negative association but not statistically significant (Alberman et al., 1992). Others have found that mothers born preterm are more likely to give birth to preterm infants; with the data suggesting a stronger association for nulliparous women, as well as for the generational transmission of spontaneous PTBs, specifically, compared to medically indicated PTBs (Bhattacharya et al., 2010). However, much more research is needed in this area.

Despite what might be a small effect of biology in the transmission of PTB, we believe the exclusion of the health and social/economic status of parents and grandparents in the examination of birth outcomes paints an incomplete picture of the determinants of health and disparities. The health of prior generations may explain better the racial disparities in birth outcomes than do the current social and economic conditions (Conley & Bennett, 2000). As a result, the purpose of this study is to examine the risk of PTB as a result of maternal gestational age and generational social and economic neighborhood context.

5.3 METHODS

5.3.1 Study population

As a result of close ties between the University Of Pittsburgh Graduate School Of Public Health and the Allegheny County Health Department, the research team initiated a research project with the assistance of the acting director at the time. A total of 7,213 infant birth records from 2009-2011 were successfully linked to their mother's birth records from 1979-1998 in Allegheny County, Pennsylvania. This study was approved by the Institutional Review Board of the University of Pittsburgh. Excluded were birth records of infants with congenital anomalies, whose maternal grandmothers were not black or white, as well as whose mothers were not NH black or NH white, based on our inclusion/exclusion criteria; we removed infants with gestational age less than 20 weeks, in order to include only viable births; and, we excluded birth records in census tracts with less than 5 births per racial group, in order to have sufficient births to examine neighborhood clustering. The latter criteria was applied only to the mothers' neighborhood (2009-2011) resulting in 350 census tracts representing mothers' neighborhoods (M neighborhoods). No minimum births per census tract were required for the 578 maternal grandmothers' (GM) neighborhoods (1979-1998). For inclusion in this research, birth records has to include race/ethnicity, infant gestational age, maternal gestational age, or census tract code. The final dataset included 6,592 linked records. The overall percentage of infant PTB was significantly lower for the records maintained in the final dataset (8.19%) when compared with the excluded observations for which we had PTB status (9.51%), $\chi^2(1, n = 2) = 695.43, p < 0.001$. No county-wide comparison data were available for this dataset.

5.3.2 Study variables

For purposes of distinction, the 2009-2011 birth records are referred to as the infant birth records while the 1979-1998 birth records are referred to as the mothers' birth records. The infant birth records include infant birth outcomes along with maternal and paternal characteristics, while the mothers' birth records include the mothers' birth outcomes and the maternal grandparents' characteristics. Of interest are infant risk of preterm birth (PTB1 = 1 if yes, PTB1 = 0 if no). Among PTB infants, those born earlier are at higher risk. So we are also interested in EPTB, LPTB, and term birth, which are coded PTB2 = 2, PTB2 = 1, PTB2 = 0, respectively. EPTB is < 34 weeks and LPTB 34-36 weeks completed gestation. PTB used without either a 1 or 2 in front of it, will denote preterm birth more generally, rather than as either a binary or multinomial variable. Mothers' gestational age (MGA) is the main predictor and is included as a continuous variable so that the interpretation of a one-unit change in the variable is equal to a one-week change in gestational age. We included the following covariates for the mothers: race, marital status, Medicaid (versus private/self-pay health insurance), educational attainment (a ratio of education achieved compared with education expected at maternal age), neighborhood racial composition and racial residential segregation, and neighborhood low income and economic segregation. For maternal grandparents we included marital status, educational attainment, neighborhood racial composition, and neighborhood low income. The individual-level factors included were only those significantly correlated with PTB1 in bivariate analysis; all neighborhood-level factors were tested because they are relevant to the objective of the study. A full description of the neighborhood variables has been published elsewhere (Chapter Four).

Data on health and obstetric factors such as chronic (pre-pregnancy) hypertension, gestational hypertension, chronic diabetes, gestational diabetes, vaginal bleeding, smoking during first trimester, adequacy of prenatal care utilization, and adequacy of gestational weight gain were available on the birth records. However, these were not included in the analyses because of concerns with reliability of the variables (DiGiuseppe et al., 2002), and to avoid over-adjustment in statistical models with variables that could be in the causal pathway (Schisterman et al., 2009).

5.3.3 Statistical analysis

We performed logistic regression with a logit link function to examine predictors of PTB, with PTB as both a binary (PTB1) and multinomial (PTB2) outcome variable. As previously mentioned, we believed that this transgenerational dataset had a hierarchical data structure, in that infants at level-1 are nested within M neighborhoods and GM neighborhoods at level-2. However, before proceeding to analyze the data in this manner we tested this assumption with a hierarchical generalized linear modeling (HGLM) unconditional model, that is, a model with no covariates. We found no significant clustering of PTB by neighborhood and proceeded with single-level logistic regression for PTB1 and PTB2. We were interested in differences by race in risk of PTB in order to better understand the perpetuation of racial disparities. So as part of our descriptive statistics we calculated the log-odds of PTB1 by mothers' race. To begin answering the question as to whether MGA is a predictor of offspring PTB, we included MGA in the models. To determine whether within-race models were appropriate we tested the interaction between MGA and race. Finding no statistically significant difference in the impact of MGA on odds of PTB1 by race, we opted to run models adjusting for race. We proceeded to run logistic regression models with MBW and race, and controlling for potential confounders. We followed a similar model-building approach when examining PTB2, using multinomial logistic regression.

Interaction terms between the covariates were explored and included if statistically significant and demonstrating an improvement in model fit. We used Likelihood Ratio (LR) tests to assess improvement in model fit during the model building process, and statistical significance was determined using $p < 0.05$. All statistical analyses of PTB1 used binomial logistic regression with maximum likelihood approximation with Stata, version 13.1, software (Stata Corporation, College Station, Texas) `logit` command, while statistical analyses of PTB2 used multinomial logistic regression with maximum likelihood approximation using the `mlogit` command.

5.4 RESULTS

5.4.1 Descriptive statistics

In this transgenerational birth file, NH black mothers are significantly more likely to have had shorter gestational age at birth ($M = 38.61$ weeks, $SD = 2.39$) than NH white mothers ($M = 39.47$ weeks, $SD = 1.72$), $p < 0.001$. The overall rate of PTB1 among the mothers was 7.34%; with 4.91% among those born to white mothers and 13.82% among those born to black mothers (the grandmothers of the infants in this birth file). Comparing mothers born to black and white grandmothers, the odds of them being born PTB1 were 3.11 times higher for blacks than for whites ($p < 0.001$). Infants of NH white mothers were significantly more likely to have longer gestational ages ($M = 38.96$ weeks, $SD = 2.03$) than infants of NH black mothers ($M = 38.57$ weeks, $SD = 2.368$), $p < 0.001$. The overall PTB1 rate among infants was 8.21%; with 7.37% among infants of NH whites and 10.33% among infants of NH black mothers. Comparing infants of NH black and white mothers, the odds of being born PTB1 are 1.45 times as high for infants of NH black mothers as for NH white mothers ($p < 0.001$).

Overall, 6.63% of infants were born LPTB and 1.58% were born EPTB. Among NH white mothers, 6.23% of infants were LPTB and 1.14% were EPTB; among NH black mothers, 7.64% of infants were LPTB and 2.69% were EPTB. This difference in distribution of PTB2 by race is statistically significant, $\chi_1^2 = 25.54, p < 0.001$. The overall relative risk of LPTB relative to term birth is 0.07, while the relative risk of EPTB relative to term birth is 0.02. For NH white mothers, infant relative risk of LPTB is 0.07 and for EPTB 0.01, relative to term birth; while for NH black mothers, infant relative risk of LPTB is 0.09 and for EPTB 0.03, relative to term birth.

Infants of NH black and NH white mothers were found to differ on a number of individual-level and neighborhood-level factors, including MGA, mothers' educational attainment, mothers' maternal age, grandmothers' maternal age, and grandmothers' educational attainment, all of which were lower among

NH blacks. Infants of NH blacks were more likely to live in M and GM neighborhoods with a high percentage of black residents and low income households, have mothers on Medicaid, unmarried mothers, mothers with gestational hypertension, and unmarried maternal grandmothers; infants of NH whites were more likely to have mothers who smoked during pregnancy and mothers with gestational diabetes. The pattern of distribution among the categorical variables of gestational weight gain and prenatal care use were significantly different at $p < 0.05$, meaning they differed by race.

5.4.2 Mothers' gestational age and infant risk of preterm birth

It was our assumption that infants born into the same M neighborhood are more alike than infants born into different M neighborhoods, as to their risk of PTB, and so first we fit the HGLM unconditional model for PTB1. The results are in Table 26 below.

Table 26. Preterm birth – Estimates for multilevel random intercept unconditional logistic regression

		Unit-Specific Model for low birth weight			
Fixed Effect	Coefficient	*se*	*exp(b)*	*z*	*p* - value
γ_{00}	-2.43	0.05	0.09	-47.05	<0.001

Random Effect	Variance Component	*se*	χ^2	*p*
u_{0j}	0.03	0.05	0.47	0.2475

The interpretation for unit-specific estimates is as follows: for M neighborhood with a 'typical' preterm birth rate, i.e. M neighborhood with no random effect, $u_{0j} = 0$, the expected log-odds of PTB1 is $\hat{\beta}_0 = -2.43, se = 0.05$. The odds of PTB1 are $e^{-2.43} = 0.088$, which corresponds to a probability of $1/(1 + e^{[-(-2.43)]} = 0.08$. The intercept for M neighborhood j is $-2.43 + u_{0j}$, where u_{0j} is estimated as $\hat{\sigma}_{u_0}^2 = 0.03$. Assuming u_{0j} is normally distributed we would expect 95% of the M neighborhoods to have a u_{0j} value that lies within two standard deviations of the mean of zero, approximately $\pm 2\sqrt{0.033} = \pm 0.361$. We would expect the proportion of infants who are PTB1 to lie between

$\left(e^{-2.43-0.361}/_{1+e^{-2.43-0.361}}\right) = 0.06$ and $\left(e^{-2.43+0.361}/_{1+e^{-2.43+0.361}}\right) = 0.11$ in the middle 95% of M neighborhoods. The intra-class correlation coefficient (ICC), which indicates the variance in PTB1 between M neighborhoods, was $\rho = 0.01$ representing a low clustering effect. A caterpillar plot is used to examine the estimate of M neighborhood effects from the unconditional model. The estimates of u_j are plotted with 95% confidence intervals and Figure 29 (in Appendix H) shows that all M neighborhood confidence intervals overlap the line at zero and thus no $\hat{u}_j$ differs significantly from the average at a 5% level. The LR test, based on Laplacian Approximation, tests the null hypothesis that the variance of the random effect $\hat{\sigma}_{u0}^2 = 0$. The LR test, $\chi_1^2 = 0.47, p = 0.2475$, suggests that the between-M neighborhood variance in log-odds of PTB1 is not significantly different from zero and thus HGLM is not required and a single level model would be appropriate. We proceed with a single-level logistic regression model. First we begin by including MGA as the predictor of PTB1. The LR test, $\chi_1^2 = 13.19, p < 0.001$, tells us that this model is better than a null model. MGA is grand-mean centered at 39.22 weeks, and its logit estimate, $\hat{\beta}_1 = -0.077, se = 0.020, p < 0.001$, indicates that a one-unit increase in MGA yields a decrease in log-odds of PTB1 which corresponds to an odds of $e^{-0.077} = 0.93$, a 7% decrease.

In Figure 13 we show the relationship between the predicted probability of PTB1 and MGA and notice that as MGA increases the confidence intervals get smaller, because there are more births in the higher gestational ages, and the probability of PTB1 decreases. The red horizontal line is the overall probability of PTB1 and for an infant whose mother has at least a mean MGA (which corresponds to being born at term) the probability of PTB1 drops below the average. So mothers who were themselves preterm are more likely to give birth to preterm infants. To determine whether the effect of MGA differed by race we tested the interaction of race and MGA and it was not statistically significant, $p = 0.911$, indicating no difference by race. Due to the slight curvature in the slope we tested the square of MGA (MGA^2) to determine whether it was a quadrature curve. MGA^2 was only marginally significant $p = 0.059$ and not included in subsequent models. We then added all level-1 covariates which were significantly associated with PTB1 in bivariate analysis, in a stepwise process.

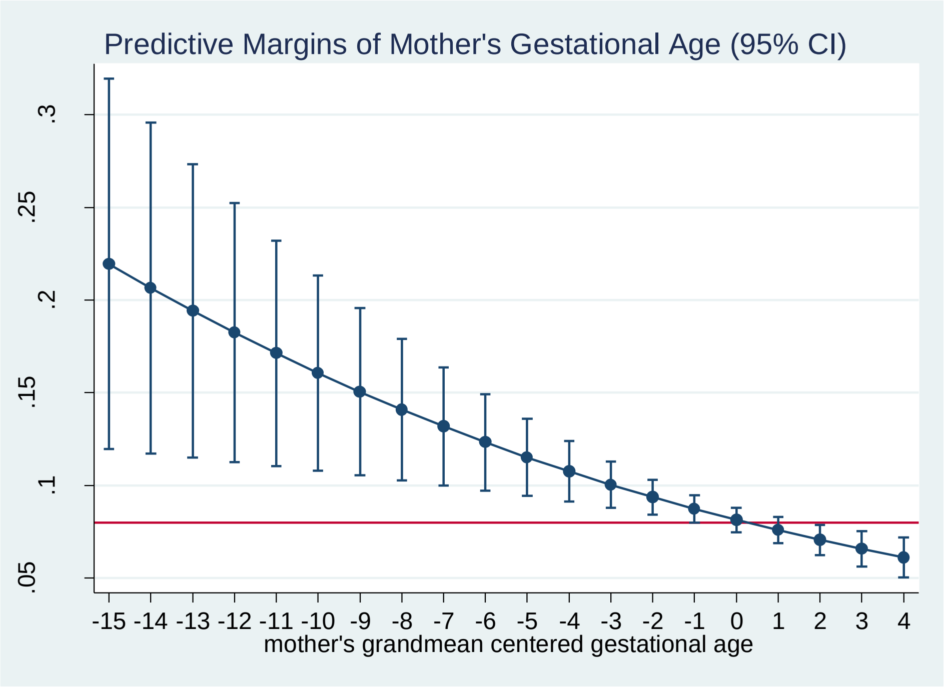

Figure 13. Predicted probability of preterm birth by mothers' gestational age

In Models 1 through 4 in Table 27 the main effect of MGA remains significant, whereas mothers' race is no longer significant after adjusting for Medicaid. Mothers' educational attainment, mothers' and grandmothers' marital status, and grandfathers' educational attainment are not significantly associated with the log-odds of PTB1 in Model 4. We find that through the model building process each model has a better fit than the simpler model before it (see Table 28).

Table 27. Preterm birth – estimates for binomial logistic regression model building

	Model 1 β (SE)	Model 2 β (SE)	Model 3 β (SE)	Model 4 β (SE)
Mothers' gestational age	-0.077 (0.020)**	-0.063 (0.021)**	-0.063 (0.021)**	-0.064 (0.023)**
Mothers' race		0.310 (0.097)**	0.256 (0.107)*	0.128 (0.137)
Mothers' education			-0.016 (0.014)	0.011 (0.018)
Medicaid				0.288 (0.118)*
Mother unmarried				0.115 (0.143)
Grandmother unmarried				0.138 (0.136)
Grandmothers' education				-0.107 (0.049)*
Grandfathers' education				-0.018 (0.048)
Number of observations	6,592	6,952	6,578	5,663

$^{+}$ <0.10 * <0.05 ** <0.01

Table 28. Summary of model fit, binomial logistic regression

Complex	*Log likelihood*	*Simpler*	*Log likelihood*	*χ^2*	*df*	*p value*
Model 2	-1858.9221	Model 1	-1863.9425	10.04	1	0.002
Model 3	-1852.2671	Model 2	-1858.9221	13.31	1	<0.001
Model 4	-1581.2449	Model 3	-1852.2671	542.04	5	<0.001

We can make the following conclusions about Model 4. Once we account for the other factors, mothers' race is no longer significant, suggesting racial disparities have been explained by these factors. Having a mother who is unmarried and a maternal grandmother who was unmarried are not related to infant log-odds of PTB1, holding other covariates constant. Changes in mothers' educational attainment and maternal grandfathers' education are also not associated with log-odds of PTB1. However, having a mother on Medicaid is associated with a higher log-odds of PTB1, $\hat{\beta}_4 = 0.288, \mathrm{z} = 2.44, p = 0.02$, such that the odds change by a factor of $e^{0.288} = 1.33$, holding constant other predictors, which is a 33% increase. MGA has an estimated log-odds of $\hat{\beta}_1 = -0.064, z = -2.80, p = 0.005$, which means a one-unit increase can be expected to change the odds ratio by $e^{-0.064} = 0.94$, which means a 6% decrease in odds of PTB1. The logit estimate for grandmothers' educational attainment is $\hat{\beta}_7 = -0.107, z = -2.18, p = 0.03$ and so we would expect a 0.1-unit increase to change in the log-odds of PTB1 by a factor of $e^{-0.0107} = 0.99$ odds ratio – a 1% decrease in odds of PTB1.

In order to better visualize the relationship between MGA and the predicted probabilities of PTB1 across a variety of covariate contributions we created Figure 30 (in Appendix H). The three lines are the 25th, 50th, and 75th percentiles of the aggregate covariate contribution. We see that the relationship between MGA and probability of PTB1 is largely independent of the aggregate contribution of the remaining covariates in the model, but see a slight increase in the effect of MGA when the covariate contribution is high (75th percentile). The main effects of Medicaid and grandmothers' education on the probability of PTB1 do not vary across a variety of covariate contributions – the change in the predicted probability is the same at the 25th, 50th, and 75th percentiles.

After building the model with individual-level covariates, we proceeded to test the following neighborhood-level characteristics as predictors of the log-odds of PTB1: continuous variables of percentage of households in the lowest income tertile and percentage of residents that are black; categorical variables of neighborhood poverty and percent black residents; log transformed local spatial racial residential segregation of black from white residents, and local spatial economic segregation of low income from high income households. In bivariate analyses we found statistically significant correlations at $p < 0.05$ for mothers' neighborhood medium percent black residents versus low percent black residents ($r = 0.03$) for infants of NH whites; no neighborhood characteristics were statistically significant for infants for NH black mothers. When included in the logistic regression models with individual-level factors none of the neighborhood characteristics were statistically significant (data not shown), and therefore Model 4 is the final binary logistic regression model.

5.4.3 Mothers' gestational age and infant risk of late and early preterm birth

We began our multinomial logistic regression by calculating the overall response probabilities in each PTB2 category. This model includes no predictors (null model) and we get the following predicted response probabilities: the probability of LPTB = $\eta_{1ij} = e^{-2.823}/1 + e^{-2.823} + e^{-4.156} = 0.055$, the probability of EPTB = $\eta_{2ij} = e^{-4.156}/1 + e^{-2.823} + e^{-4.156} = 0.015$, and the probability of term birth = $1 - 0.055 - 0.015 = 0.93$. As mentioned in the descriptive statistics there are differences in risk by racial group. The risk ratio of LPTB, relative to term birth, is expected to be 1.27 times higher for infants of NH blacks, $p = 0.03$, while the relative risk of EPTB is expected to be 2.44 times higher for infants of NH black mothers compared with NH white, $p < 0.001$. We proceed with single-level multinomial logistic regression and model the relationship between MGA and PTB2.

Model 1 in Table 29 shows the results of the model including MGA as a predictor and the findings are that the logit estimate, $\hat{\beta}_{1(1)} = -0.070, z = -3.16, p = 0.002$, for a one-unit increase in MGA is associated with a decrease in the relative log-odds of being in the LPTB versus term birth category. The relative risk ratio of a one-week increase in MGA is $e^{-0.070} = 0.93$, a 7% decrease, for being LPTB versus term birth. The logit estimate, $\hat{\beta}_{1(2)} = -0.103, z = -2.54, p = 0.011$, for a one week increase in MGA is associated with a decrease in the relative log-odds of being in the EPTB versus term birth category. The relative risk ratio of this one-week increase in MGA is $e^{-0.103} = 0.90$, a 10% decrease, for being EPTB versus term birth. We see in Figure 14 below that the probabilities of LPTB and EPTB decrease with an increase in MGA. However, the slope of MGA in the EPTB graph is less steep, thus having a smaller effect on the reduction in probability. We build our model in a step-wise manner as we did for PTB1.

Table 29. Preterm birth – estimates for multinomial logistic regression model building

	Model 1 β (SE)	Model 2 β (SE)	Model 3 β (SE)	Model 4 β (SE)
LPTB				
Mothers' gestational age	-0.070 (0.022)**	-0.063 (0.023)**	-0.057 (0.024)*	-0.068 (0.025)**
Mothers' race		0.178 (0.109)	0.006 (0.128)	0.094 (0.154)
Mothers' education			-0.010 (0.017)	0.000 (0.020)
Medicaid			0.287 (0.118)*	0.243 (0.131)$^{+}$
Mother unmarried				0.018 (0.156)
Grandmother unmarried				0.002 (0.151)
Grandmothers' education				-0.105 (0.054)$^{+}$
Grandfathers' education				-0.054 (0.053)
EPTB				
Mothers' gestational age	-0.103 (0.041)*	-0.066 (0.042)	-0.049 (0.045)	-0.048 (0.049)
Mothers' race		0.828 (0.203)**	0.630 (0.242)**	0.230 (0.284)
Mothers' education			0.018 (0.034)	0.051 (0.039)
Medicaid			0.650 (0.235)**	0.460 (0.254)$^{+}$
Mother unmarried				0.646 (0.356)$^{+}$
Grandmother unmarried				0.670 (0.294)*
Grandmothers' education				-0.122 (0.106)
Grandfathers' education				0.147 (0.108)
Number of observations	6,592	6,592	6,122	5,663

$^{+}$ <0.10 * <0.05 ** <0.01

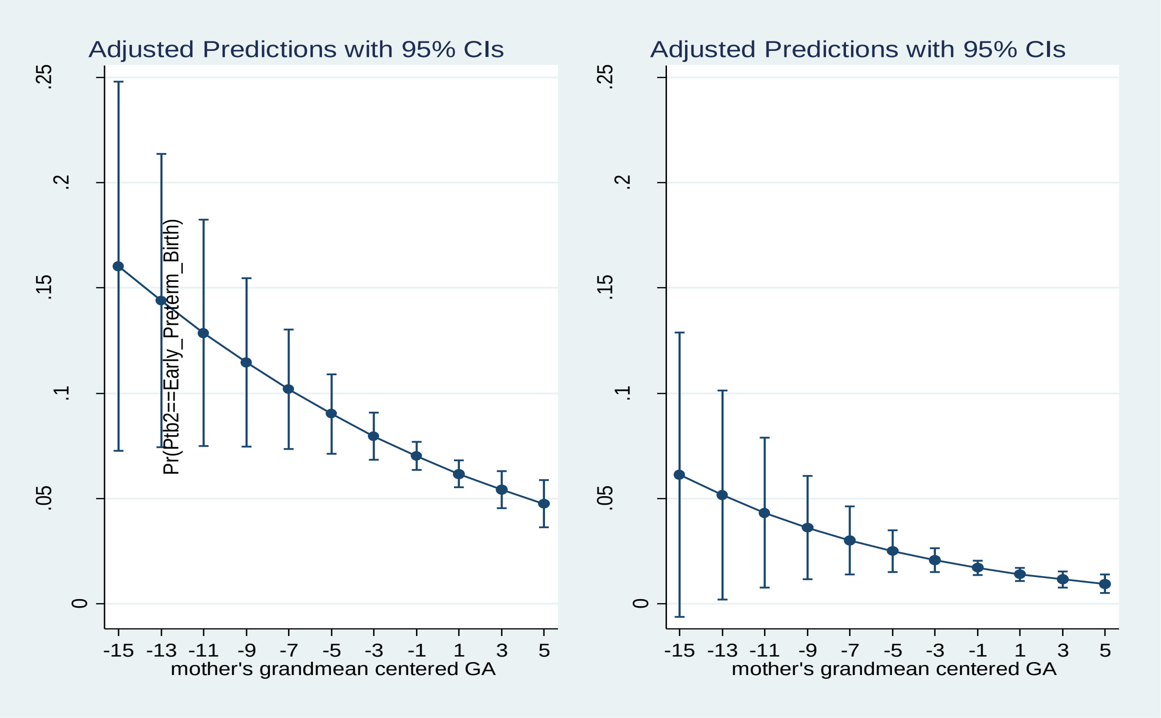

Figure 14. Predicted probabilities by mothers' gestational age, for late preterm birth and early preterm birth

For LPTB, MGA remains significantly associated with the multinomial log-odds in all models. In Model 4 the logit estimate, $\hat{\beta}_{1(1)} = -0.068, z = -2.71, p = 0.007$, can be interpreted to mean we would expect an increase in MGA to yield a decrease in the relative log-odds of being in the LPTB versus term birth category. The relative risk ratio of a one-week increase in MGA is $e^{-0.068} = 0.93$, a 7% decrease, for being LPTB versus term birth, holding all other variables constant. There is no change in relative risk as calculated in Model 1, suggesting the effect of MGA is unaffected by the other covariates included.

The logit estimate for MGA, $\hat{\beta}_{1(2)} = -0.048, z = -0.97, p = 0.332$, is not significant in the EPTB models after covariates are added. The only logit estimate that is statistically significant at $p < 0.05$ is maternal grandmothers' marital status, $\hat{\beta}_{6(2)} = 0.670, z = 2.28, p = 0.022$. This suggests that infants with maternal grandmothers who were unmarried relative to those who were married would be expected to have their relative risk of EPTB relative to term birth increase by a factor of $e^{0.670} = 1.95$, a 95% increase.

As with grandmothers' educational in the PTB1 models, grandmothers' marital status here likely captures the social and economic support of the mother in childhood.

After including all the individual-level factors we began to test neighborhood-level covariates. See Table 30 for multinomial logistic regression models with M and GM neighborhood-level covariates, controlling for mothers' race. Racial residential segregation and economic segregation were not significantly associated with either LPTB or EPTB (data not shown). For LPTB, only living in a medium percent black M neighborhood was statistically significant. None of the M or GM neighborhood factors were significantly associated with infant risk of LPTB in the multivariate models including individual-level factors. For EPTB, the continuous and categorical measures of M neighborhood poverty, and the categorical measure of GM neighborhood poverty were statistically significant. As a result we tested the economic mobility variable as well (see Table 31). For LPTB, although generational economic mobility is not statistically significant in Model 9, Medicaid and grandmothers' educational attainment, which were marginally significant in Model 4 are not significant at $p < 0.05$.

Table 30. Preterm birth - Estimates of multinomial logistic regression, neighborhood-level covariates

For LPTB	Model 5 β (SE)	Model 6 β (SE)	Model 7 β (SE)	Model 8 β (SE)
Individual-level factors				
Mother's race	0.240 (0.163)	0.055 (0.174)	0.132 (0.158)	0.141 (0.178)
Neighborhood-level factors				
Mothers' neighborhood black, continuous	-0.071 (0.334)			
Mothers' neighborhood poverty, continuous	0.121 (0.455)			
Grandmothers' neighborhood black, continuous		0.135 (0.274)		
Grandmothers' neighborhood poverty, continuous		0.351 (0.369)		
Mothers' neighborhood black, categorical				
High			0.292 (0.217)	
Medium			0.370 (0.158)*	
Low			Ref	
Grandmothers' neighborhood black, categorical				
High				0.198 (0.207)
Medium				0.003 (0.175)
Low				Ref
Mothers' neighborhood poverty, categorical				
High			-0.213 (0.143)	
Low			Ref	
Grandmothers' neighborhood poverty, categorical				
High				-0.053 (0.119)
Low				Ref

Table 30. Preterm birth – Estimates of multinomial logistic regression, neighborhood-level covariates (continued)

For EPTB				
Individual-level factors				
Mother’s race	0.796 (0.294)**	0.619 (0.313)*	0.573 (0.298)$^+$	0.525 (0.331)
Neighborhood-level factors				
Mothers’ neighborhood black, continuous	-0.764 (0.603)			
Mothers’ neighborhood poverty, continuous	1.852 (0.853)*			
Grandmothers’ neighborhood black, continuous		-0.176 (0.497)		
Grandmothers’ neighborhood poverty, continuous		1.266 (0.729)$^+$		
Mothers’ neighborhood black, categorical				
High			-0.322 (0.395)	
Medium			-0.264 (0.332)	
Low			Ref	
Grandmothers’ neighborhood black, categorical				
High				0.058 (0.375)
Medium				-0.067 (0.341)
Low				Ref
Mothers’ neighborhood poverty, categorical				
High			0.922 (0.288)**	
Low			Ref	
Grandmothers’ neighborhood poverty, categorical				
High				0.768 (0.265)**
Low				Ref
Number of observations	6,952	6,952	6,952	6,592

$^+$ <0.10 * <0.05 ** <0.01

In this final model, the interpretation of the estimates is as follows: a one-week increase in MGA is expected to reduce the odds of LPTB relative to term birth by 7%; a mother on Medicaid rather than private/self-pay insurance is ($e^{0.269} = 1.31$) 31% more likely to have a LPTB, relative to term, infant; and, a 0.1-unit increase in grandmothers’ educational attainment is expected to reduce the infants’ odds of LPTB by $(0.1 \times (-0.107) = -0.0107, e^{-0.0107} = 0.99)$ 1%. None of the individual-level factors remain significantly associated with EPTB after including generational poverty. Infants whose families have lived in high neighborhood poverty for two generations had higher log-odds of EPTB relative to term birth when compared with infants whose families lived in low poverty neighborhoods, $1.124, z = 3.06, p = 0.002$. We would expect infants whose families have lived in high poverty areas for generations to have their risk of EPTB, relative to term birth, increase by a factor of $e^{1.124} = 3.08$, which is a 208% increase.

Table 31. Preterm birth - Estimates for multinomial logistic regression, individual- and neighborhood-level covariates

	Model 9 β (SE) LPTB	 EPTB
Individual-level factors		
Mothers' gestational age	-0.069 (0.025)**	-0.046 (0.049)
Mothers' race	0.227 (0.169)	-0.184 (0.302)
Mothers' education	-0.004 (0.021)	0.064 (0.039)
Medicaid	0.269 (0.132)*	0.387 (0.255)
Mother unmarried	0.049 (0.157)	0.508 (0.364)
Grandmother unmarried	0.037 (0.153)	0.525 (0.293)$^+$
Grandmothers' education	-0.107 (0.054)*	-0.118 (0.105)
Grandfathers' education	-0.064 (0.053)	0.184 (0.109)$^+$
Neighborhood-level factors		
Generational economic mobility		
High-low	-0.121 (0.145)	0.266 (0.363)
Low-high	-0.168 (0.235)	-0.107 (0.638)
High	-0.351 (0.179)$^+$	1.124 (0.368)**
Low	Ref	Ref
Number of observations	5,663	

$^+$ <0.10 * <0.05 ** <0.01

5.4.4 Population attributable risk factor (PARF)

Assuming the relationship between maternal gestational age and infant gestational age is truly causal, and that the maternal PTB rates in this transgenerational dataset are representative of the County, then 3.68% of all LPTB infants are as a result of maternal PTB. Due to racial disparities in PTB, only 1.33% of all LPTB is as a result of maternal PTB for infants of NH white mothers, whereas the PARF is 7.77% for infants of NH black mothers.

5.5 DISCUSSION

5.5.1 Summary

In the final PTB1 model we find that MGA, Medicaid and maternal grandmothers' educational attainment are significant predictors of PTB1. Longer MGA and higher grandmothers' educational attainment are protective for infant risk for PTB1, while having a mother on Medicaid increases infant risk of PTB1. The statistically significant role of MGA indicates a potential heritability of PTB1 risk, with a one-week increase in MGA associated with a 6% decrease in odds of PTB1. This study includes MGA as a continuous variable while other studies may look at maternal PTB1, earlier studies have found maternal preterm birth not to be associated with infant preterm birth after adjusting for covariates (Castrillio, Rankin, David, & Collins, 2014; Klebanoff et al., 1997; Selling, Carstensen, Finnstrom, & Sydsjo, 2006). Contrary to those findings, even when examining maternal PTB1, instead of a continuous variable, we find a statistically significant adjusted odds of infant PTB1. Medicaid is a measure of individual-level poverty and captures many factors associated with low income status. Infants with mothers on Medicaid were 1.3 times more likely to be PTB1 than their counterparts whose mothers had private/self-pay insurance. Grandmothers' educational attainment, is a measure of the mothers' socioeconomic status (SES) during childhood, and is significant even after adjusting for mother' educational attainment. Grandmothers' education is suggestive of a minimal, but statistically significant, residual effect of higher SES in one generation being protective for the next generation. This finding is similar to that of an earlier study which found mothers' childhood SES, as measured by grandmothers' education and income, to have an indirect causal relationship with infant low birth weight mediated by mothers' adult SES (Gavin, Hill, Hawkins, & Maas, 2011). None of the mothers' or grandmothers' neighborhood characteristics are significantly associated with the odds of preterm birth in multivariate models.

In the final multivariate model, MGA is the only significant predictor of LPTB, relative to term birth, from among the variables tested in this analysis. A one-week increase in MGA decreases the odds of

LPTB by 7%, and this effect on the relative risk of LPTB appears unmitigated by other covariates included in the model. The association between MGA and PTB1, therefore, could be the result of the biological contribution of MGA to LPTB specifically, and not preterm birth generally. None of the neighborhood characteristics were significantly associated with the risk of LPTB.

MGA was not significantly associated with EPTB, relative to term birth, but generational exposure to high poverty neighborhoods, relative to low poverty neighborhoods, was associated with a 208% increased risk of EPTB, relative to term birth. Interestingly, none of the other individual-level factors were significant predictors of the relative risk of EPTB in the multivariate model. The racial disparity in both the binary and multinomial measures of preterm birth were explained by the variables included in this study.

5.5.2 Limitations and strengths

This study does not include paternal gestational age and thus only tells part of the story of the impact of parental biological factors on infant birth outcomes. We used birth records to obtain variables for our analyses, which do not always have reliably reported data. However, concerns typically arise with the maternal health and obstetric factors and these were not included in the multivariate analyses. Additionally, vital statistics have a high percentage of partially observed birth records. Deleting those records with missing data typically biases the results towards a lower risk sample. However, multivariate imputation is a way to address this issue. Another limitation is that the mothers included in the dataset were fairly young; not including mothers within the full spectrum of reproductive age limits the generalizability of our findings. And, research into generational, or life course, perinatal health may be best suited for structural equation modeling which is designed for the testing of causal relationships. Including both the mother' and maternal grandmothers' covariates in the model may mask the indirect effects that would otherwise be observed.

A major strength of this study is that there are few transgenerational datasets that have been created in the United States (Porter, Fraser, Hunter, Ward, & Varner, 1997) and as a result doing so allowed the researchers the unique opportunity to add to the body of research examining the generational transmission of risk for preterm birth as a result of biology, and social and economic neighborhood context factors. We were conservative in the inclusion of covariates in an attempt not to over-adjust our statistical models with factors that may be intermediate to the factors we intended to study.

5.5.3 Future research

There is need for research that examines the joint contribution of maternal and paternal gestational age in the transmission of risk for infant preterm birth. None of the socio-demographic factors were significantly associated with early and late preterm birth in multivariate models, which could be the result of including a limited number of variables to assess socioeconomic position, for example. Including additional individual-level factors such as income and wealth could allow for a more accurate assessment of the impact of socioeconomic status.

More research is needed to determine the pathway through which parental gestational age affects infant gestational age, with a focus on spontaneous preterm births. The former will require the testing of theory on the biological role of fetal programming on birth outcomes of offspring, and the latter will require access to medical records with more detailed health and obstetric factors. Other researchers have found generational poverty to be a risk factor for preterm birth (J. W. Collins Jr et al., 2011); in this study we found this to be the case only for early preterm birth, but not for late preterm birth. There is a need for further research to explore this finding.

6.0 SUMMARY OF FINDINGS

6.1 SUMMARY OF RESEARCH AIM 1

The first aim of this research was to perform a systematic review and meta-analysis of the literature on neighborhood social and economic context and the adverse birth outcomes of PTB and LBW. We found that studies that controlled for mothers' race/ethnicity in the statistical model were less likely to find a statistically significant association between PTB/LBW and neighborhood disadvantage. However, studies that performed statistical models separately for each racial/ethnic group were likely to find that neighborhood disadvantage was significantly associated with an increase in odds of PTB and LBW for infants of both NH white and NH black mothers, but with smaller effects for NH blacks.

Fewer than half of the studies used a theoretical framework/theory or mentioned a specific conceptual model. Because of interest in the role of neighborhood context above and beyond individual-level variables, and acknowledging the possibility of residents within a neighborhood being more like each other than like those of other neighborhoods, almost 40% of studies performed multilevel multivariate regression. Almost 50% performed multivariate regression which does not account for the hierarchical nature of the data, although almost a third of those studies attempted to account for the clustering of infants born to mothers living in the same census tract.

More than a third of studies ran within-race/ethnicity analyses as was recommended by some researchers. The study of the interaction between individual-level and neighborhood-level variables, or even between individual-level variables, was not commonplace, even though such interactions have been found to be significant. Only a third of the studies explored such interactions, despite their significance in other studies. For the majority of articles, analysis at the neighborhood-level was typically conducted with the use of census tracts as the geographical unit of analysis. The neighborhood predictors used varied, the most common being poverty, deprivation, racial residential segregation or racial composition, and crime.

Through the meta-analysis we found that studies that controlled for mothers' race/ethnicity in the statistical model were not likely to find a statistically significant association between PTB/LBW and neighborhood disadvantage. However, studies that perform statistical models separately for each racial/ethnic groups were likely to find that neighborhood was significantly associated with PTB and LBW for infants of both NH white and NH black mothers, albeit with smaller effects for NH blacks. NH white mothers in the most disadvantaged neighborhoods were about 1.5 times and 1.6 times more likely to have PTB and LBW infants, respectively, compared with NH white mothers resident in the least disadvantaged neighborhoods. NH black mothers in the most disadvantaged areas were about 1.2 times more like to have PTB and LBW infants, relative to their counterparts in the least disadvantaged areas.

6.2 SUMMARY OF RESEARCH AIM 2

The second aim of this research was to examine of the impact of MBW and intergenerational neighborhood social and economic context on infants' risk of LBW. The following hypotheses were proposed and the findings from the research mentioned:

Hypothesis I: A mother of lower birth weight will tend to have an infant of LBW, even after controlling for socio-demographic factors. *Finding*: An increase in MBW reduces the odds of infant LBW, even after controlling for mothers' race, maternal age, educational attainment, Medicaid, and marital status. LBW infants can be of either MLBW or VLBW; and we found that MBW is not significantly associated with the risk of VLBW, but only the risk of MLBW, relative to normal birth weight.

Hypothesis II: Infants of NH white mothers will have a stronger association between infant LBW and MBW compared with NH black mothers. *Finding:* Using an interaction term between MBW and race to test this hypothesis, the effect of MBW on infant odds of LBW1 did not differ significantly by race.

Hypothesis III: The relationship between MBW and infant LBW is mediated by maternal health and obstetric factors such as pre-pregnancy BMI, weight gain during pregnancy, gestational/chronic diabetes mellitus, gestational/chronic hypertension, and vaginal bleeding. *Finding:* For the purposes for this dissertation research it was not possible to carry out mediation analysis as intended. The un-imputed dataset has a high percentage of missing health and obstetric data which were hypothesized to mediate the relationship between MBW and infant LBW. Performing the analysis would likely have resulted in significantly biased parameter estimates and "invalid estimates of precision" (J. R. Carpenter et al., 2011). After performing multiple imputation the mediation analysis will be explored.

Hypothesis IV: There is a significant contextual effect of M neighborhood characteristics which explains the variation in LBW rates across neighborhoods. *Finding:* After adjusting for individual-level factors, which explained the majority of the variation in the binary measure of LBW and MLBW rates by mothers' neighborhood, there were no statistically significant contextual effects of mothers' neighborhood characteristics. However, neighborhood poverty explained a significant amount of variation in VLBW rates across mothers' neighborhoods.

Hypothesis V: There is a significant additive contextual effect of grandmothers' neighborhood characteristics which explains the variation in LBW rates across neighborhoods. *Finding:* There was low, but significant clustering of LBW1 rates across neighborhoods and they were cross-classified across mothers' and grandmothers' neighborhoods. However, after adjusting for individual-level factors the variance across grandmothers' neighborhoods could not be estimated and a simpler two-level model was used for analyses. This prevented the researchers from examining any contextual effects of grandmothers' neighborhood characteristics.

6.3 SUMMARY OF RESEARCH AIM 3

The third aim of this research was to examine of the impact of MGA and intergenerational neighborhood social and economic context on the infants' risk of PTB. The following hypotheses were proposed and the findings from the research mentioned:

Hypothesis I: A mother of lower gestational age is more likely to have a preterm infant, even after controlling for socio-demographic factors. *Finding*: Longer MGA reduces odds of infant PTB, even after controlling for mothers' race, educational attainment, Medicaid, and marital status; along with maternal grandparents' marital status and educational attainment. PTB infants can be of either LPTB or EPTB, and we found that MGA is not significantly associated with the risk of EPTB, but only the risk of LPTB, relative to term birth.

Hypothesis II: Infants of NH white mothers will have a stronger association between infant PTB and MGA compared with NH black mothers. *Finding:* Using an interaction term between MGA and race, the effect of MGA on infant odds of PTB1 did not differ significantly by race.

Hypothesis III: The relationship between MGA and infant PTB is mediated by maternal health and obstetric factors such as pre-pregnancy BMI, weight gain during pregnancy, gestational/chronic diabetes mellitus, gestational/chronic hypertension, and vaginal bleeding. *Finding:* As mentioned in the Summary of Research Aim 2, for the purposes for this dissertation research it was not possible to carry out mediation analysis as intended.

Hypothesis IV: Mothers' neighborhood characteristics are significantly associated with infant risk for PTB. *Finding:* After adjusting for individual-level factors there were no significant effects of mothers' neighborhood characteristics on infant odds of PTB.

Hypothesis V: Grandmothers' neighborhood characteristics are, in addition to mothers' neighborhood characteristics, significantly associated with infant risk for PTB. *Finding:* Generational neighborhood poverty was the main predictor of EPTB, relative to term birth, but no neighborhood characteristics were significantly associated with the odds of LPTB or PTB generally.

6.4 LIMITATIONS

The parental information used in this transgenerational dataset only includes data from the mother and omits the contribution of paternal gestational age and birth weight, as well as socio-demographic factors that could be of significance. Previous research has found both maternal and paternal birth weight to be significantly associated with infant risk of LBW and PTB, albeit to varying degrees.

This transgenerational dataset excludes women who did not give birth to a live singleton infant and thus they may differ from those whose risk associated with having poor birth outcomes themselves resulted in their premature death or the loss of their infant due to miscarriage, for example. This research study is based on birth record data which lacks detailed and, sometimes, consistently collected obstetric information and inaccuracies in the reporting of birth weight and gestational are a possibility. Lastly, individual-level income, and other individual-level socioeconomic position data, is not available on United States birth records. Additionally, being that the data used in this study are not from experimental studies we cannot prove a causal relationship between offspring birth outcomes and MBW/MGA or neighborhood poverty.

7.0 CONCLUSION

The United States is a race-conscious society which has a history of social inequality along racial lines. Social inequality is woven into the fabric of this society in a way that should not be ignored in the study of health and health disparities. To begin explaining this we will use concepts from Camara Jones' 'Gardner's tale'. Assuming there were no discriminatory actions against any one group on the basis of race it is the assumption of some that all groups would have equal opportunity to excel in society. If that were the case, and if social inequality does in fact cause disparities in birth outcomes, we would expect the disappearance of disparities in birth outcomes. Since slavery has been abolished, some argue that discrimination based on race is no longer an issue. And yet we still have health disparities, in more areas than birth outcomes. Now even if race-based discrimination no longer existed, according to Jones there would still exist institutional racism. The social and economic histories of NH white and NH black populations in this county are very different and so a change in social dynamics in the present day would not correct the initial historical insult(s) that occurred; thus it is reasonable to posit that the impact of these histories would continue to shape the status of those groups into the future, assuming no compensatory actions were made (Jones, 2000). NH white, NH black and Hispanic mothers live in different neighborhood contexts such that they have very limited shared experiences and are therefore differentially exposed to stressors. Despite decades of medical innovation and public health interventions we still see the double and triple increased risk of PTB and LBW for black infants compared to white infants. Receipt of timely prenatal care has increased (Kogan et al., 1998), smoking during pregnancy has decreased (Kleinman & Kopstein, 1987), and college educational attainment has increased (McDaniel, DiPrete, Buchmann, & Shwed, 2011), for example. These are viewed as protective factors but the degree of any protective effects obtained varies by race and neighborhood context. Link and Phelan believe that socioeconomic status determines where people live and their neighborhoods bring with them health-enhancing or health-degrading circumstances as part of a "package deal" (Phelan & Link, 2013). According to Krieger "[LBW] as an embodied expression of social inequality reflects socially patterned exposures" and "since birth weight is clearly dependent on the social circumstances, nutritional status, and health of mothers, there are potentially important intergenerational influences on health" (Krieger & Davey Smith, 2004).

Through the lens of the ecosocial theory and Link and Phelan's fundamental causes of disease, the findings of this intergenerational research contribute to the body of work that is exploring the simultaneous interplay of current and historical biological and social conditions. We found that biology plays an important role in the risk of MLBW and LPTB in our sample, and this relationship remained significant regardless of the other covariates included in the model. The results also showed that social and economic neighborhood context has an important role. Neighborhood poverty is associated with the risk of VLBW and EPTB even after adjusting for individual-level factors; however, it should be noted that substance abuse and mental health, for example, were not included in the analyses but have been identified as risk factors. The study of transgenerational data holds a lot of promise for the examination of perpetuated racial disparities that have been documented for decades when studied through the perspective of epigenetics and cultural transmission. This research found racial disparities in LBW to persist despite adjusting for individual- and neighborhood-level factors, but the racial disparity in PTB was fully explained by the factors examined in this study. Statistically ‘explaining’ racial disparities can be different from explaining their genesis and so more research into causal pathways would be a logical next step; however, the findings of this research stand alone and establish a firm foundation on which to further explore intergenerational factors.

What was not found in this research was an association between birth outcomes and racial residential segregation or economic segregation. Allegheny County is a very segregated County (Deitrick & Brienm, 2014). As a result, the lack of a statistically significant finding likely speaks more to the segregation measure than the theory behind segregation’s impact on health.

7.1 NEXT STEPS FOR RESEARCHERS

There is a need for more intergenerational research studies of birth outcomes to include paternal factors (Alberman et al., 1992; Coutinho, David, & Collins, 1997). Some researchers have argued that only the maternal behavioral factors during pregnancy have an influence on the health of the infant, but the argument for the importance of the biological contribution of both parents would be difficult to challenge. Fetal programming is proposed as a factor that might explain the generational transmission of LBW and PTB risk. There is a need for further research into the mechanisms of fetal programming as they relate to LBW or PTB, in order to appropriately select the parental birth outcome potentially responsible for the infant outcomes; for example, does MBW cause LBW and MGA cause PTB, or does MBW cause both LBW and PTB, or is there a role for intrauterine growth retardation?

There is a scarcity of articles that include a measure of maternal health as a covariate. When included, very few have anything extensive on the woman's health other than parity and gravidity. In studies examining the role of socioeconomic status/neighborhood context in PTB/LBW it is rare to find history of preterm delivery, pre-pregnancy BMI, adequacy of weight gained during pregnancy, the inter-pregnancy interval, chronic diseases, or whether the delivery was medically indicated included as covariates – confounders or mediators. This is likely due to the preponderant use of vital birth records where access to this kind of information is limited due to missing or unreliably reported data. There is a need for hospital medical records to supplement the birth records for more reliable analysis of these health and obstetric factors. When maternal health factors are included, they tend to be analyzed as confounders rather than potential mediators. There is a need for mediation analysis into the causal relationship between parental birth outcomes and offspring birth outcomes, as well as analysis of the way in which generational disadvantage has an indirect pathway to infant risk of poor birth outcomes.

There is a need for research into the intergenerational transmission of risk for LBW and PTB among racial/ethnic groups other than NH whites and NH blacks in the United States; a few researchers have created datasets that would allow for such research (Emanuel et al., 1999). Population groups such as Hispanics and Asians, and the subgroups therein, are increasing in size and it is important for perinatal and social epidemiologists to have an understanding of the heritability of poor birth outcomes among the diversity of population groups present in this country. Taking it a step further, adding an additional generation to the intergenerational study of birth outcomes could elucidate even more so the genesis of racial/ethnic disparities in birth outcomes.

Although a logistical challenge, having access to birth records of foreign-born mothers would allow researchers to study the effect that social and economic disadvantage in the United States has on immigrant groups and perhaps tease out the biological from the social factors when it comes to the genesis of disparities. One could tackle the question as to whether the intergenerational transmission of risk for

PTB/LBW differs among immigrant racial/ethnic groups and whether this varies from what we see in native-born groups.

It is my postulation that the persistent exposure to harsh social and economic environments negatively affects the human physiology and psychology in ways that induce the body to deliver LBW and premature infants. Although this could be protective in that it removes the infant from uterine exposure to stress it also results in an underdeveloped infant who is at risk for numerous morbidities and even mortality. It is imperative that as public health researchers we begin to conceptualize strategies to prevent the transmission of LBW and PTB risk. There is a lot of research that still remains to be done and questions that remain unanswered, but while tackling those we should propose interventions based on current knowledge that could prevent poor birth outcomes.

7.2 PUBLIC HEALTH PRACTITIONERS AND HEALTHCARE PROVIDERS

This research presents the case for the possibility that VLBW and EPTB are the result of primarily economic disadvantage rather than a genetic component. Confirmation of this through additional research would be mean that these high risk births can be prevented (Klebanoff et al., 1997) and we could see a reduction in infant deaths and racial disparities. It would be in the purview of public health practitioners to develop interventions that would moderate the effect of economic disadvantage on these birth outcomes. The particular interventions that could effectively accomplish this feat would depend on additional research

Assuming a biological pathway between parental and infant birth outcomes, the collection of parental birth weight and gestational age as part of the prenatal screening could aid the health care providers in more comprehensively assessing infant risk. Under the premise that maternal birth outcomes affect her risk for chronic conditions and health/obstetric factors in adulthood, and that maternal behaviors can moderate either the effect of MBW/MGA on the health factors and/or the effect of the health factors on infant birth outcomes, using the tools of bioinformatics, an algorithm of sort could be created to incorporate these various factors and propose areas for intervention that could reap the largest impact. Taking this approach could result in more informed recommendations for women during the perinatal period.

APPENDIX A: BIVARIATE ANALYSES OF COMPLETE AND PARTIALLY OBSERVED DATA

The association between mother's race and infant low birth weight status was significant for both complete and incomplete birth records χ^2 (1, N = 2,345) = 43.60, $p < 0.001$, and χ^2 (1, N = 4,288) = 35.47, $p < 0.001$, respectively.

Mother's race = NH white

Infant LBW status	Complete birth records	Incomplete birth records	Total
Normal birth weight	1,908 (95.21%)	2,579 (93.61%)	4,487 (94.28%)
Low birth weight	96 (4.79%)	176 (6.39%)	272 (5.72%)
Total	2,004 (100%)	2,755 (100%)	4,759 (100%)

χ^2 (1, N = 4,759) = 5.50, p = 0.019

Mother's race = NH black

Infant LBW status	Complete birth records	Incomplete birth records	Total
Normal birth weight	293 (85.92%)	1,355 (88.39%)	1,648 (87.94%)
Low birth weight	48 (14.08%)	178 (11.61%)	226 (12.06%)
Total	341 (100%)	1,533 (100%)	1,874 (100%)

χ^2 (1, N = 1,874) = 1.60, p = 0.206

There is a statistically significant difference in LBW rates in complete and incomplete birth records for NH white mothers whose incomplete births records have higher rates of LBW. For NH black mothers, rates of LBW did not differ by completeness of data.

The association between mother's race and infant preterm birth status was significant for both complete and incomplete birth records $\chi_1^2 = 11.60, p = 0.001$, and $\chi_1^2 = 5.22, p = 0.022$, respectively.

Mother's race = NH white

Infant PTB status	Complete birth records	Incomplete birth records	Total
Term birth	1,867 (93.40%)	2,517 (92.06%)	4,384 (92.63%)
Preterm birth	132 (6.60%)	217 (7.94%)	349 (7.37%)
Total	1,999 (100%)	2,734 (100%)	4,733 (100%)

$\chi_1^2 = 3.01, p = 0.083$

Mother's race = NH black

Infant PTB status	Complete birth records	Incomplete birth records	Total
Term birth	298 (88.17%)	1,369 (90.01%)	1,667 (89.67%)
Preterm birth	40 (11.83%)	152 (9.99%)	192 (10.33%)
Total	338 (100%)	1,521 (100%)	1,859 (100%)

$\chi_1^2 = 1.01, p = 0.314$

There is a marginally significant difference in PTB rates between complete and incomplete birth records for NH white mothers, with incomplete birth records having slightly higher PTB rates. For NH black mothers, PTB rates did not differ between complete and incomplete birth records.

The association between mother's race and marital status was significant for both complete and incomplete birth records χ^2 (1, N = 2,345) = 360.24, $p < 0.001$, and χ^2 (1, N = 4,285) = 767.58, $p < 0.001$, respectively.

Mother's race = NH white

Mother's marital status	Complete birth records	Incomplete birth records	Total
Married	1,272 (63.47%)	1,164 (42.30%)	2,436 (51.22%)
Unmarried	732 (36.53%)	1,588 (57.70%)	2,320 (48.78%)
Total	2,004 (100%)	2,752 (100%)	4,756 (100%)

χ^2 (1, N = 4,756) = 208.13, $p < 0.001$

Mother's race = NH black

Mother's marital status	Complete birth records	Incomplete birth records	Total
Married	28 (8.21%)	40 (2.61%)	68 (3.62%)
Unmarried	313 (91.79%)	1,493 (97.39%)	1,806 (96.37%)
Total	341 (100%)	1,533 (100%)	1,874 (100%)

χ^2 (1, N = 1,874) = 25.03, $p < 0.001$

Marital status differs between incomplete and complete birth records among both NH white and NH black mothers, whose incomplete birth records are more likely to be of unmarried mothers.

There is no association between mother's race and infant's gender for both complete and incomplete birth records χ^2 (1, N = 2,345) = 1.69, $p = 0.193$, and χ^2 (1, N = 4,288) = 0.042, $p = 0.838$, respectively.

Mother's race = NH white

Infant gender	Complete birth records	Incomplete birth records	Total
Female	999 (49.85%)	1,373 (49.84%)	2,372 (49.84%)
Male	1,005 (50.15%)	1,382 (49.84%)	2,387 (50.16%)
Total	2,004 (100%)	2,755 (100%)	4,759 (100%)

χ^2 (1, N = 4,759) = 0.0001, $p = 0.993$

Mother's race = NH black

Infant gender	Complete birth records	Incomplete birth records	Total
Female	157 (46.04%)	769 (50.16%)	926 (49.41%)
Male	184 (53.96%)	764 (49.84%)	948 (50.59%)
Total	341 (100%)	1,533 (100%)	1,874 (100%)

χ^2 (1, N = 1,874) = 1.90, $p = 0.169$

Complete and incomplete birth records do not differ in their prevalence of infant gender for either NH black or white mothers.

The association between mother's race and Medicaid insurance status is significant for both complete and incomplete birth records χ^2 (1, N = 2,345) = 235.28, $p < 0.001$, and χ^2 (1, N = 3,826) = 479.64, $p < 0.001$, respectively.

Mother's race = NH white

Insurance at delivery	Complete birth records	Incomplete birth records	Total
Private and self-pay	1,641 (81.89%)	1,693 (70.78%)	3,334 (75.84%)
Medicaid	363 (18.11%)	699 (29.22%)	1,062 (24.16%)
Total	2,004 (100%)	2,392 (100%)	4,396 (100%)

χ^2 (1, N = 4,396) = 73.44, $p < 0.001$

Mother's race = NH black

Insurance at delivery	Complete birth records	Incomplete birth records	Total
Private and self-pay	149 (43.70%)	496 (34.59%)	645 (36.34%)
Medicaid	192 (56.30%)	938 (65.41%)	1,130 (63.66%)
Total	341 (100%)	1,434 (100%)	1,775 (100%)

χ^2 (1, N = 1,775) = 9.88, $p = 0.002$

There is a statistically significant difference in Medicaid rates between incomplete and complete birth records for both NH black and white mothers, whose incomplete birth records are more likely to be of Medicaid mothers.

There is no association between mother's race and her risk for pre-pregnancy diabetes for both complete and incomplete birth records χ^2 (1, N = 2,345) = 2.61, $p = 0.106$, and χ^2 (1, N = 4,288) = 0.00, $p = 0.997$, respectively.

Mother's race = NH white

Pre-pregnancy diabetes mellitus	Complete birth records	Incomplete birth records	Total
No	2,001 (99.85%)	2,737 (99.35%)	4,738 (99.56%)
Yes	3 (0.15%)	18 (0.65%)	21 (0.44%)
Total	2,004 (100%)	2,755 (100%)	4,759 (100%)

χ^2 (1, N = 4,759) = 6.70, $p = 0.01$

Mother's race = NH black

Pre-pregnancy diabetes mellitus	Complete birth records	Incomplete birth records	Total
No	339 (99.41%)	1.523 (99.35%)	1,862 (99.36%)
Yes	2 (0.59%)	10 (0.65%)	12 (0.64%)
Total	341 (100%)	1,533 (100%)	1,874 (100%)

χ^2 (1, N = 1,874) = 0.02, $p = 0.890$

The prevalence of mother's pre-pregnancy diabetes differs significantly between complete and incomplete birth records for only NH white mothers, whose incomplete birth records are more likely to be of diabetic mothers.

There is an association between mother's gestational diabetes and race for the incomplete birth records χ^2 (1, N = 4,288) = 10.13, p = 0.001, but not for the complete χ^2 (1, N = 2,345) = 0.50, p = 0.481.

Mother's race = NH white

Gestational diabetes mellitus	Complete birth records	Incomplete birth records	Total
No	1,943 (96.96%)	2,648 (96.12%)	4,591 (96.47%)
Yes	61 (3.04%)	107 (3.88%)	168 (3.53%)
Total	2,004 (100%)	2,755 (100%)	4,759(100%)

χ^2 (1, N = 4,759) = 2.40, p = 0.121

Mother's race = NH black

Gestational diabetes mellitus	Complete birth records	Incomplete birth records	Total
No	333 (97.65%)	1,501 (97.91%)	1,834 (97.87%)
Yes	8 (3.19%)	32 (2.09%)	40 (2.13%)
Total	341 (100%)	1,533 (100%)	1,874 (100%)

χ^2 (1, N = 1,874) = 0.09, p = 0.765

Complete and incomplete birth records do not differ in their prevalence of mother's gestational diabetes for either NH black or white mothers.

There is no association between mother's race and her risk for pre-pregnancy hypertension in both complete and incomplete birth records χ^2 (1, N = 2,345) = 0.02, p = 0.902, and χ^2 (1, N = 4,288) = 0.55, p = 0.457, respectively.

Mother's race = NH white

Pre-pregnancy hypertension	Complete birth records	Incomplete birth records	Total
No	1,982 (98.90%)	2,726 (98.95%)	4,708 (98.93%)
Yes	22 (1.10%)	29 (0.72%)	51 (1.07%)
Total	2,004 (100%)	2,755 (100%)	4,759 (100%)

χ^2 (1, N = 4,759) = 0.02, p = 0.881

Mother's race = NH black

Pre-pregnancy hypertension	Complete birth records	Incomplete birth records	Total
No	337 (98.83%)	1,513 (98.70%)	1,850 (98.72%)
Yes	4 (1.17%)	20 (1.30%)	24 (1.28%)
Total	341 (100%)	1,533 (100%)	1,874 (100%)

χ^2 (1, N = 1,878) = 0.01, p = 0.934

The prevalence of mother's pre-pregnancy hypertension does not differ significantly between complete and incomplete birth records for either NH black or NH white mothers.

There is an association between mother's gestational hypertension and race for the incomplete birth records χ^2 (1, N = 4,288) = 8.00, p = 0.005, but not for the complete χ^2 (1, N = 2,345) = 1.23, p = 0.268.

Mother's race = NH white

Gestational hypertension	Complete birth records	Incomplete birth records	Total
No	1,888 (94.21%)	2,620 (95.10%)	4,508 (94.73%)
Yes	116 (5.79%)	135 (4.90%)	251 (5.27%)
Total	2,004 (100%)	2,755 (100%)	4,759 (100%)

χ^2 (1, N = 4,759) = 1.83, p = 0.176

Mother's race = NH black

Gestational hypertension	Complete birth records	Incomplete birth records	Total
No	316 (92.67%)	1,426 (93.02%)	1,745 (92.96%)
Yes	25 (7.33%)	107 (6.98%)	132 (7.04%)
Total	341 (100%)	1,533 (100%)	1,874 (100%)

χ^2 (1, N = 1,874) = 0.05, p = 0.818

The prevalence of mother's gestational hypertension does not differ significantly between complete and incomplete birth records for either NH black or NH white mothers.

There is no association between mother's race and her risk for vaginal bleeding in both complete and incomplete birth records χ^2 (1, N = 2,345) = 1.52, p = 0.218, and χ^2 (1, N = 4,288) = 0.22, p = 0.639, respectively.

Mother's race = NH white

Vaginal bleeding	Complete birth records	Incomplete birth records	Total
No	1,960 (97.80%)	2,710 (98.37%)	4,670 (98.13%)
Yes	44 (2.20%)	45 (1.63%)	89 (1.87%)
Total	2,004 (100%)	2,755 (100%)	4,759 (100%)

χ^2 (1, N = 4,759) = 2.00, p = 0.157

Mother's race = NH black

Vaginal bleeding	Complete birth records	Incomplete birth records	Total
No	337 (98.83%)	1,505 (98.17%)	1,842 (98.29%)
Yes	4 (1.17%)	28 (1.83%)	32 (1.71%)
Total	341 (100%)	1,533 (100%)	1,874 (100%)

χ^2 (1, N = 1,878) = 0.01, p = 0.923

There is no significant difference in prevalence of mother's vaginal bleeding between complete and incomplete data for either NH black or NH white mothers.

There is an association between mother's infertility treatment and race for the complete birth records χ^2 (1, N = 2,345) = 3.78, p = 0.052, but not for the incomplete χ^2 (1, N = 4,288) = 4.28, p = 0.039.

Mother's race = NH white

Infertility treatment	Complete birth records	Incomplete birth records	Total
No	1,982 (98.90%)	2,740 (99.46%)	4,722 (99.22%)
Yes	22 (1.10%)	15 (0.54%)	37 (0.78%)
Total	2,004 (100%)	2,755 (100%)	4,759 (100%)

χ^2 (1, N = 4,759) = 4.60, p = 0.032

Mother's race = NH black

Infertility treatment	Complete birth records	Incomplete birth records	Total
No	341 (100%)	1,531 (99.87%)	1,876 (99.89%)
Yes	0 (0.00%)	2 (0.13%)	2 (0.11%)
Total	341 (100%)	1,533 (100%)	1,874 (100%)

χ^2 (1, N = 1,874) = 0.45, p = 0.505

There is a statistically significant difference in the use of infertility treatment between complete and incomplete birth records only among NH white mothers. Those with incomplete birth records were less likely to use infertility treatment.

There is an association between grandmother's race and her marital status in both complete and incomplete birth records χ^2 (1, N = 2,345) = 653.83, p < 0.001, and χ^2 (1, N = 4,288) = 1.4e+03, p < 0.001, respectively.

Grandmother's race = white

Grandmother's marital status	Complete birth records	Incomplete birth records	Total
Married	1,777 (88.41%)	2,176 (77.47%)	3,953 (82.03%)
Unmarried	233 (11.59%)	633 (22.53%)	866 (17.97%)
Total	2,010 (100%)	2,809 (100%)	4,819 (100%)

χ^2 (1, N = 4,819) = 95.17, p < 0.001

Grandmother's race = black

Grandmother's marital status	Complete birth records	Incomplete birth records	Total
Married	93 (27.76%)	257 (17.38%)	350 (19.29%)
Unmarried	242 (72.24%)	1,222 (82.62%)	1,464 (80.71%)
Total	335 (100%)	1,479 (100%)	1,814 (100%)

χ^2 (1, N = 1,814) = 18.92, p < 0.001

There is a statistically significant difference in marital status between complete and incomplete birth records among both black and white grandmothers. Those with incomplete birth records were more likely to be unmarried.

There is no association between grandmother’s race and mother’s plurality in both complete and incomplete birth records χ^2 (1, N = 2,345) = 2.28, p = 0.131, and χ^2 (1, N = 4,288) = 0.01, p = 0.907, respectively.

Grandmother’s race = white

Mother’s plurality	Complete birth records	Incomplete birth records	Total
Singleton	1,976 (98.31%)	2,746 (97.76%)	4,722 (97.99%)
Twin/triplet	34 (1.69%)	63 (2.24%)	97 (2.01%)
Total	2,010 (100%)	2,809 (100%)	4,819 (100%)

χ^2 (1, N = 4,819) = 1.81, p = 0.179

Grandmother’s race = black

Mother’s plurality	Complete birth records	Incomplete birth records	Total
Singleton	333 (99.40%)	1,445 (97.70%)	1,778 (98.02%)
Twin/triplet	2 (0.60%)	34 (2.30%)	36 (1.98%)
Total	335 (100%)	1,479 (100%)	1,814 (100%)

χ^2 (1, N = 1,814) = 4.07, p = 0.044

There is a statistically significant difference in mother’s plurality between complete and incomplete birth records for only black grandmothers. Those with incomplete birth records were more likely to be higher order births.

There is an association between mother’s race and smoking status in the first trimester in both complete and incomplete birth records χ^2 (1, N = 2,345) = 5.15, p = 0.023, and χ^2 (1, N = 4,191) = 69.95, p < 0.001, respectively.

Mother’s race = NH white

Mother’s smoking status	Complete birth records	Incomplete birth records	Total
Non-smoker	1,685 (84.08%)	2,056 (76.40%)	3,741 (79.68%)
Smoker	319 (15.92%)	635 (23.60%)	954 (20.32%)
Total	2,004 (100%)	2,691 (100%)	4,695 (100%)

χ^2 (1, N = 4,695) = 41.83, p < 0.001

Mother’s race = NH black

Mother’s smoking status	Complete birth records	Incomplete birth records	Total
Non-smoker	303 (88.86%)	1,307 (87.13%)	1,610 (87.45%)
Smoker	38 (11.14%)	193 (12.87%)	231 (12.55%)
Total	341 (100%)	1,500 (100%)	1,841 (100%)

χ^2 (1, N = 1,841) = 0.75, p = 0.386

There is a statistically significant difference in mother’s smoking status between complete and incomplete birth records for only NH white mothers. Those with incomplete birth records are more likely to be smokers.

Two sample t-tests are used to compare the means of specified variables among complete and incomplete birth records.

Sample descriptive statistics using t-test for equality of means – NH white mothers

	Complete		Incomplete		t-test
	Mean	SD	Mean	SD	
Infant birth weight	3,356.36	520.80	3304.90	565.61	3.20*
Mother's age	25.62	3.81	24.42	4.26	10.02**
Father's age	28.11	4.95	27.89	5.18	1.34
Mother's education	0.83	0.29	0.72	0.34	11.43**
Father's education	0.82	0.29	0.79	0.31	3.32**

** $p < 0.001$, * $p < 0.05$, Education = ratio of educational attainment adjusted for age

Among NH white mothers there is a significant effect of missing data such that infant birth weight, maternal age, and educational attainment are lower among incomplete birth records.

Sample descriptive statistics using t-test for equality of means – NH black mothers

	Complete		Incomplete		t-test
	Mean	SD	Mean	SD	
Infant birth weight	3,065.10	654.56	3,059.66	617.25	0.15
Mother's age	21.20	3.47	20.42	3.40	3.81*
Father's age	23.80	6.06	23.99	5.89	-0.46
Mother's education	0.51	0.33	0.42	0.30	5.13**
Father's education	0.50	0.33	0.49	0.32	0.43

** $p < 0.001$, * $p < 0.05$, Education = ratio of educational attainment adjusted for age

Among NH black mothers there is a significant effect of missing data on maternal age and maternal educational attainment which are lower in the incomplete birth records.

Sample descriptive statistics using t-test for equality of means – white grandmothers

	Complete		Incomplete		t-test
	Mean	SD	Mean	SD	
Mother's birth weight	3,337.17	538.05	3,315.92	521.48	1.38
Grandmother's age	26.57	4.69	26.03	5.12	3.73**
Grandfather's age	29.02	5.54	28.84	6.05	1.06
Grandmother's education	0.81	0.11	0.81	0.11	-0.67
Grandfather's education	0.82	0.12	0.81	0.12	1.72

** $p < 0.001$, * $p < 0.05$, Education = ratio of educational attainment adjusted for age

Among white maternal grandmothers there is a significant effect of missing data on maternal grandmother's age, which are lower in incomplete birth records.

Sample descriptive statistics using t-test for equality of means – black grandmothers

	Complete		Incomplete		t-test
	Mean	SD	Mean	SD	
Mother’s birth weight	3,001.99	539.63	3010.78	591.46	-0.25
Grandmother’s age	24.06	5.47	23.41	5.58	1.93
Grandfather’s age	26.50	6.87	26.43	7.33	0.16
Grandmother’s education	0.84	0.12	0.82	0.12	1.93
Grandfather’s education	0.82	0.12	0.81	0.10	1.87

** $p < 0.001$, * $p < 0.05$, Education = ratio of educational attainment adjusted for age

Among black maternal grandmothers there is not significant effect of missing data on the variables tested.

APPENDIX B: MAPS OF LOCAL SPATIAL SEGREGATION IN ALLEGHENY COUNTY, 2010

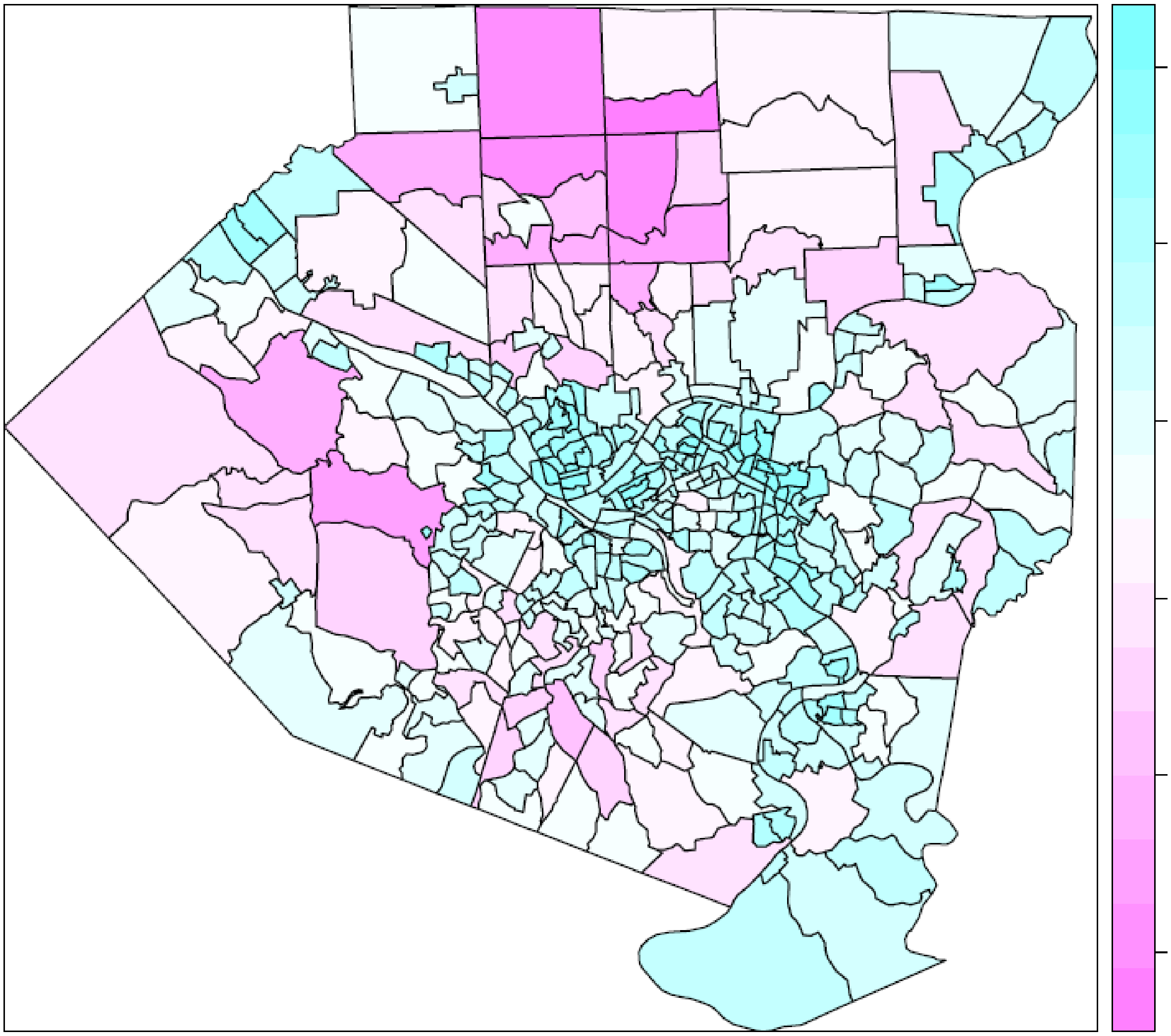

Figure 15. Local spatial racial residential segregation of non-Hispanic black residents from non-Hispanic white residents in 2010, Allegheny County, PA

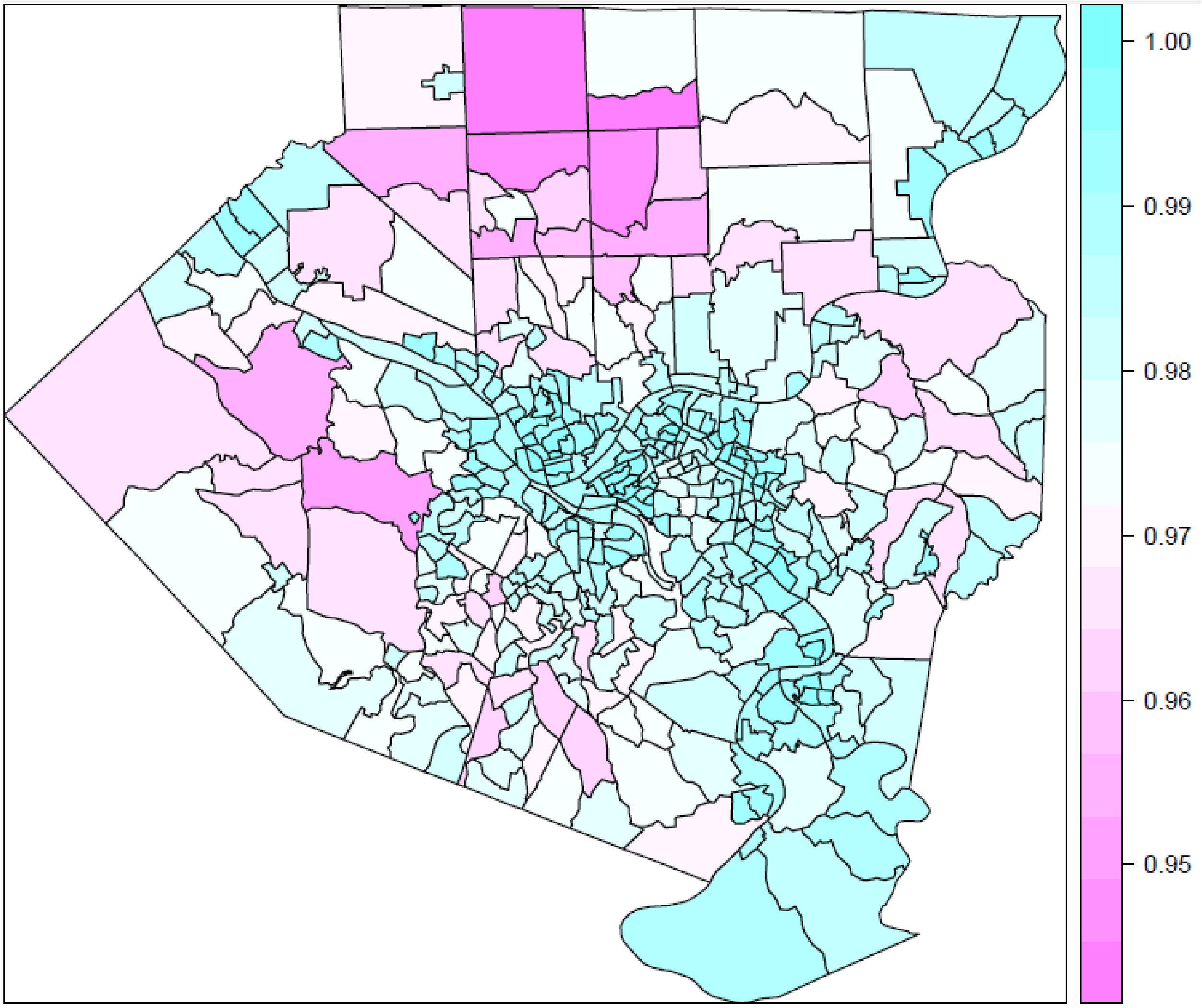

Figure 16. Local spatial economic segregation of low income households from hig income households in 2010, Allegheny County, PA

APPENDIX C: CORRELATION MATRIX (PAIRWISE CORRELATION) FOR LOW BIRTH WEIGHT DATASET

* = $p < 0.05$. Grayscale font = NH white; Black font = NH black

Infant	1	2	3	4	5	6	7	8	9	10	11
1. Gender		-0.0240	-0.0355	0.0132	0.0251	-0.0009	-0.0017	0.0651*	0.0176	0.0232	0.0323
2. LBW	0.0065		**0.8446***	0.4869*	-0.0070	0.0114	0.0020	0.0307	0.0325	0.0524*	-0.0121
Multinomial birth weight											
3. MLBW	-0.0007	**0.9027***		-0.0564*	0.0006	-0.0016	0.0056	0.0143	0.0383	0.0021	-0.102
4. VLBW	0.0165	0.4100*	-0.0224		-0.0140	0.0238	-0.0055	0.0338	-0.0019	0.0942*	-0.0059
Mother											
5. Unmarried	-0.0024	0.0531*	0.0392*	0.0403*		-0.0202	-0.0503*	-0.0540*	-0.0023	0.0256	-0.0811*
6. Diabetes – chronic	-0.0034	-0.0164	-0.0148	-0.0067	-0.0206		-0.0119	0.0504*	0.0302	0.0411	-0.0026
7. Diabetes -gestational	-0.0029	-0.0177	-0.0103	-0.0193	-0.0204	-0.0127		0.0489*	0.0026	0.0090	-0.0048
8. Hypertension – chronic	-0.0065	0.0447*	0.0250	0.0508*	-0.0363*	-0.0069	0.0022		-0.0314	0.0583*	-0.0037
9. Hypertension - gestational	-0.0017	0.0796*	0.0763*	0.0232	-0.0347*	-0.0015	-0.0095	-0.0246		-0.0041	-0.0090
10. Vaginal bleeding	-0.0082	0.0662*	0.0352*	0.0792*	-0.0075	-0.0092	-0.0012	0.0007	-0.0256		-0.0043
11. Assist. Reproductive techn.	0.0117	0.0091	0.0142	-0.0089	-0.0768*	0.0302*	-0.0040	0.0140	-0.0102	0.0054	
12. Twin/triplet	0.0080	0.0157	0.0104	0.0144	-0.0260	0.0095	0.0192	0.0149	0.0247	-0.0247	0.0126
13. Smoke pre-pregnancy	-0.0063	0.0780*	0.0636*	0.0462*	0.3702*	-0.0013	-0.0013	-0.0057	-0.0379*	0.0079	-0.0252
14. Smoke 1st trimester	-0.0065	0.0811*	0.0709*	0.0381*	0.3717*	-0.0005	-0.0101	-0.0070	-0.0203	0.0052	-0.0330*
15. Smoke 2nd trimester	-0.0041	0.0895*	0.0755*	0.0479*	0.3415*	0.0043	-0.0058	-0.0105	-0.0191	0.0073	-0.0348*
16. Smoke 3rd trimester	-0.0024	0.0850*	0.0777*	0.0327*	0.3349*	0.0061	-0.0102	-0.0079	-0.0184	0.0041	-0.0332*
17. Medicaid	-0.0054	0.0805*	0.0612*	0.0569*	0.4856*	0.0092	-0.0040	0.0033	-0.0109	0.0028	-0.0506*
Prenatal care											
18. Inadequate	-0.0015	-0.0078	-0.0113	0.0072	0.0980*	0.0027	-0.0058	0.0104	-0.0076	0.0127	-0.0201
19. Intermediate	-0.0162	-0.0513*	-0.0476*	-0.0182	-0.0490*	-0.0212	-0.0172	-0.0332*	-0.0364*	-0.0063	0.0350*
20. Adequate plus	0.0205	0.2715*	0.2502*	0.1007*	0.0006	0.0839*	0.0365*	0.0690*	0.0833*	0.0155	0.0064
Pregnancy BMI											
21. BMI – underweight	0.0072	0.0313	0.0272	0.0151	0.1068*	-0.0142	0.0015	-0.0244	0.0051	-0.0154	-0.0213
22. BMI – overweight	-0.0062	-0.0139	-0.0031	-0.0256	-0.0596*	-0.0098	0.0528*	-0.0025	0.0201	-0.0275	-0.0257
23. BMI – obese	-0.0044	-0.0079	-0.0198	0.0236	-0.0073	0.0599*	0.0963*	0.1214*	0.0990*	0.0055	0.0176
Gestational weight gain											
24. Inadequate	-0.0030	0.1382*	0.1017*	0.1053*	0.0582*	-0.0061	-0.0157	0.0144	-0.0513*	-0.0134	0.0005
25. Excessive	0.0032	-0.0860*	-0.0558*	-0.0812*	-0.0319	0.0072	-0.0168	0.0122	0.0437*	-0.0058	-0.0046
26. Mother education	-0.0058	-0.0465*	-0.0248	-0.0558*	**-0.6035***	0.0043	0.0378*	0.0240	0.0231	0.0067	0.0655*
27. Father education	0.0059	-0.0346*	-0.0115	-0.0561*	**-0.5910***	0.0107	0.0322*	0.0121	0.0231	0.0059	0.0610*
28. Mothers BW	0.0037	-0.0817*	-0.0901*	0.0012	-0.0592*	0.0219	0.0039	-0.0164	-0.0156	-0.0243	0.0003
29. Mothers age	-0.0129	-0.0397*	-0.0244	-0.0404*	**-0.6331***	0.0067	0.0470*	0.0317*	0.0223	0.0203	0.0893*

30. Neigh % black	0.0175	0.0315*	0.0235	0.0232	0.2210*	-0.0121	0.0027	0.0110	-0.0216	-0.0085	-0.0303*
31. Neigh % low income	-0.0001	0.0429*	0.0298*	0.0366*	0.3276*	-0.0291*	0.0106	0.0134	-0.0205	0.0061	-0.0526*
32. Neigh mean mother educ	0.0122	-0.0624*	-0.0467*	-0.0460*	-0.3783*	0.0256	-0.0072	-0.0222	0.0125	-0.0027	0.0615*
33. Neigh mean father educ	0.0070	-0.0603*	-0.0453*	-0.0441*	-0.3722*	0.0275	-0.0064	-0.0291*	0.0143	-0.0106	0.0572*
34. Neigh mean mothers BW	0.0207	-0.0250	-0.0220	-0.0113	-0.1615*	0.0180	-0.0209	-0.0017	-0.0109	-0.0132	0.0438*
35. Neigh mean maternal age	0.0090	-0.0625*	-0.0492*	-0.0411*	-0.3845*	0.0360*	-0.0052	-0.0224	0.0169	-0.0028	0.0636*
Maternal grandmother											
36. Black	0.0044	-0.0017	-0.0088	0.0146	0.0258	-0.0060	0.0212	0.0365*	0.0105	-0.0124	-0.0079
37. Unmarried	-0.0092	0.0476*	0.0294*	0.0483*	0.3202*	0.0030	-0.0213	-0.0045	-0.0036	-0.0058	-0.0342*
38. GM Education	-0.0049	-0.0186	-0.0174	-0.0064	-0.1177*	0.0063	0.0021	-0.0041	-0.0018	-0.0119	0.0188
39. GF Education	0.0255	-0.0277	-0.0238	-0.0140	-0.2512*	-0.0074	0.0054	-0.0319*	-0.0062	-0.0176	0.0400*
40. Grandmothers age	-0.0001	-0.0270	-0.0182	-0.0242	-0.1250*	-0.0203	-0.0022	0.0182	0.0057	-0.0038	0.0068
41. Neigh % black	0.0078	0.0137	0.0132	0.0039*	0.0886*	-0.0027	0.0013	0.0089	-0.0127	-0.0288*	0.0001
42. Neigh % low income	-0.0016	0.0363*	0.0194	0.0431*	0.3140*	-0.0085	-0.0157	0.0087	-0.0242	-0.0051	-0.0358*
43. Neigh mean GM educ	0.0081	-0.0164	-0.0035	-0.0307*	-0.1258*	0.0122	0.0187	-0.0073	0.0199	-0.0084	0.0444*
44. Neigh mean GF educ	0.0174	-0.0346*	-0.0194	-0.0393*	-0.2408*	-0.0158	0.0234	-0.0100	0.0247	0.0063	0.0333*
45. Neigh mean maternal age	-0.0060	-0.0461*	-0.0385*	-0.0256	-0.2001*	-0.0031	0.0032	-0.0124	0.0430*	0.0020	0.0113

Infant	12	13	14	15	16	17	18	19	20	21	22
1. Gender	-0.0135	0.0198	0.0236	0.0326	0.0294	0.0171	0.0260	0.0123	0.0386	0.0168	0.0103
2. LBW	0.0068	0.0776*	0.0998*	0.0827*	0.0768*	0.0640*	0.0027	0.0049	0.3079*	0.0204	-0.0226
Multinomial birth weight											
3. MLBW	0.0051	0.0429	0.0648*	0.0617*	0.0662*	0.0484*	-0.0020	-0.0028	0.2538*	0.0075	-0.0247
4. VLBW	0.0043	0.0747*	0.0800*	0.0534	0.0353	0.0410	0.0096	0.0159	0.1668*	0.0265	-0.0016
Mother											
5. Unmarried	-0.0077	0.0473*	0.0481*	0.0552*	0.0538*	0.1178*	-0.0180	0.0072	-0.0103	0.0428	0.0025
6. Diabetes – chronic	0.0115	0.0820*	0.0712*	0.0410	0.0425	0.0194	0.0268	-0.0147	0.0296	-0.0172	0.0494
7. Diabetes -gestational	-0.0049	-0.0186	-0.0227	-0.0244	-0.0231	-0.0146	0.0064	-0.0315	0.0263	-0.0090	-0.0004
8. Hypertension – chronic	0.0164	0.0075	0.0143	0.0261	0.0278	0.0073	0.0017	0.0061	0.0116	-0.0236	-0.0088
9. Hypertension - gestational	0.0100	-0.0110	-0.0148	-0.0203	-0.0175	0.0159	0.0004	-0.0290	0.0054	-0.0148	0.0605*
10. Vaginal bleeding	-0.0103	0.0328	0.0179	0.0019	0.0034	-0.0033	0.0202	0.0002	-0.0028	0.0074	-0.0318
11. Assist. Reproductive techn.	0.0047	0.0334	0.0373	0.0443	0.0454	-0.0445	-0.0080	-0.0073	-0.0185	-0.0061	-0.0154
12. Twin/triplet		0.0485*	0.0426	0.0345	0.0334	0.0024	-0.0202	0.0261	-0.0099	-0.0185	-0.0179
13. Smoke pre-pregnancy	-0.0117		**0.9278***	**0.8061***	**0.7886***	0.0883*	0.0579*	0.0201	0.0280	0.0140	-0.0557*
14. Smoke 1st trimester	-0.0101	**0.8562***		**0.8061***	**0.8445***	0.0899*	0.0325	-0.0116	0.0395	0.0302	-0.0578*
15. Smoke 2nd trimester	-0.0054	**0.7827***	**0.9027***		**0.9599***	0.0575*	0.0008	-0.0198	0.0154	0.0275	-0.0516
16. Smoke 3rd trimester	-0.0053	**0.7566***	**0.8679***	**0.9552***		0.0548*	0.0117	-0.0303	0.0137	0.0175	-0.0463
17. Medicaid	-0.0180	0.2836*	0.3041*	0.2925*	0.2917*		0.0258	0.0066	0.0319	0.0108	-0.0769*
Prenatal care											
18. Inadequate	-0.0323*	0.0812*	0.0626*	0.0553*	0.0427*	0.0828*		-0.0451	-0.1139*	0.0178	-0.0344
19. Intermediate	-0.0061	0.0544*	0.0128	0.0094	-0.0080	-0.0122	-0.0713*		-0.1044*	-0.0113	-0.0220
20. Adequate plus	0.0234	0.0220	0.0118	0.0090	0.0171	0.0322*	-0.1133*	-0.1641*		-0.0368	0.0640*
Pregnancy BMI											

21. BMI – underweight	0.0132	0.0565*	0.0639*	0.0514*	0.0508*	0.0572*	-0.0181	-0.0174	0.0054		-0.1209*
22. BMI – overweight	-0.0034	-0.0066	-0.0322	-0.0297	-0.0248	-0.0371*	0.0052	0.0011	-0.0013	-0.1248*	
23. BMI – obese	-0.0002	0.0109	0.0000	-0.0022	0.0011	0.0142	0.0305	-0.0293	0.0426*	-0.1057*	-0.2396*
Gestational weight gain											
24. Inadequate	-0.0013	0.0234	0.0441*	0.0542*	0.0481*	0.0362	0.0242	0.0283	0.0458*	0.0592*	-0.1226*
25. Excessive	-0.0250	0.0308	-0.0054	-0.0208	-0.0202	-0.0095	-0.0143	-0.0192	0.0112	-0.1460*	0.1853
26. Mother education	0.0043	-0.3052*	-0.3046*	-0.2763*	-0.2692*	-0.3762*	-0.0947*	0.0293	-0.0218	-0.1052*	0.0608*
27. Father education	-0.0142	-0.3198*	-0.3129*	-0.2905*	-0.2770*	-0.3807*	-0.0866*	0.0162	-0.0388*	-0.1187*	0.0482*
28. Mothers BW	0.1951*	-0.0449*	-0.0559*	-0.0453*	-0.0507*	-0.0411*	-0.0224	0.0049	-0.0394*	-0.0593*	-0.0056
29. Mothers age	0.0016	-0.2627*	-0.2675*	-0.2388*	-0.2327*	-0.3847*	-0.1015*	0.0164	-0.0229	-0.1135*	0.0772*
30. Neigh % black	0.0085	0.1158*	0.1309*	0.1337*	0.1270*	0.1816*	0.0138	-0.0752*	0.0168	0.0509*	-0.0122
31. Neigh % low income	0.0132	0.1660*	0.1849*	0.1708*	0.1708*	0.2522*	0.0315*	-0.0853*	0.0359*	0.0581*	-0.0225
32. Neigh mean mother educ	-0.0023	-0.2202*	-0.2320*	-0.2214*	-0.2180*	-0.2868*	-0.0408*	0.0662*	-0.0497*	-0.0705*	0.0315
33. Neigh mean father educ	-0.0020	-0.2126*	-0.2256*	-0.2160*	-0.2127*	-0.2830*	-0.0404*	0.0668*	-0.0562*	-0.0618*	0.0332*
34. Neigh mean mothers BW	0.0259	-0.0929*	-0.1101*	-0.1057*	-0.1079*	-0.1452*	-0.0255	0.0399*	-0.0164	-0.0353*	0.0047
35. Neigh mean maternal age	-0.0018	-0.2126*	-0.2235*	-0.2133*	-0.2086*	-0.2883*	-0.0434*	0.0594*	-0.0496*	-0.0725*	0.0340*
Maternal grandmother											
36. Black	-0.0210	-0.0046	-0.0043	0.0021	-0.0018	0.0564*	-0.0201	0.0075	0.0064	-0.0194	-0.0024
37. Unmarried	0.0097	0.1566*	0.1740*	0.1803*	0.1746*	0.2669*	0.0742*	-0.0379*	0.0223	0.0580*	-0.0056
38. GM Education	0.0025	-0.0945*	-0.0874*	-0.0854*	-0.0879*	-0.1231*	-0.0108*	-0.0186	-0.0180	-0.0028	-0.0166
39. GF Education	0.0003	-0.1701*	-0.1677*	-0.1675*	-0.1679*	-0.1927*	-0.0303	0.0201	-0.0276	-0.0448*	-0.0070
40. Grandmothers age	-0.0338*	-0.0967*	-0.1135*	-0.1104*	-0.1052*	-0.1180*	-0.0131	0.0279	-0.0337*	-0.0335*	-0.0112
41. Neigh % black	0.0167	0.0411*	0.0397*	0.0402*	0.0307*	0.1014*	0.0001	-0.0123	0.0092	-0.0034	0.0057
42. Neigh % low income	0.0235	0.1621*	0.1677*	0.1679*	0.1648*	0.2552*	0.0211	-0.0043	0.0338*	0.0454*	0.0099
43. Neigh mean GM educ	0.0124	-0.0883*	-0.0902*	-0.0919*	-0.0876*	-0.1009*	-0.0084	-0.0161	-0.0024	-0.0278	-0.0213
44. Neigh mean GF educ	-0.0024	-0.1341*	-0.1477*	-0.1421*	-0.1398*	-0.1689*	-0.0139	0.0106	-0.0324*	-0.0263	-0.0161
45. Neigh mean maternal age	-0.0451*	-0.1084*	-0.1155*	-0.1104*	-0.1022*	-0.1536*	0.0108	0.0216	-0.0182	-0.0394*	0.0118

Infant	23	24	25	26	27	28	29	30	31	32	33
1. Gender	0.0075	-0.0057	0.0280	0.0042	0.0225	-0.0067	0.0121	-0.0299	-0.0196	0.0501*	0.0537*
2. LBW	-0.0097	0.1864*	-0.1503*	0.0456*	0.0800*	-0.1336*	0.0382	0.0036	0.0333	-0.0217	-0.0246
Multinomial birth weight											
3. MLBW	-0.0040	0.1445*	-0.1139*	0.0136	0.0390	-0.1211*	0.0197	0.0182	0.0441	-0.0419	-0.0357
4. VLBW	-0.0119	0.1127*	-0.0952*	0.0628*	0.0843*	-0.0516*	0.0391	-0.0229	-0.0098	0.0280	0.0124
Mother											
5. Unmarried	-0.0815*	-0.0091	-0.0100	-0.2468*	-0.2768*	-0.0150	-0.2673*	0.0887*	0.09933*	-0.0973*	-0.0789*
6. Diabetes – chronic	0.0084	-0.0170	-0.0199	0.0739*	0.0403	-0.0073	0.0884*	0.0252	-0.0128	-0.0085	-0.0035
7. Diabetes -gestational	0.0734*	-0.0483	0.0519	0.0673*	0.0662	-0.0279	0.0501*	-0.0315	-0.0463*	0.0425	0.0398
8. Hypertension – chronic	0.1585*	-0.0302	0.0490	0.0843*	0.0932*	-0.0044	0.1157*	-0.0121	-0.0213	0.0161	0.0188
9. Hypertension - gestational	0.0364	-0.0480	0.0823*	0.0282	0.0480	-0.0243	0.0327	-0.0040	-0.0043	-0.0010	-0.0106
10. Vaginal bleeding	-0.0086	0.0192	-0.0053	0.0092	0.0151	0.0221	0.0060	-0.0087	-0.0012	0.0086	0.0131
11. Assist. Reproductive techn.	-0.0142	-	-	0.0665*	0.0530	0.0380	0.0806*	-0.0112	0.0006	0.0178	0.0003
12. Twin/triplet	0.0366	-0.0370	0.0407	0.0395	0.0021	0.2668*	0.0292	0.0111	0.0027	0.0090	-0.0035

13. Smoke pre-pregnancy	0.0483	0.0411	-0.0247	0.0113	0.0789*	0.0228	0.0595*	-0.0265	0.0692*	-0.0326	-0.0361
14. Smoke 1st trimester	0.0496	0.0421	-0.0317	0.0117	0.0816*	0.0057	0.0538*	-0.0455	0.0620*	-0.0309	-0.0219
15. Smoke 2nd trimester	0.0484	0.0518	-0.0214	0.0205	0.0629	-0.0152	0.0488*	-0.0371	0.0743*	-0.0352	-0.0398
16. Smoke 3rd trimester	0.0480	0.0415	-0.0236	0.0188	0.0575	-0.0269	0.0568*	-0.0351	0.0751*	-0.0352	-0.0416
17. Medicaid	0.0242	0.0492	0.0019	-0.1003*	-0.1205*	-0.0699*	-0.1130*	0.0696*	0.1203*	-0.0727*	-0.0657*
Prenatal care											
18. Inadequate	0.0234	-0.0038	-0.0301	0.0192	0.0064	-0.0005	0.0360	0.0387	-0.0033	-0.0103	-0.0084
19. Intermediate	0.0188	0.0488	-0.0412	0.0021	-0.0087	0.0289	-0.0221	0.0094	0.0067	0.0372	0.0612*
20. Adequate plus	-0.0006	0.0726*	-0.0423	0.0239	0.0350	-0.0374	0.0362	-0.0614*	-0.0429	0.0751*	0.0400
Pregnancy BMI											
21. BMI – underweight	-0.1115*	0.0208	-0.0491	-0.0122	-0.0650	-0.0497	-0.0402	0.0438	0.0241	-0.0021	0.0011
22. BMI – overweight	-0.2827*	-0.1057*	0.1621*	0.0073	-0.0099	0.0054	0.0299	-0.0216	-0.0343	0.0368	0.0168
23. BMI – obese		0.0133	0.0929*	0.1771*	0.2084*	0.0421	0.1840*	0.0044	0.0230	-0.0139	0.0022
Gestational weight gain											
24. Inadequate	0.0191		**-0.6053***	-0.0342	-0.0169	-0.0580	-0.0663*	0.0437	0.0816*	-0.0557	-0.0499
25. Excessive	0.0666*	**-0.5195***		0.0712*	0.0565	0.0803*	0.0838*	-0.0065	-0.0208	0.0107	0.0045
26. Mother education	0.0226	-0.0734*	0.0424*		**0.9816***	0.0048	**0.8012***	-0.0897*	-0.1521*	0.2528*	0.2123*
27. Father education	0.0017	-0.0621*	0.0391*	**0.9690***		0.0285	**0.7939***	-0.1012*	-0.1543*	0.2432*	0.3075*
28. Mothers BW	0.0577*	-0.0462*	0.0518*	0.0677*	0.0475*		-0.0159	-0.0110	-0.0476*	0.0205	0.0072
29. Mothers age	0.0535*	-0.0643*	0.0365*	**0.8203***	**0.7828***	0.0518*		-0.0822*	-0.1406*	0.2259*	0.1818*
30. Neigh % black	0.0271	0.0426*	-0.0172	-0.2178*	-0.2183*	-0.0495*	-0.1966*		**0.5598***	**-0.6027***	**-0.5771***
31. Neigh % low income	0.0766*	0.0315	0.0048	-0.3080*	-0.3127*	-0.0668*	-0.2915*	**0.6177***		**-0.6563***	**-0.5845***
32. Neigh mean mother educ	-0.0725*	-0.0473*	0.0170	0.4155*	0.4058*	0.0758*	0.3821*	**-0.6344***	**-0.7649***		**0.8601***
33. Neigh mean father educ	-0.0791*	-0.0508*	0.0144	0.4001*	0.4327*	0.0708*	0.3647*	**-0.5898***	**-0.7463***	**0.9501***	
34. Neigh mean mothers BW	-0.0379*	-0.0037	-0.0161	0.1703*	0.1581*	0.2276*	0.1558*	-0.4823*	-0.4090*	0.4645*	0.4261*
35. Neigh mean maternal age	-0.0657*	-0.0394*	0.0199	0.3944*	0.3832*	0.0727*	0.4027*	**-0.6265***	**-0.7518***	**0.9556***	**0.9024***
Maternal grandmother											
36. Black	0.0179	0.0108	0.0163	-0.0426*	-0.0248	-0.0913*	-0.0475*	0.0633*	0.0411*	-0.0382*	-0.0388*
37. Unmarried	-0.0117	0.0551*	-0.0264	-0.3958*	-0.3780*	-0.1131*	-0.3760*	0.1821*	0.2548*	-0.2644*	-0.2551*
38. GM Education	-0.0520*	0.0131	-0.0214	0.1367*	0.1390*	0.0656*	0.0770*	-0.0725*	-0.1031*	0.1416*	0.1399*
39. GF Education	-0.0723*	-0.0218	0.0230	0.2553*	0.2476*	0.0646*	0.2025*	-0.1155*	-0.1896*	0.2428*	0.2370*
40. Grandmothers age	-0.0307	0.0071	-0.0142	0.1188*	0.1175*	0.0416*	0.0963*	-0.0519*	-0.1225*	0.1335*	0.1337*
41. Neigh % black	0.0070	0.0290	-0.0039	-0.1148*	-0.1051*	-0.0654*	-0.1119*	0.1994*	0.1511*	-0.1361*	-0.1304*
42. Neigh % low income	0.0165	0.0468*	0.0021	-0.3300*	-0.3265*	-0.0724*	-0.3371*	0.2314*	0.3416*	-0.3428*	-0.3398*
43. Neigh mean GM educ	0.0087	-0.0001	0.0057	0.1258*	0.1206*	0.0670*	0.10069*	-0.0688*	-0.1068*	0.1771*	0.1733*
44. Neigh mean GF educ	-0.0405*	-0.0329	0.0236	0.2453*	0.2337*	0.0674*	0.2355*	-0.1159*	-0.2152*	0.2875*	0.2858*
45. Neigh mean maternal age	-0.0460*	-0.0252	0.0192	0.1887*	0.1865*	0.0462*	0.1745*	-0.1439*	-0.2107*	0.2329*	0.2348*

Infant	34	35	36	37	38	39	40	41	42	43	44	45
1. Gender	0.0033	0.0440	-0.0020	-0.0399	-0.0003	0.0130	-0.0120	0.0319	0.0235	0.0132	-0.0286	-0.0339
2. LBW	-0.0138	-0.0119	0.0207	0.0346	-0.0299	0.0161	-0.0015	0.0215	0.0211	-0.0658*	-0.0174	-0.0239
Multinomial birth weight												
3. MLBW	-0.0337	-0.0325	0.0062	0.0273	-0.0277	0.0023	-0.0095	0.0100	0.0051	-0.0427	0.0210	-0.0100

4. VLBW	0.0292	0.0308	0.0286	0.0199	-0.0105	0.0261	0.0126	0.0238	0.0311	-0.0530*	-0.0666*	-0.0283
Mother												
5. Unmarried	-0.0549*	-0.0978*	0.0057	0.0980*	-0.0413	-0.0395	-0.0297	0.0786*	0.1022*	-0.0404	-0.0342	-0.0263
6. Diabetes – chronic	-0.0108	-0.0082	-0.0112	-0.0277	-0.0202	-0.0229	0.0181	0.0134	-0.0035	0.0022	-0.0023	0.0253
7. Diabetes -gestational	0.0279	0.0391	0.0181	-0.0478*	0.0188	0.0195	0.0577*	-0.0071	-0.0456*	0.0313	0.0130	0.0214
8. Hypertension – chronic	0.0055	0.0201	-0.0372	0.0085	0.0423	0.0416	-0.0152	-0.0073	-0.0148	0.0102	0.0200	0.0230
9. Hypertension - gestational	-0.0127	0.0014	0.0272	-0.0319	-0.0024	0.0191	-0.0173	-0.0084	0.0112	-0.0031	0.0433	0.0011
10. Vaginal bleeding	0.0281	0.0017	-0.0245	0.0444	0.0254	0.0238	-0.0070	0.0322	0.0255	0.0189	-0.0133	-0.0285
11. Assist. Reproductive techn.	-0.0320	0.0161	0.0077	-0.0250	0.0142	-0.0450	-0.0093	0.0031	-0.0107	0.0826*	-0.0055	-0.0400
12. Twin/triplet	0.0488*	-0.0015	0.0342	-0.0044	0.0190	-0.0066	-0.0736*	-0.0128	-0.0085	-0.0086	-0.0052	-0.0329
13. Smoke pre-pregnancy	-0.0150	-0.0191	-0.0073	0.0168	-0.0402	-0.0537*	-0.0167	0.0295	0.0614*	-0.0336	-0.0609*	-0.0513*
14. Smoke 1st trimester	-0.0161	-0.0186	-0.0218	0.0182	-0.0443	-0.0418	-0.0215	0.0074	0.0429	-0.0344	-0.0588*	-0.0418
15. Smoke 2nd trimester	-0.0012	-0.0252	-0.0042	-0.0010	-0.0363	-0.0427	-0.0129	0.0110	0.0227	-0.0202	-0.0476*	-0.0204
16. Smoke 3rd trimester	-0.0085	-0.0213	-0.0069	-0.0019	-0.0266	-0.0403	-0.0105	0.0063	0.0165	-0.0178	-0.0512*	-0.0152
17. Medicaid	-0.0420	-0.0723*	-0.0482*	0.0984*	-0.0732*	-0.0625*	-0.0423	0.0585*	0.0942*	-0.0879*	-0.0655*	-0.0328
Prenatal care												
18. Inadequate	-0.0050	-0.0121	-0.0055	0.0135	-0.0012	0.0299	0.0300	-0.0270	0.0084	0.0121	0.0043	-0.0202
19. Intermediate	0.0225	0.0199	0.0161	-0.0032	0.0362	0.0223	-0.0267	-0.0067	-0.0175	0.0373	0.0363	-0.0316
20. Adequate plus	0.0344	0.0791*	-0.0067	0.0049	-0.0560*	-0.0100	0.0197	0.0196	0.0249	-0.0272	-0.0116	-0.0119
Pregnancy BMI												
21. BMI – underweight	-0.0235	-0.0091	-0.0085	0.0018	-0.0010	0.0136	0.0276	-0.0113	0.0007	0.0020	-0.0053	0.0279
22. BMI – overweight	0.0301	0.0383	0.0529	-0.0276	-0.0146	-0.0545	-0.0056	0.0056	-0.0118	-0.0296	0.0050	0.0198
23. BMI – obese	-0.0391	-0.0134	-0.0104	-0.0263	0.0163	-0.0306	0.0036	0.0006	0.0190	-0.0056	-0.0315	0.0098
Gestational weight gain												
24. Inadequate	-0.0227	-0.0593	0.0199	-0.0009	-0.0523	-0.0203	0.0146	0.0332	0.0731*	-0.0258	-0.0152	-0.0611*
25. Excessive	0.0070	0.0137	-0.0118	0.0178	0.0223	0.0017	0.0240	-0.0329	-0.0498	-0.0171	0.0094	0.0689*
26. Mother education	0.0741*	0.2176*	0.0384	-0.2281*	0.0298	0.0507*	0.0682*	-0.0181	-0.1260*	0.0716*	0.0861*	0.0835*
27. Father education	0.0631	0.1957*	0.0342	-0.2529*	0.0514	0.0407	0.0534	-0.0112	-0.1376*	0.0546	0.0580	0.0625
28. Mothers BW	0.1809*	0.0176	-0.0586*	-0.0824*	0.0622*	0.0053	-0.0093	-0.0433	-0.0276	0.0611*	0.0151	0.0085
29. Mothers age	0.0719*	0.2406*	0.0533*	-0.2248*	0.0352	0.0374	0.0416	-0.0412	-0.1589*	0.0512*	0.0932*	0.1103*
30. Neigh % black	-0.3958*	**-0.6214***	0.0715*	0.0569*	-0.0198	-0.0708*	-0.0249	0.1956*	0.0464*	-0.0137	0.0065	-0.0324
31. Neigh % low income	-0.4863*	**-0.6430***	0.0145	0.1003*	-0.0207	-0.0647*	-0.0839*	0.1080*	0.1727*	-0.0847*	-0.0980*	-0.0998*
32. Neigh mean mother educ	0.4303*	**0.9347***	-0.0319	-0.0919*	0.0344	0.0872*	0.0333	-0.0761*	-0.1131*	0.0878*	0.0791*	0.0750*
33. Neigh mean father educ	0.3319*	**0.7788***	-0.0368	-0.0859*	0.0140	0.0708*	0.0317	-0.0932*	-0.0975*	0.0858*	0.0720*	0.0649*
34. Neigh mean mothers BW		0.4492*	-0.0253	-0.0782*	0.0203	0.0367	0.0440	-0.0784*	-0.0762*	0.0867*	0.0606*	0.0565*
35. Neigh mean maternal age	0.4524*		-0.0381	-0.0982*	0.0206	0.0880*	0.0336	-0.0859*	-0.1115*	0.0638*	0.0749*	0.0845*
Maternal grandmother												
36. Black	-0.0599*	-0.0476*		0.0890*	0.0474*	0.0632*	-0.0481*	0.1986*	0.1099*	0.0329	0.0200	-0.1158*
37. Unmarried	-0.1684*	-0.2627*	0.0962*		0.0870*	0.0512*	-0.3191*	0.1299*	0.1962*	0.0139	0.0025	-0.1685*
38. GM Education	0.1096*	0.1359*	0.0214	0.0021		0.4753*	-0.4688*	-0.0372	-0.0750*	0.3029*	0.1313*	-0.0543*
39. GF Education	0.1495*	0.2373*	0.0214	-0.1505*	0.4286*		-0.2364*	-0.0572*	-0.0815*	0.1687*	0.2930*	0.0077
40. Grandmothers age	0.0656*	0.1272*	-0.0335*	-0.3195*	-0.0607*	0.1740*		-0.0613*	-0.0947*	-0.0796*	-0.0302	0.2608*
41. Neigh % black	-0.1416*	-0.1422*	0.3125*	0.1406*	-0.0277	-0.0542*	-0.0766*		**0.6576***	0.0199	-0.0572*	-0.4050*
42. Neigh % low income	-0.2135*	-0.3459*	0.1284*	0.2762*	-0.1496*	-0.2543*	-0.2085*	0.4029*		-0.1930*	-0.2435*	-0.4760*
43. Neigh mean GM educ	0.1116*	0.1698*	0.0324*	-0.0760*	0.3713*	0.2643*	0.0833*	0.0106	-0.3189*		0.5162*	-0.1402*

44. Neigh mean GF educ	0.1476*	0.2812*	-0.0070	-0.1680*	0.2383*	0.4383*	0.1883*	-0.0784*	**-0.5184***	**0.6084***		0.0862*
45. Neigh mean maternal age	0.1240*	0.2372*	-0.0768*	-0.2301*	0.0869*	0.2089*	0.3949*	-0.2711*	**-0.5282***	0.1683*	0.4452*	

APPENDIX D: CORRELATION MATRIX (PAIRWISE CORRELATION) FOR PRETERM BIRTH DATASET

	NH white			NH black		
Infant	2	3	4	2	3	4
1. Gender	0.0356*	0.0281	0.0236	-0.0204	-0.0388	0.0253
2. PTB						
Multinomial gestational age						
3. LPTB	**0.9138***			**0.8474***		
4. EPTB	0.3808*	-0.0277		0.4899*	-0.0478*	
Mother						
5. Unmarried	0.0402*	0.0266	0.0385*	-0.0220	-0.0335	0.0135
6. Diabetes – chronic	0.0541*	0.0617*	-0.0072	0.0609*	0.0527*	0.0281
7. Diabetes -gestational	0.0081	0.0177	-0.0204	-0.0016	-0.0008	-0.0017
8. Hypertension – chronic	0.0489*	0.0323*	0.0466*	0.0420	0.0228	0.0416
9. Hypertension - gestational	0.0631*	0.0599*	0.0190	0.0713*	0.0782*	0.0058
10. Vaginal bleeding	0.0637*	0.0298*	0.0890*	0.0774*	0.0242	0.1058*
11. Assist. Reproductive techn.	0.0117	0.0069	0.0131	-0.0111	-0.0094	-0.0055
12. Twin/triplet	0.0166	0.0113	0.0152	0.0116	0.0129	0.0005
13. Smoke pre-pregnancy	0.0398*	0.0249	0.0411*	0.0437	0.0217	0.0465*
14. Smoke 1st trimester	0.0425*	0.0327*	0.0300*	0.0666*	0.0406	0.0584*
15. Smoke 2nd trimester	0.0426*	0.0285	0.0398	0.0377	0.0152	0.0458
16. Smoke 3rd trimester	0.0370*	0.0289*	0.0254	0.0300	0.0187	0.0256
17. Medicaid	0.0510*	0.0359*	0.0434*	0.0417	0.0344	0.0218
Prenatal care						
18. Inadequate	0.0197	0.0104	0.0267	0.0187	0.0116	0.0177
19. Intermediate	-0.0528*	-0.0475*	-0.0223	-0.0165	-0.0173	-0.0019
20. Adequate plus	0.3722*	0.3546*	0.1070*	0.4562*	0.4210*	0.1635*
Pregnancy BMI						
21. BMI – underweight	0.0217	0.0234	0.0000	0.0135	0.0081	0.0121
22. BMI – overweight	-0.0077	0.0013	-0.0224	0.0080	0.0072	0.0031
23. BMI – obese	0.0164	0.0063	0.0266	-0.0077	-0.0243	0.0260
Gestational weight gain						
24. Inadequate	0.0790*	0.0471*	0.0903*	0.1300*	0.0669*	0.1387*
25. Excessive	-0.0744*	-0.0492*	-0.0734*	-0.0929*	-0.0506	-0.0944*
26. Mother education	-0.0360*	-0.0198	-0.0437	0.0288	-0.0120	0.0738*
27. Father education	-0.0338*	-0.0189	-0.0418	0.0737*	0.0178	0.1092*
28. Mothers BW	-0.0326*	-0.0349	-0.0008	-0.0638*	-0.0373	-0.0588*
29. Mothers GA	-0.0326*	-0.0309*	-0.0099	-0.0492*	-0.0383	-0.0297
29. Mothers age	-0.0265	-0.0158	-0.0292*	0.0292	0.0005	0.0541*
30. Neigh % black	0.0175	0.0098	0.0207	-0.0197	-0.0125	-0.0166
31. Neigh % low income	0.0192	0.0026	0.0413*	-0.0000	-0.0008	0.0013
Maternal grandmother						
36. Black	0.0011	-0.0042	0.0122	0.0233	0.0122	0.0238
37. Unmarried	0.0355*	0.0184	0.0455*	0.0071	-0.0061	0.0234
38. GM Education	-0.0300*	-0.0338*	0.0030	-0.0406	-0.0375	-0.0147
39. GF Education	-0.0461*	-0.0455*	-0.0097	0.0113	-0.0122	0.0416
40. Grandmothers age	-0.0157	-0.0011	-0.0361*	0.0348	0.0370	0.0047
41. Neigh % black	0.0047	0.0055	-0.0011	0.0329	0.0258	0.0195
42. Neigh % low income	0.0254	0.0120	0.0351*	0.0290	0.0262	0.0115

APPENDIX E: SYSTEMATIC LITERATURE REVIEW DATABASE SEARCH STRATEGIES

PubMed search strategy

#1 ("Birth weight"[MeSH] OR "Birthweight"[TIAB] OR "birthweight"[OT] OR "Infant, low birth weight"[MeSH Terms] OR "low birth weight"[TIAB] OR "low birth weight"[OT] OR "low birth weights"[TIAB] OR "low birth weights"[OT])

#2 ("Premature birth"[MeSH Terms] OR "premature birth"[TIAB] OR "premature birth"[OT] OR "premature births"[TIAB] OR "premature births"[OT] OR "preterm birth"[TIAB] OR "preterm birth"[OT] OR "preterm births"[TIAB] OR "preterm births"[OT])

#3 ("neighborhood"[TIAB] OR "neighborhood"[OT] OR "neighbourhood"[TIAB] OR "neighbourhood"[OT] OR neighborhoods[TIAB] OR neighborhoods[OT] OR Neighbourhoods[TIAB] OR Neighbourhoods[OT])

#4 ("residence characteristics"[OT] OR "residence characteristics"[MeSH Terms])

#5 (Communities[TIAB] OR communities[OT])

#6 #1 OR #2

#7 #3 OR #4 OR #5

#8 #6 AND #7

Filters for United States and English language were applied

EMBASE and MEDLINE search strategy

#1 preterm AND birth

#2 'prematurity'/exp OR 'prematurity'

#3 'premature'/exp OR 'premature'

#4 'low birth weight'/exp OR 'low birth weight'

#5 'neighborhood'/exp OR neighborhood

#6 neighbourhood

#7 'residential area'/exp OR 'residential area'

#8 #1 OR #2 OR #3 OR #4

#9 #5 OR #6 OR #7

#10 #8 AND #9

CINAHL search strategy

#1 (MH "Infant, Premature")

#2 (MH "Labor, Premature")

#3 (MH "Infant, Low Birth Weight+")

#4 preterm birth

#5 low birth weight

#6 "neighborhood*"

#7 neighbourhood*

#8 residential area*

#8 #1 OR #2 OR #3 OR #4 OR #5

#9 #6 OR #7 OR #8

#10 #8 AND #9

PsycINFO search strategy

1. premature birth.mp. [mp=title, abstract, heading word, table of contents, key concepts, original title, tests & measures]

2. exp Premature Birth/

3. preterm birth.mp. [mp=title, abstract, heading word, table of contents, key concepts, original title, tests & measures]

4. exp Birth Weight/

5. low birth weight.mp. [mp=title, abstract, heading word, table of contents, key concepts, original title, tests & measures]

6. exp Neighborhoods/

7. neighborhood*.mp. [mp=title, abstract, heading word, table of contents, key concepts, original title, tests & measures]

8. residential area.mp. [mp=title, abstract, heading word, table of contents, key concepts, original title, tests & measures]

9. exp Social Environments/

10. social environments.mp. [mp=title, abstract, heading word, table of contents, key concepts, original title, tests & measures]

11. 1 or 2 or 3 or 4 or 5

12. 6 or 7 or 8 or 9 or 10

13. 11 and 12

14. neighbourhood*.mp. [mp=title, abstract, heading word, table of contents, key concepts, original title, tests & measures]

15. 6 or 7 or 8 or 9 or 10 or 14

16. 11 and 15

<u>ProQuest Dissertations and Theses Full Text</u>

#1 SU.exact("LOW BIRTH WEIGHT")

#2 all(infant premature)

#3 all(preterm birth)

#4 all(infant low birth weight)

#5 all(low birth weight)

#6 all(premature birth

#7 all(neighborhood*)

#8 all(neighbourhood*)

#9 all(residential area*))

#10 #1 OR #2 OR #3 OR #4 OR #5 OR #6

#11 #7 OR #8 OR #9

#12 #10 AND #11

APPENDIX F: CHARACTERISTICS OF STUDIES INCLUDED IN SYSTEMATIC LITERATURE REVIEW

First Authors, year	**Location**	**Year of births**	**Year of geographic unit data**	**Geographic unit**	**Sample size**	**Maternal race/ethnicity/birthplace**	**Maternal age**	**Infant Inclusion criteria**
(Anthopolos, James, Gelfand, & Miranda, 2011)	5 counties, NC	1998-2002	2000	CBG	127,049	NH white, NH black	15-44	Singleton births, no congenital anomalies
(Anthopolos, Kaufman, Messer, & Miranda, 2014)	Durham County, NC	2000-2008	2000	Other	5,327	NH white, NH black	15-44	Singleton births, no congenital anomalies, >20 weeks but <42 weeks, ≥400g, 1st-4th birth
(Baker & Hellerstedt, 2006)	7 counties, MN	1990-1999	1990	CT	27,936	Native-born vs. foreign-born black	-	Singleton births
(Bloch, 2011)	Philadelphia, PA	2003-2005	2000	CT	48,024	Native-born vs. foreign-born black, white	-	All births
(Brewin, 2007)	US	1996-2002	1994	CT	1,213	NH white, NH black	12-27	Singleton birth
(Chu, 2010)	Tri-county area, MI	1995-2007	-	CT	73,143	Native-born vs. foreign-born	All	All live singleton births
Collins 1 (J. W. Collins Jr & David, 1990) (J. W. Collins Jr & Shay, 1994) (J. W. Collins Jr & David, 1997) (J. W. Collins Jr et al., 1997)	Chicago, IL	1982-1983	1980	CT	103,072	White, black	≤35	All births
	Chicago, IL	1982-1983	1980	CA/CT	22,892	Hispanic	≤35	All live singleton births
	Chicago, IL	1983	1983	CT	7,592	AA	≤35	All live singleton births
	Chicago, IL	1982-1983	1980	CT	62,841	NH white, NH black	-	All singleton births
(J. W. Collins Jr, Schulte, & Drolet, 1998)	Chicago, IL	1990	1990	CA	50,308	NH white, NH black, Mexican-American	≤35	Singleton births
Collins 3 (J. W. Collins Jr, David,	Chicago, IL	1989-1991 (infants), 1956-1975 (mothers)	1960, 1970, 1990	CT	3,104	NH white, NH black	≤35	Singleton births

Simon, & Prachand, 2007) (J. W. Collins Jr, Wambach, et al., 2009) (J. W. Collins Jr, David, et al., 2009) (J. Collins Jr et al., 2011) (J. W. Collins Jr et al., 2011) (J. Collins Jr, Rankin, & Hedstrom, 2012) (J. Collins Jr, Rankin, & Janowiak, 2013) (Love et al., 2010)	Chicago, IL	1989-1991 (infants), 1956-1975 (mothers)	1960, 1970, 1990	CA/CT	36,061	NH white, NH black	15-35	Singleton births
	Chicago, IL	1989-1991 (infants), 1956-1976 (mothers)	1960, 1970, 1990	CA	40,648	NH black	15-35	Live singleton births
	Chicago, IL	1989-1991 (infants), 1956-1976 (mothers)	1960, 1970, 1990	CA/CT	72,555	NH white, NH black	15-35	Singleton births
	Chicago, IL	1989-1991 (infants), 1956-1976 (mothers)	1960, 1970, 1990	CA	-	NH black	15-35	All live singleton births
	Chicago, IL	1989-1991 (infants), 1956-1976 (mothers)	1960, 1970, 1990	CA/CT	3,456	Mexican-American	15-35	Live singleton births
	Chicago, IL	1989-1991 (infants), 1956-1976 (mothers)	1960, 1970, 1990	CA/CT	86,356	NH white, NH black	≤35	Singleton births
	Cook County, IL	1989-1991 (infants), 1956-1976 (mothers)	1960, 1970, 1990	CA	-	NH white, NH black	15-35	Live singleton births, >20 weeks
(Cubbin et al., 2008)	FL and WA	1997-1998	2000	CT	8,359	AA, Asian/Pacific Islander, Latina, Native American, European American, other/unknown	All	Live singleton births
(Debbink & Bader, 2011)	MI	2000	2000	CT	109,238	White, black	-	Singleton births
(Devine, 2009)	CO	2000-2005	2000	CT	356,389	NH white, black, Hispanic white; Mexican-born and US-born Mexican origin	11-53	All live singleton births
(Doebler, 2011)	Pittsburgh, PA	2003-2006	2000	CBG/CT	52,551	NH white, NH black	-	All singleton births
(Dooley, 2010)	Hamilton County, OH	2001-2003	2000	Other	28,793	NH white, NH black, Asian/Pacific Islander, Hispanic	All	-
(English et al., 2003)	San Diego County, CA	1980, 1990	1980, 1990	Gridpoints (0.5 miles)	39,729	NH white, NH black, Hispanic	All	Live singleton births
(Fang et al., 1999)	New York City, NY	1988-1994	1990	CT	553,947	NH white, native-born NH black, foreign-born NH black	All	Live singleton births
(Finch, Lim, Perez, & Do, 2007)	Los Angeles County, CA	2000	2000	CT	140,472	NH white, NH black, NH Asian, Hispanic, other	12-54	Singleton births without extreme birth weight or gestational age
(Gould & LeRoy, 1988)	Los Angeles County, CA	1982-1983	1980	Other	127,558	NH white, NH black	-	Singleton births, > 500g

Grady 1 (Grady, 2006)	New York City, NY	2000	2000	CT	96,882	Native-born and foreign-born AA, native-born and foreign-born white	-	Live singleton births
(Grady & McLafferty, 2007)	New York City, NY	2000	2000	CT	36,397	Native-born black, foreign-born black	-	Live singleton births
(Grady & Ramírez, 2008)	New York City, NY	2000	2000	CT	91,748	AA, white	All	Live singleton births
(Grady, 2010)	Detroit, MI	2004-2006	2000	CT	137,965	AA, other	-	Live births
(Gray, Edwards, Schultz, & Miranda, 2014)	NC	2002-2006	2000	CT	457,642	NH white, NH black, Hispanic	15-44	Live singleton births, no congenital anomalies, ≤4 previous deliveries, 24-42 weeks, ≥400g
(Henry Akintobi, 2006)	FL, GA, LA	1999-2001	2000	CT	255,548	US-residents NH white, NH black	15-49	Live singleton births, 1st birth, <45 weeks, within 2.5 standard deviations of gestational age mean
(Hillemeier, Weisman, Chase, & Dyer, 2007)	PA	2002	2000	ZIP code	11,546	NH white, NH black, Hispanic, other	All	Singleton births, 1st birth
MODE-PTD Project (Holzman et al., 2009)	PA, MD, MI, NC	1995-2001	2000	CT	182,938	NH white, NH black	20-39	Singleton births
(Mason et al., 2009)	Wake & Durham County, NC	1999-2001	2000	CT	31,715	NH white, NH black	All	Live singleton births, >20 weeks, <3,888g for PTB
(Messer, Kaufman, Dole, Herring, & Laraia, 2006)	Raleigh, Wake County, NC	1999-2001	1999, 2000, 2001	CBG	30,481	NH white, NH black	All	Live singleton births
(Messer, Kaufman, Dole, Savitz, & Laraia, 2006)	Raleigh, Wake County, NC	1999-2001	1999, 2000, 2001	CBG	30,481	NH white, NH black	All	Live singleton births
(Messer, Kaufman, Mendola, & Laraia, 2008)	Wake County, NC	1999-2001	2000	CT	22,713	NH white, NH black	All	Singleton births, <3,888g for PTB
(Messer, Vinikoor, et al., 2008)	PA, MD, MI, NC	1995-2001	2000	CT	231,912	NH white, NH black	-	Singleton births, <3,888g for PTB
(Messer et al., 2010)	Wake & Durham County, NC	1999-2001	2000	CT	31,715	NH white, NH black	All	Live singleton births, >20 weeks, <3,888g for PTB
(P. O'Campo et al., 2008)	PA, MD, MI, NC	1995-2001	2000	CT	-	NH white, NH black	All	Singleton births, <3,888g for PTB

(Schempf et al., 2011)	Wake & Durham County, NC	1999-2001	2000	CBG	31,489	NH white, NH black	All	Singleton births, >500g, >20 weeks but <44 weeks
(Vinikoor, Kaufman, MacLehose, & Laraia, 2008)	Wake & Durham County, NC	1999-2001	2000	CT	10,355	AA	All	Singleton births, >300g but <5,000g
(Howell, Pettit, & Kingsley, 2005)	OH, CO, IN, CA	1990-2000	1990-2000	CT	-	NH white, NH black, Hispanic	-	-
(Huynh & Maroko, 2014)	New York City, NY	2008-2010	1990, 2005-2009	Other	126,165	NH white, NH black, NH Asian/Pacific Islander, Hispanic	20+	Singleton births, 1st birth, no congenital anomalies, 20-45 weeks
(Jaffee & Perloff, 2003)	New York City, NY	1991-1992	1990	ZIP code	138,761	NH white, NH black	-	Live singleton births
New York (Janevic et al., 2010)	New York City, NY	1998-2002	1990, 2000	CT	492,332	NH white, AA, African, East Asian, South Asian, NH Caribbean, Hispanic Caribbean, Mexican, Central/South American	All	Live singleton births
(Mason et al., 2010)	New York City, NY	1995-2003	1990, 2000	CT	249,785	African-, Caribbean-, and US-born black (NH black)	All	Live singleton births, >20 weeks
(Mason et al., 2011b)	New York City, NY	1995-2003	1990, 2000	CT	887,887	NH white, NH black, Spanish Caribbean, Central American (plus Mexican), South American Hispanic, East Asian, & South Asian	All	Live singleton births, >20 weeks
(Mason et al., 2011a)	New York City, NY	1995-2003	1990, 2000	CT	256,673	NH black	All	Live singleton births, >20 weeks
(T. Johnson, Drisko, Gallagher, & Barela, 1999)	Denver, CO	1992-1994	1990, 1992-1994	Other	23,818	AA, white, Hispanic	-	Singleton births, no congenital anomalies
(M. A. Johnson & Marchi, 2009)	CA	1995-2005	2000	CT	-	Mexican Hispanic	15-47	Live singleton births
(Kent, McClure, Zaitchik, & Gohlke, 2013)	AL	1990-2010	2000	ZIP code	490,366	NH white, NH black, Hispanic	-	Births ≥24 weeks, ≥200g
(M. Kramer, Dunlop, & Hogue, 2014)	GA	1994-2007	1990, 2000, 2005-2009	CT	1,000,437	NH white, NH black, Hispanic	10+	Live singleton births
(Kruger, Munsell, & French-Turner, 2011)	Flint, MI	-	2000	Gridpoints (0.25 miles)	-	AA, white	-	Singleton births
(Ma, 2013)	SC	2008-2009	2000	CT	98,456	NH white, NH black	-	Singleton births, within 3 standard

								deviations of birth weight, ≥20 weeks
(Madkour, Harville, & Xie, 2014)	US	2007-2008	-	CBG	600	NH white, NH black	<20	Live singleton births
(Mair & Gruenewald, 2011)	CA	2001-2009	-	ZIP code	-	NH white, NH black, Hispanic, Asian/Pacific Islander	-	-
(Mendez, Hogan, & Culhane, 2011)	Philadelphia, PA	1999-2004	1999-2004	CT	4,104	NH white, NH black, Hispanic, other	-	Singleton births
Chicago91 (Masi et al., 2007) (Pickett, Collins, Masi, & Wilkinson, 2005)	Chicago, IL	1991	1990, 1991	CT	55, 130	NH white, NH black, Hispanic	-	Live singleton births, ≥500g but ≤5,000g, ≥20 weeks but ≤43 weeks
	Chicago, IL	1991	1990	CT	25,186	AA	All	Singleton births, ≥300g but ≤5,000g
(Messina & Kramer, 2013)	Atlanta, GA	1998-2006	1997-2006; 1990, 2000, 2005-2009	CBG, CT	54,036	NH white, NH black, other	All	Live singleton births, ≥20 weeks, ≥500g
(Miranda, Messer, & Kroeger, 2012)	Durham County, NC	2004-2008	2006-2007, 2008	Other	4,279	NH white, NH black, Hispanic	15-44	Singleton births, ≥28 weeks but ≤42 weeks, 1st-4th birth
(Morenoff, 2003)	Chicago, IL	1995-1996	1990, 1995	Clusters	101,662	Foreign-born vs. native-born NH white, NH black, Mexican, Puerto Rican, other Hispanic, other NH	-	Live singleton births
Nkansah-Amankra 2010 (Nkansah-Amankra, Luchok, Hussey, Watkins, & Liu, 2010) (Nkansah-Amankra, Dhawain, Hussey, & Luchok, 2010) (Nkansah-Amankra, 2010)	SC	2000-2003	2000	CT	8,064	AA, white	All	Live singleton births, ≥20 weeks, ≥500g, no congenital anomalies
	SC	2000-2003	2000	CT	5,730	AA, white	All	Live singleton births, ≥20 weeks, ≥500g, no congenital anomalies
	SC	2000-2003	2000	CT	8,064	AA	All	Live singleton births, ≥20 weeks, ≥500g, no congenital anomalies
O'Campo 1997 (P. O'Campo et al., 1997) (Patricia O'Campo, Caughy, Aronson, & Xue, 1997)	Baltimore, MD	1985-1989	1988, 1989	CT	50,757	White, black	-	-
	Baltimore, MD	1985-1989	1990	CT	-	-	-	-

(Pardo-Crespo et al., 2013)	Olmsted County, MN	-	2000	CBG	746	-	-	-
BWHS (G. S. Phillips et al., 2009)	US	1997-2003	2000	CBG	6,410	Black	21-45	Singleton births
(G. S. Phillips, Wise, Rich-Edwards, Stampfer, & Rosenberg, 2013)	US	1997-2003	2000	CBG	6,390	Black	-	Singleton births
(Ponce, Hoggatt, Wilhelm, & Ritz, 2005)	Los Angeles County, CA	1994-1996	1990	CT	37,347	NH white, NH black, Hispanic, other	All	Singleton births, ≥500g but ≤5000g, ≥90 days but ≤320 days, no cesarean section deliveries
(Rauh et al., 2001)	New York City, NY	1987-1993	1990	Other	158,174	Native-born NH white, NH black	20-39	Singleton births, 1st-2nd birth
(Reagan & Salsberry, 2005b)	US	1979-1998	1980, 1990, 2000	CT	5,892	Native-born NH white, NH black, Hispanic	14-41	Singleton births
(Reed, 2012)	NC	2004	2000	CBG	83,439	NH white, NH black	12-52	Singleton births, >20 weeks, no birth defects
(Richard, 2006)	East Baton Rouge Parish, LA	1990-1992, 1999-2001	1990, 2000	CBG, CT	75,157	White, black	15-44	All births
(Rich-Edwards et al., 2003)	Chicago, IL	1994-1996	1990	CT	96,887	Black, NH white	15-45	Singleton births
(Roberts, 1997)	Chicago, IL	1990	1990	CAs	112,327	NH white, NH black, Hispanic	-	All births
Sims 1 (Sims & Rainge, 2002)	Milwaukee, WI	1992-1994	1990	CBG	-	AA, white	-	-
(Sims, Sims, & Bruce, 2008)	US	1992-1994	1990	CBG	-	NH white, NH black, Latino	-	Live singleton births
(Sims, Sims, & Bruce, 2007)	WI	1998-1999	1990	ZIP code	100,074	NH white, NH black, Latino	≤35	Live singleton births
(South et al., 2012)	Hamilton County, OH	2003-2006	2000	CBG	41,724	NH white, NH black, Hispanic	All	Singleton births, 23-44 weeks, no congenital anomalies
(Strutz, Dozier, van Wijngaarden, & Glantz, 2012)	Finger lakes region, NY	2006-2007	2000	ZIP code	19,475	NH white	All	Live singleton hospital births

(Subramanian, Chen, Rehkopf, Waterman, & Krieger, 2006)	MA	1989-1991	1990	CBG, CT	226,927	NH white, NH black, NH Asian/Pacific Islander, NH American Indian, NH other, Hispanic	15-55	Singleton births, ≥150g and ≤6,000g,
(Vinikoor-Imler, Messer, Evenson, & Laraia, 2011)	Alamance, Chatham, Durham & Orange Counties, NC	2001-2005	2005, 2006	CBG	23,304	NH white, NH black	All	Live singleton births, 22-42 weeks, >500g but <6,000g
(D. Wallace, 2011)	New York City, NY	1998-2001	1970, 1980, 1990, 2000	Other	293	AA, Dominican	-	Live births
(M. Wallace et al., 2013)	Bogalusa, LA	1990-2009	2000	CBG	866	AA, white	13-41	Live singleton births, 1st birth

CT = census tract; CBG = census block group; CA = community area; Other = health districts, health areas, city planning department neighborhood designations, and other non-standardized community areas

APPENDIX G: SUPPLEMENTARY GRAPHS FOR MANUSCRIPT 2

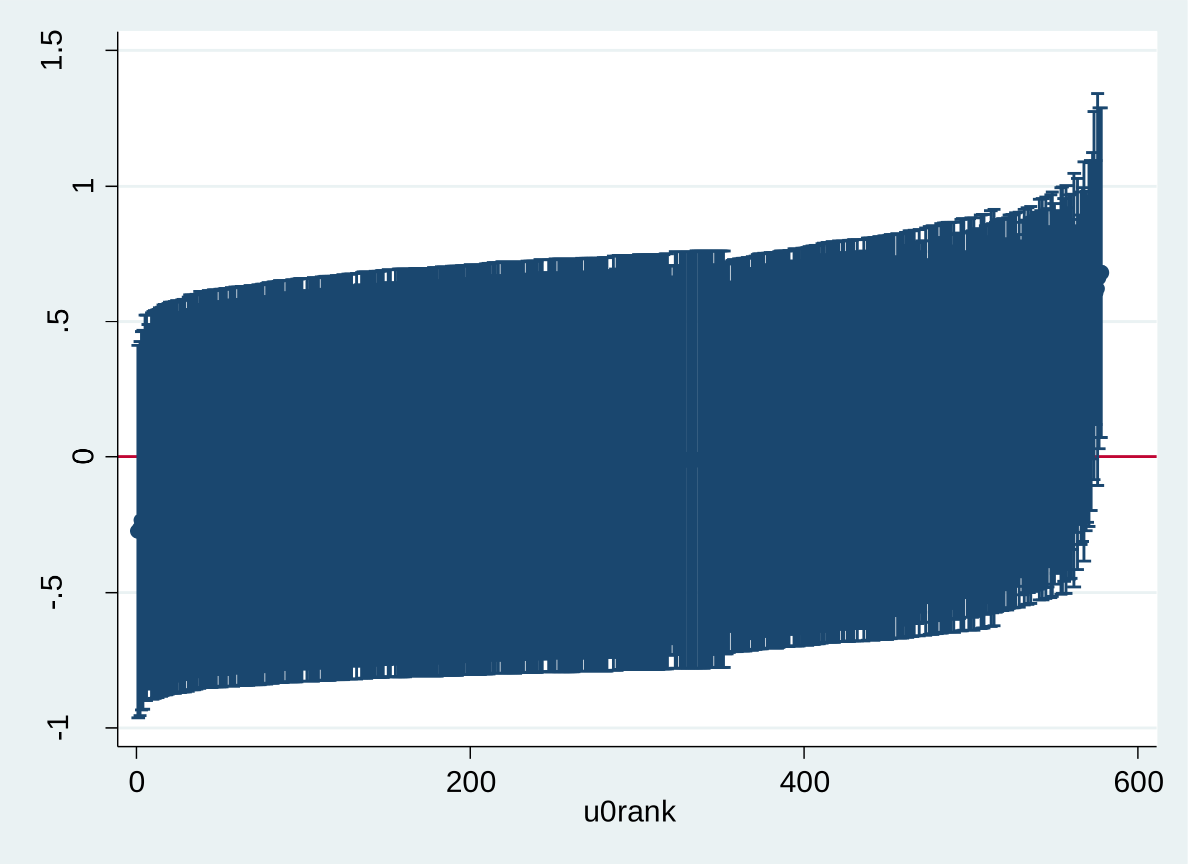

Figure 17. Caterpillar plot showing grandmother's neighborhood residuals with 95% confidence intervals for log-odds of infant low birth weight

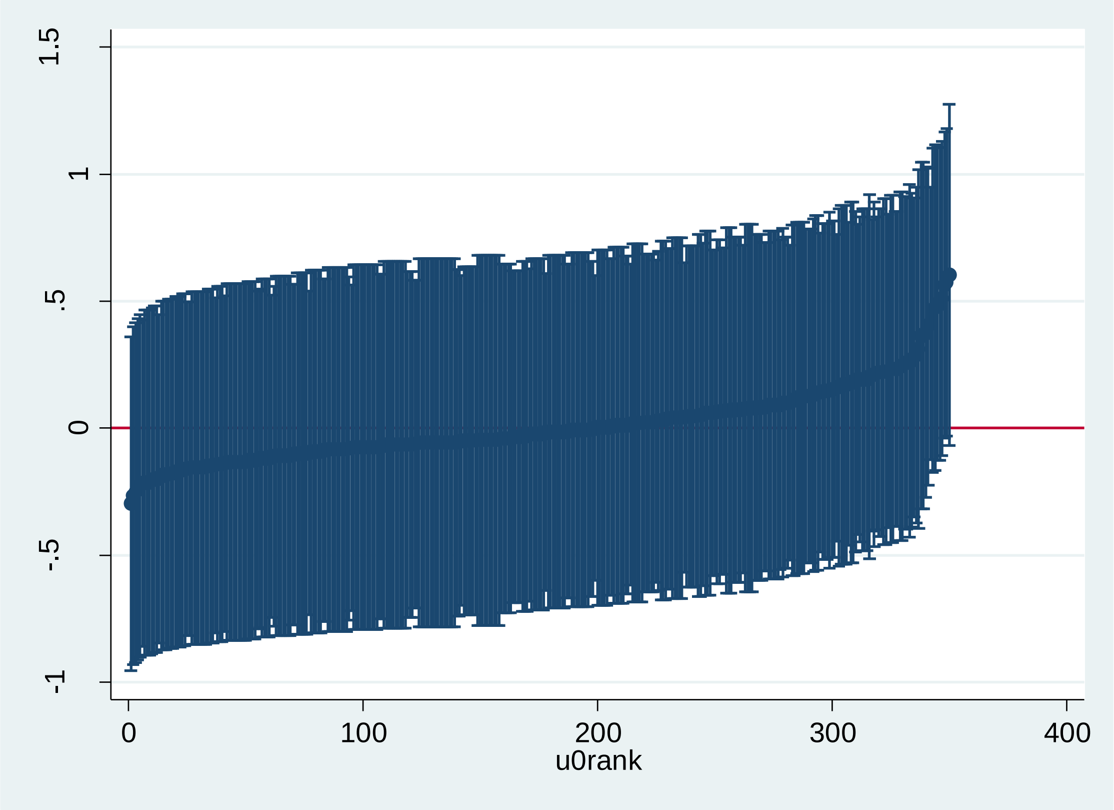

Figure 18. Caterpillar plot showing mother's neighborhood residuals with 95% confidence intervals for log-odds of infant low birth weight

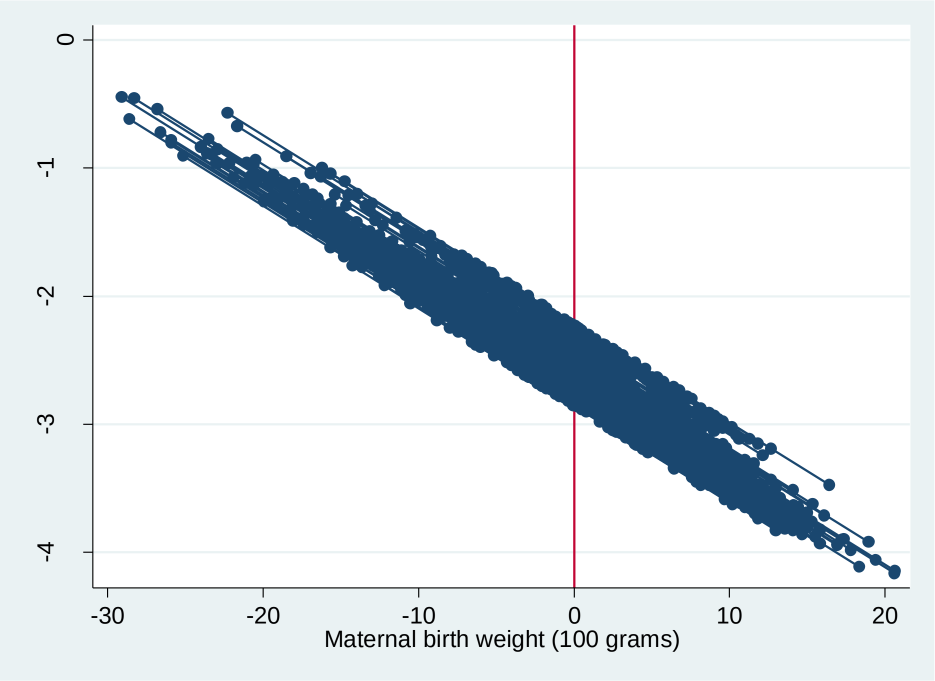

Figure 19. Predicted mothers' neighborhood lines for relationship between log-odds of infant low birth weight and mother's birth weight

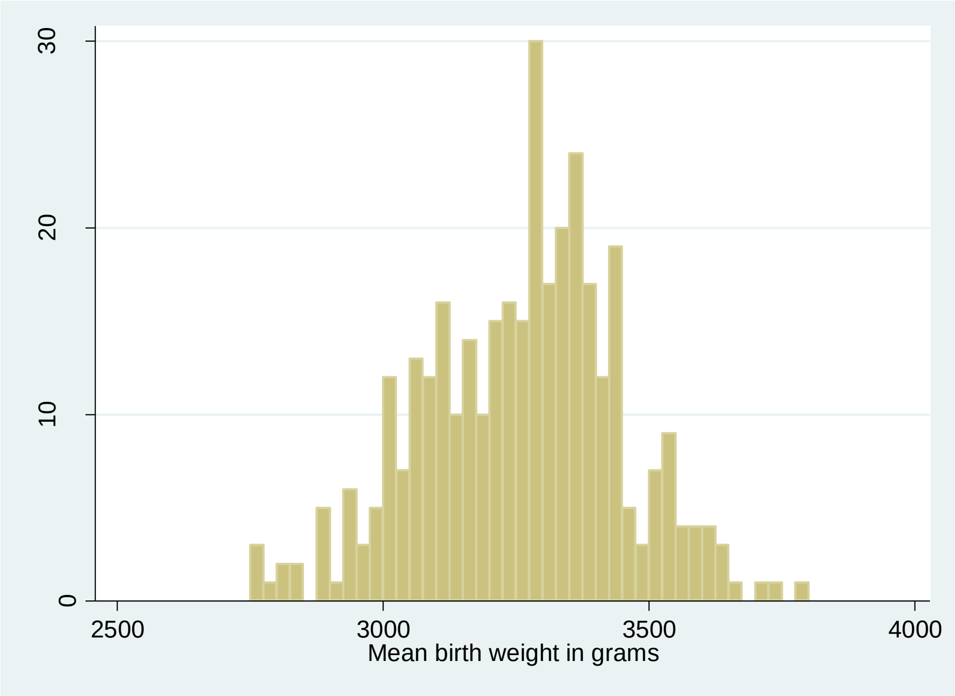

Figure 20. Distribution of census tract mean mother's birth weight

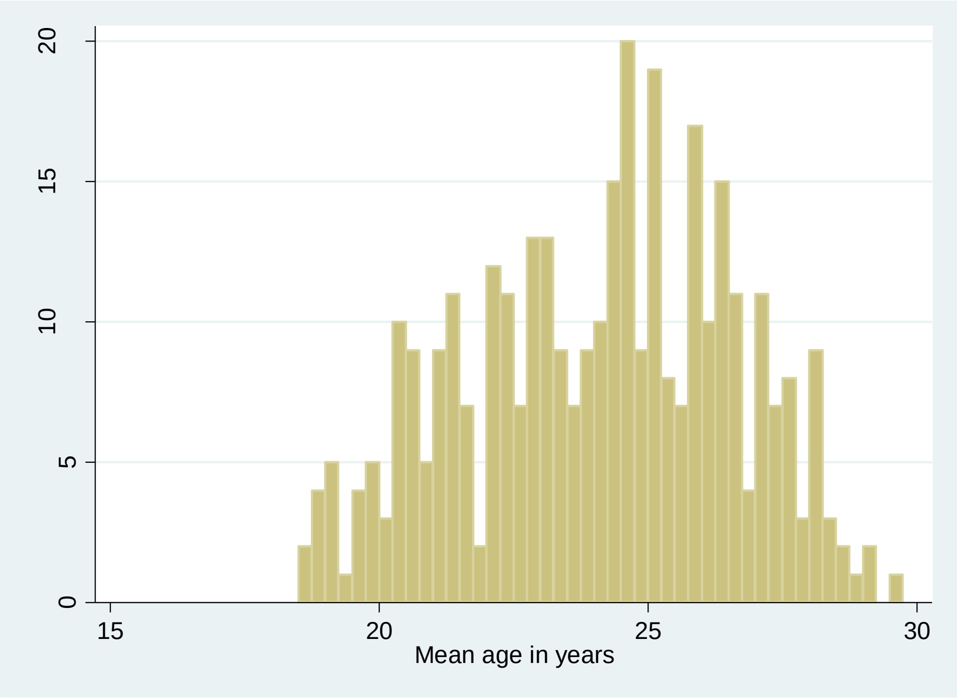

Figure 21. Distribution of census tract mean mother's age

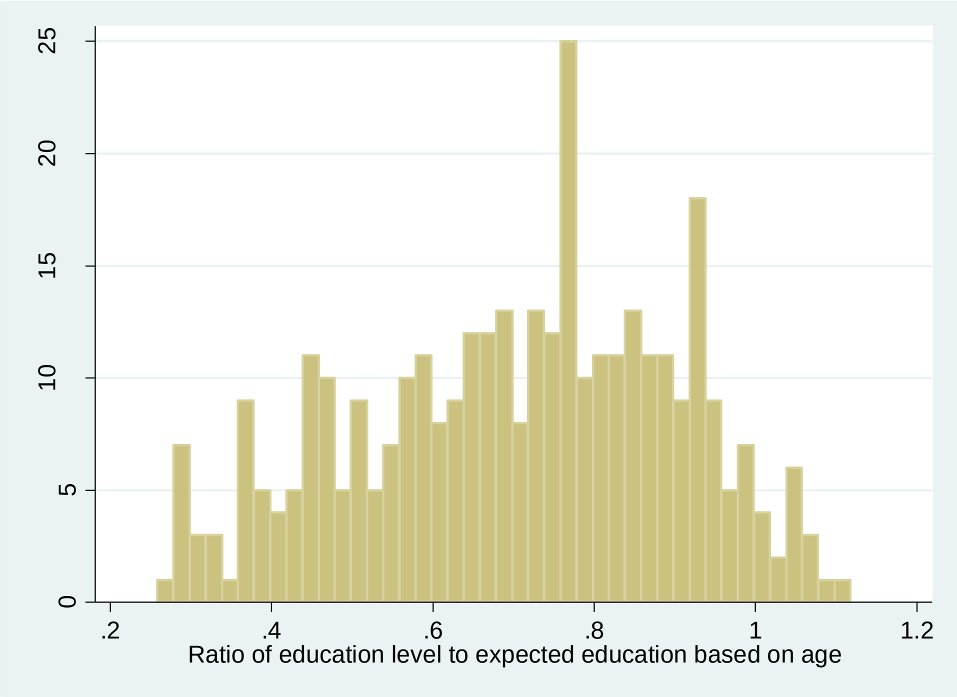

Figure 22. Distribution of census tract mean mother's educational attainment ratio

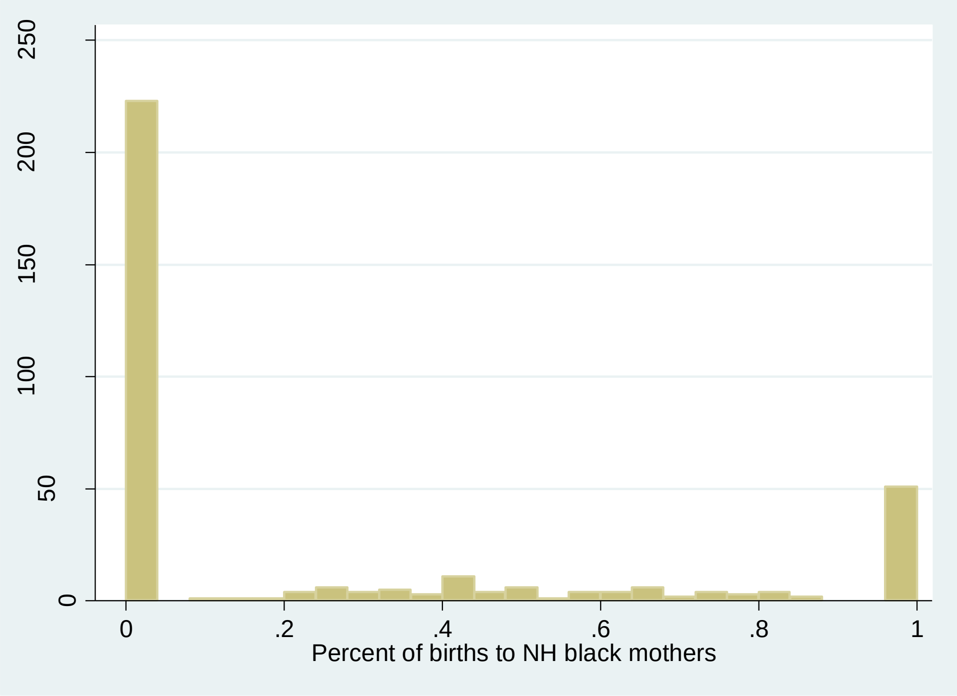

Figure 23. Distribution of census tract proportion of births to NH black mothers

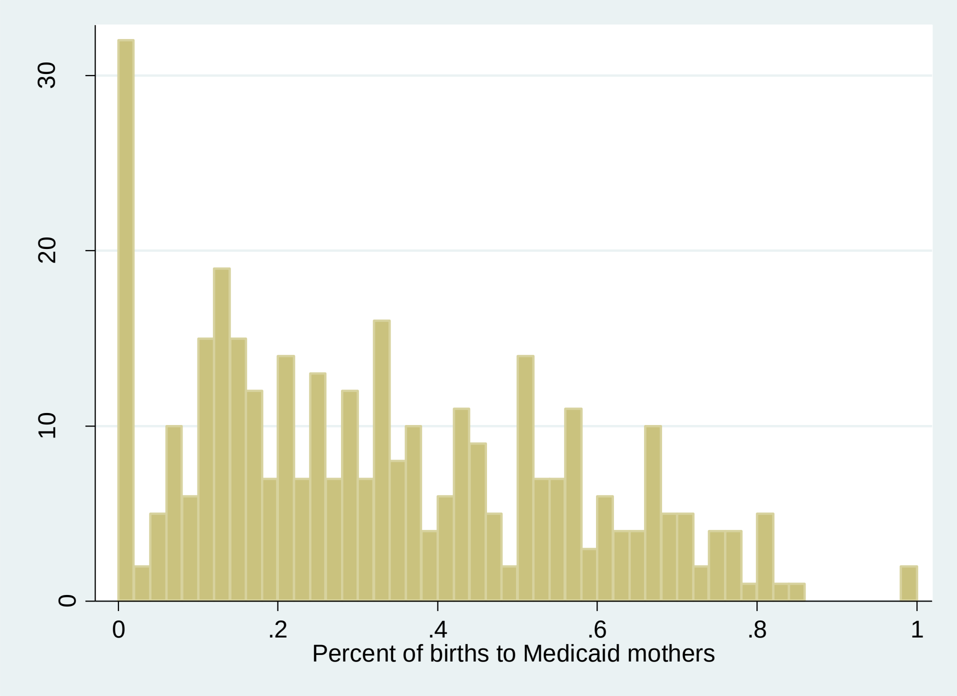

Figure 24. Distribution of census tract proportion of births to mothers on Medicaid

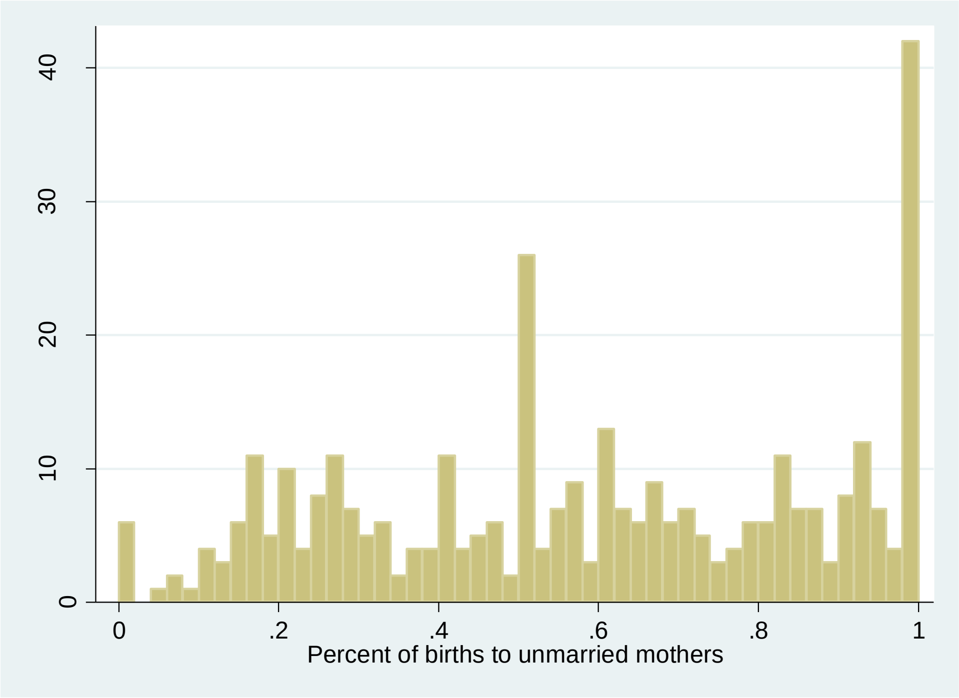

Figure 25. Distribution of census tract proportion of births to unmarried mothers

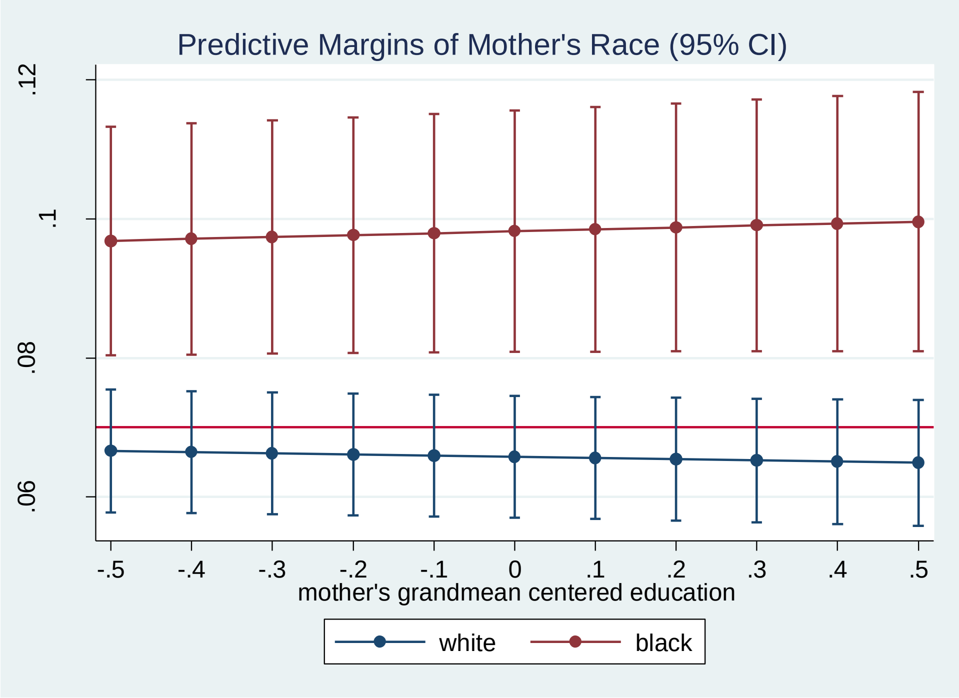

Figure 26. Predictive margins of the effect of mother's race on infant low birth weight dependent on mother's education ratio

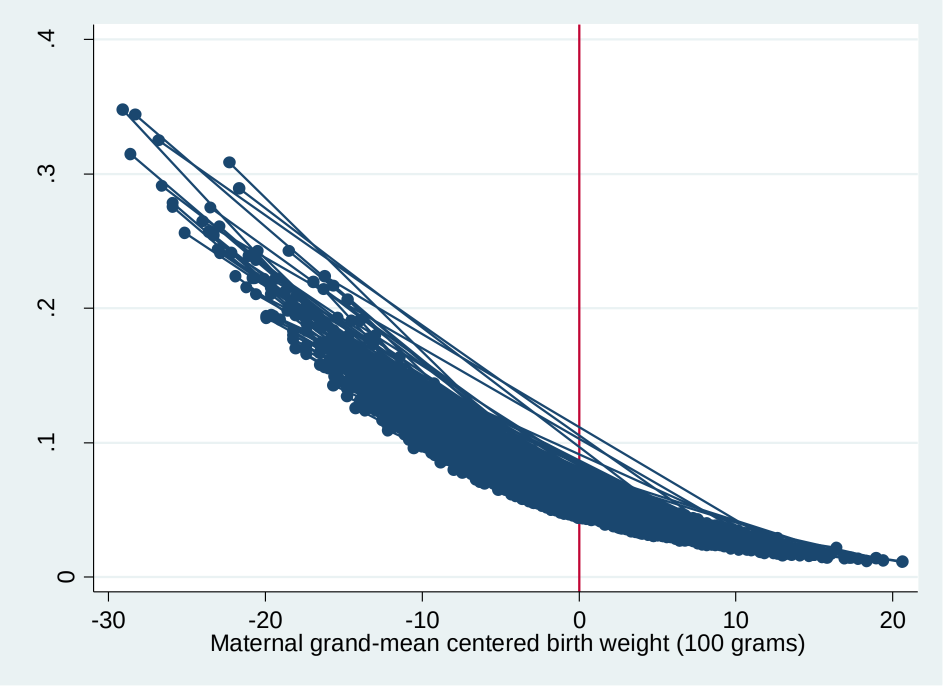

Figure 27. Predicted mothers' neighborhood lines for relationship between log-odds of infant moderate low birth weight and mother's birth weight

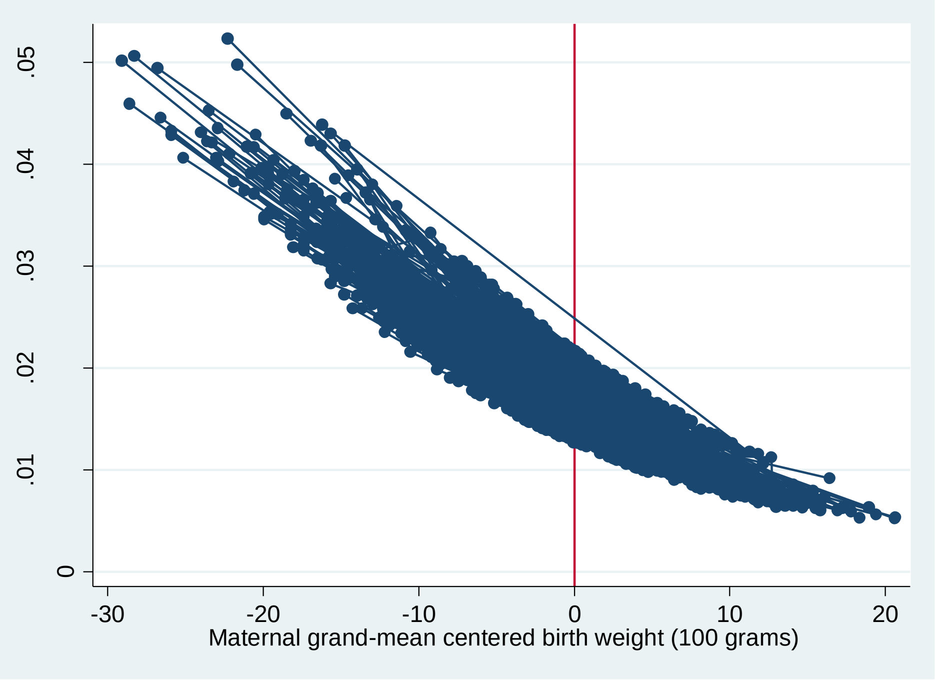

Figure 28. Predicted mothers' neighborhood lines for relationship between log-odds of infant very low birth weight and mother's birth weight

APPENDIX H: SUPPLEMENTARY GRAPHS FOR MANUSCRIPT 3

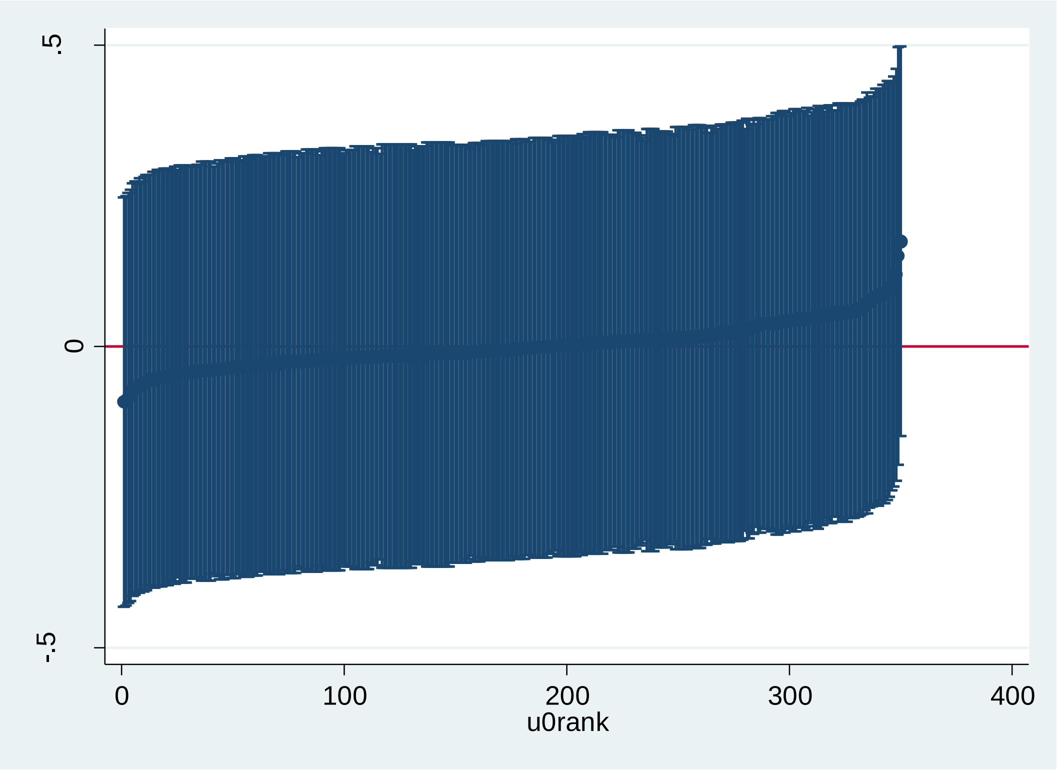

Figure 29. Caterpillar plot showing mother's neighborhood residuals with 95% confidence intervals for log-odds of infant preterm birth

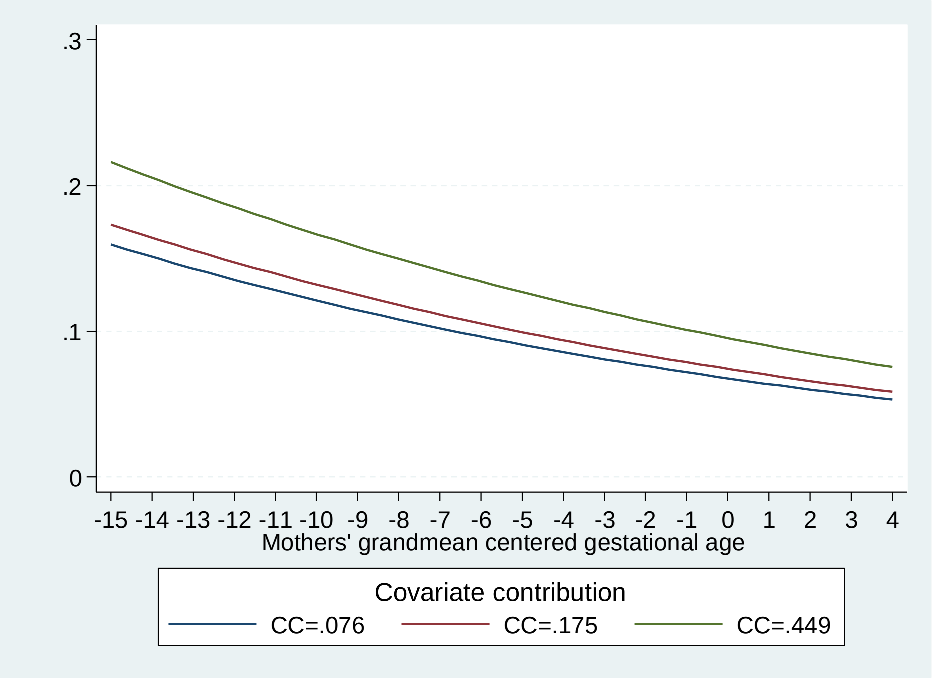

Figure 30. Predicted probabilities of preterm birth as a function of mothers' gestational age and other covariates

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