THE ESTIMATION OF NEIGHBORHOOD DEPRIVATION AND PRETERM BIRTH USING LONGITUDINALLY LINKED NATALITY RECORDS

By

Cristin Elizabeth McArdle

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Epidemiology—Doctor of Philosophy

2019

ABSTRACT

THE ESTIMATION OF NEIGHBORHOOD DEPRIVATION AND PRETERM BIRTH USING LONGITUDINALLY LINKED NATALITY RECORDS

By

Cristin Elizabeth McArdle

This dissertation examined the association between neighborhood-level deprivation and perinatal outcomes. We studied the association between neighborhood poverty rate and pre-term birth (PTB; birth < 37 weeks) using longitudinal maternally-linked natality files of women and their infants in Michigan during the period 1990-2012. This study examined the embodiment of place and role of maternal characteristics during pregnancy in an effort to understand how selection into neighborhood may bias our understanding of neighborhood level associations. We looked at pregnancy outcomes across multiple pregnancies for the same woman (the mother) as she changed neighborhoods, and levels of poverty between pregnancies. In the first study examining residential mobility between pregnancies, we reported that approximately half of our sample changed residences between pregnancies. We further exploited our data structure to examine the association with prior PTB on subsequent mobility in two sub-samples restricted by parity: births 1 and 2, and births 2 and 3. We found the strongest risk factors for mobility were related to marital change (Divorce: births 1 to 2 OR: 2.5 95% CI: 2.4-2.6, births 2 to 3 OR: 3.3, 95% CI: 3.1-3.6); Married: births 1 to 2 OR: 2.8, 95% CI: 2.7-2.8, births 2 to 3 OR: 1.9, 95% CI:1.9-2.0) but not prior PTB (prior PTB: births 1 to 2 OR: 1.0, 95% CI:1.0-1.0, births 2 to 3 OR: 1.1 95%CI: 1.0-1.1). In the second study, we report that most women did not experience a change in the level of neighborhood poverty, based on quartile of neighborhood poverty. Women who remained in the poorest neighborhoods experienced the highest percentage of PTB across two births samples, Births 1 to 2 (11.4% PTB) and Births 2 to 3 (12.3% PTB). We found

increased odds of PTB for births 1 to 2 with strong downward neighborhood trajectory (OR 1.2, 95% CI 1.0-1.3) but also increased odds of PTB among strong upward neighborhood poverty trajectory (OR 1.1, 95%CI: 1.1- 1.2) compared to the static trajectory group of lowest neighborhood poverty quartile. In Study 3, we then employed a novel approach, maternal fixed effects, utilizing data linked over time to compare birth outcomes for the same mother under different exposures which allows the mother to act as her own control, analogous to a case-crossover design, while comparing the contextual effects of neighborhood deprivation on PTB. We conducted logistic regression, random effects and fixed effects analysis to evaluate n=2,191,063 eligible births during our study period. Because a fixed effects model relies on variation over time within a mother to identify the estimated association of neighborhood deprivation and PTB, the primary analytic sample was restricted (n=280,277 births to 103,328 women).We found a null association between neighborhood poverty and PTB when using a maternal fixed effects analysis (OR: 1.0, 95% CI: 1.0-1.0). This was one of the first studies to profile the maternal neighborhood mobility patterns over a long period of time, between successive pregnancies and evaluated by neighborhood poverty rate.

This dissertation is dedicated to my mother, you are simply the most intelligent and loving person and it is the great fortune of my life to call you Mom. I love you.

ACKNOWLEDGEMENTS

I would like to thank my advisor and dissertation committee chair, Dr. Claire Margerison, for her invaluable suggestions and guidance from the beginning to end of this process. I am also very grateful to my dissertation committee members, Dr. Nigel Paneth, Dr. Zhehui Luo, and Dr. Sue Grady, for their encouragement and guidance throughout this process. Thank you to Dr. David Barondess and Nancy Beiber for your help navigating this process. I would like to thank Dr. Ellen Velie for starting me on this journey and the strong foundation she provided. I would like to express my appreciation to Glenn Copeland for his work in developing the maternally-linked dataset and Dr. Yu ‘Seashore’ Li, for her work in cleaning much of the initial datasets.

I want to thank my many champions, none greater than my friends and family. Thank you for the strength and support when needed and for many hours of laughter and love. In particular, I want to thank my Dad, who spent his lifetime filling my head with sage advice and gentle encouragement – I will always hear your voice even if you cannot speak. LYC. Mom, you are the best. I love you. Mick and Tim, I love you too.

For Joel, thank you for your love and time and many hours of discussion that made these papers and my life so much better. I love you. For Sammy and Jackie, you are my world and I hope to spend my life filling yours with all the love, sage advice, and gentle encouragement so that you too find yourselves in the delightful position of setting out and achieving a dream. I am the luckiest. I love you.Thank you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

KEY TO ABBREVIATIONS

ACS	American Community Survey
AGA	Appropriate for gestational age
CI	Confidence Interval
FE	Fixed effect
GA	Gestational age
HS	High school
LGA	Large for gestational age
MAUP	Modifiable aerial unit problem
MI	Michigan
MDHHS	Michigan Department of Health and Human Services
NCDB	Neighborhood Change Database
NH	Non-Hispanic
AI/AN	Non-Hispanic American Indian/ Alaska Native
A/PI	Non-Hispanic Asian/Pacific Islander
NHB	Non-Hispanic Black
NHW	Non-Hispanic White
OR	Odds Ratio
PTB	Preterm Birth
Q1	Quartile 1
Q2	Quartile 2
Q3	Quartile 3
Q4	Quartile 4
RE	Random effect

RR	Relative Risk
SGA	Small for gestational age
SES	Socioeconomic status
SD	Standard deviation
US	Unites States

INTRODUCTION

Background

Preterm Birth and Disparities

Adverse perinatal outcomes have potential negative lifelong consequences (Barker et al. 1993) and thus provide a salient opportunity for intervention with lasting impact. Preterm birth, or birth before 37 weeks of completed gestation, is the most significant cause of neonatal mortality and morbidity worldwide (Harrison and Goldenberg 2016). The global incidence of PTB varies by location but is estimated at between 5-15% representing 15 million births per year (Blencowe et al. 2013). In the U.S. the incidence of PTB is approximately 11-12% of live births. Compared with other developed countries the U.S. has the highest rates of preterm birth PTB accounting for 42% of the 1.2 million preterm births occurring in developed countries (Koullali et al. 2016). This extreme discrepancy suggests a greater need for prevention (MacDorman and Mathews 2011).

Prevention can be a challenge given that in almost half of PTB cases there is no risk factor identified (Blencowe et al. 2013; Menon 2008). The most significant indicator of risk for preterm birth is a maternal history of prior preterm birth, although the exact mechanism for this risk is not fully understood it may be related to genetic, epigenetic or environmental factors (Plunkett and Muglia 2008; Yang et al. 2016). Additional maternal risk factors for PTB include young or advanced maternal age (Muglia and Katz 2010), increased parity, shorter inter-pregnancy interval (DeFranco et al. 2007; Thiel de Bocanegra et al. 2014). Risk factors specific to pregnancy include smoking during pregnancy, adequacy of prenatal care, male infant sex, and multiple pregnancy (Committee on Practice Bulletins—Obstetrics, The American College of Obstetricians and Gynecologists 2012). Additional social risks include low socioeconomic status (Bertin et al. 2015; Smith et al. 2007) and Non-Hispanic Black race/ethnicity. The rates of PTB vary by race and socioeconomic status, even after controlling for individual level medical and behavioral factors, hinting at an underlying social process (Culhane and Goldenberg 2011; Lhila and Long 2012; Thoma et al. 2019). There are enormous societal and medical costs related to prematurity, which affects survival and quality of life of the infant that extends beyond infancy. Recent estimates report that the cost of care in a single year for the 1 in 10 infants born prematurely was $6 billion, as the most conservative estimate based on employer-sponsored plans (Grosse et al. 2017).

Racial and ethnic disparities in preterm birth have long been the subject of study. The black-white disparity in risk for preterm birth is well established but remains particularly stubborn (Kramer et al. 2010; McKinnon et al. 2016). Possible explanations have focused on fetal programming potential reproductive outcomes(Burris and Collins 2010) and cumulative weathering as a physical manifestation of lifelong accumulative of deleterious social exposures (Geronimus et al. 2006). The complex and multifactorial pathways are incompletely understood, and may not be the same for individual birth outcomes and health disparities, but the consequences of PTB remain severe and well documented including being the foremost cause for infant mortality and development of chronic comorbidities (MacDorman and Mathews 2011).

Neighborhood as a Determinant of Adverse Birth Outcomes

Maternal characteristics, measured at the individual-level, fail to explain persistent disparities in preterm birth outcomes which may be driven by structural conditions (Lhila and Long 2012). One example of a growing body of literature that examines structural conditions is that of the neighborhood effects on birth outcomes. Research focusing on neighborhood as a determinant of adverse birth often defines the neighborhood context in relation to deprivation, constrained socioeconomic position measured at the area-level, such as high poverty, or crime, or as a composite score of neighborhood deprivation income and other neighborhood contextual factors (e.g. % college education and % housing owner-occupied). Neighborhoods are often defined using administrative boundaries such as census tracts. In the U.S. census tracts are relatively homogenous and permanent geographical groupings encompassing between 2,500-8,000 people (Bureau n.d.). Using census tract neighborhood definitions evidence consistently shows a modest association between neighborhood deprivation and PTB (Holzman et al. 2009; Messer et al. 2008; O'Campo et al. 2008; Yang et al. 2016; Vos et al. 2014). The association between neighborhood deprivation and increased risk for adverse perinatal outcomes persists even after adjustment for maternal covariates (Luo et al. 2006; Schempf, Strobino, and O'Campo 2009; Janevic et al. 2010). A recent meta-analyses of neighborhood deprivation and PTB showed a 27% higher risk for PTB [OR 1.27, 95%CI:1.16,1.39] for mothers living in the most (compared to the least) deprived neighborhoods (Ncube et al. 2016).

These studies of neighborhood deprivation have primarily measured exposure to neighborhood deprivation at a cross section single point in time. More recent scholarship builds on the study of neighborhood deprivation by evaluating trajectory patterns in and out of deprived areas over at least two time points (Collins, Rankin, and David 2015; Bruckner, Kane, and Gailey 2019) using longitudinal data linked to census geographic data. Generally these trajectory patterns show the direction of neighborhood poverty exposure where upward trajectory reflects decreased neighborhood poverty, downward trajectory reflects increased neighborhood poverty, and static trajectory represents no change in neighborhood poverty level. These trajectory patterns explore exposures in a single individual and across families. Deprivation trajectories are thus measured inter-generationally (Collins, Mariani, and Rankin 2018; Collins, Rankin, and David 2015; Pearl et al. 2018) and within mothers (Bruckner, Kane, and Gailey 2019). Similar to cross sectional findings, studies of neighborhood trajectories report a modest association between neighborhood deprivation and adverse birth outcomes. The magnitudes of the reported effects are related to the magnitude of the trajectory change, with greater trajectory changes representing stronger associations between neighborhood deprivation and PTB. Upward trajectory reduced preterm birth among upper born white women while downward mobility was more deleterious for birth outcomes (Collins, Rankin, and David 2015). The authors also report a stronger effect of downward mobility among women who were born into more impoverished areas.

Neighborhood Context and Pathway

While the neighborhood effects literature consistently shows modest association with birth outcomes there is less consistency in identifying or directly addressing the pathway by which neighborhood context affects health (Kane et al. 2017). The neighborhood context itself can represent several different pathways by which birth outcome risk operates with a variety of measures represented including crime (Messer, Vinikoor-Imler, and Laraia 2012), income (Farley et al. 2006; Metcalfe et al. 2011), housing tenure (Morris, Manley, and Sabel 2018), built environment (Miranda, Messer, and Kroeger 2012), greenspace (Cusack et al. 2018) and walkability (Messer, Vinikoor-Imler, and Laraia 2012), residential segregation (A. H. Schempf et al. 2011) and racial isolation (Anthopolos et al. 2011), and social environment (Messer, Vinikoor-Imler, and Laraia 2012). While these area-level measures may each contribute to a full contextual understanding of the associations with neighborhoods and birth outcomes we chose to focus on neighborhood deprivation because we believe structural conditions may be addressed through policy action and because it is one of the most studied, making methodological comparisons more informative.

For birth outcomes, there may be a two-fold mechanism by which neighborhood deprivation is thought to affect birth outcomes either through psychosocial factors or through access to material resources or both simultaneously. Psychosocial factors related to neighborhood deprivation include stress (allostatic load, susceptibility to infection), as well as poor coping behaviors leading to worse birth outcomes (smoking, alcohol use). Material resources include housing, proximity to health care, food security and access, as well as the physical environment. A mother's neighborhood environment informs her health through these factors; however, the pathway may not be the same for each birth outcome. Here we focus on the material resources pathway by examining poverty although there may be unmeasured psychosocial factors related to moving and poverty. In fact, we structure our analysis in response to the absence of a complete understanding of the mechanism of these neighborhood effects.

Selection Bias in Neighborhood Effects

A major problem in the identification of causality in studies reporting neighborhood effects is related to selection bias (Jencks and Mayer 1990; Verheij et al. 1998; Bergström and Van Ham 2010; Hedman and van Ham 2012; Ha et al. 2016; Chetty, Hendren, and Katz 2016; van Ham, Boschman, and Vogel 2018). However, few epidemiological studies include controls for selection bias in the estimation of neighborhood effects despite a firm consensus on the potential interference with causality. In our studies, selection bias occurs when the mechanism of living in a neighborhood (selection) is not independent from preterm birth. As an example, if Non-Hispanic Black women are more likely to move into a neighborhood with high poverty compared to Non-Hispanic White women and this selection mechanism is not controlled for adequately we may incorrectly observe a correlation between maternal race/ethnicity and PTB as a neighborhood effect. Therefore, the validity of findings from studies examining associations between neighborhood deprivation and PTB depends upon the extent to which the neighborhood measure represents the exposures of the population measured. Unobserved maternal characteristics are particularly problematic when examining selection bias as they are not explicitly measured and therefore we cannot control for them the way we can for race/ethnicity. If there is a large amount of selection bias then the measurement reflects the factors that cause a woman to live in a neighborhood. If these are also associated with her risk of PTB we may have confounding in our estimates.

In order to better understand selection we examine 3 mechanisms by which there may be selection bias in the study of the association between neighborhood poverty and preterm birth (1) residential mobility, selective sorting by changing residential locations (2) poverty trajectory, selective sorting into specific levels of poverty and (3) unobserved maternal characteristics, selective sorting into neighborhoods by maternal characteristics which are not measured as covariates in our data. In order to better control for selection mechanisms we need to better understand the selective sorting patterns before we can distinguish between the causal effects of neighborhood and the results of neighborhood selection.

Study Objectives

Main Research Question: The overall goal of this dissertation is to characterize maternal neighborhood mobility between pregnancies, to determine the association between neighborhood poverty mobility and PTB, and to assess whether previously observed associations between neighborhood poverty and PTB are due to selection of mothers into neighborhoods. Our studies aim to answer the following questions related to the association between neighborhood deprivation and PTB.

Study Aim 1a: To characterize and descriptively summarize the extent to which mothers move neighborhoods between pregnancies within the state of Michigan.

Hypothesis 1a: Based on a previous study in a similar population, we hypothesize that approximately 25% of our sample will move neighborhoods between pregnancies. This analysis will create and characterize a sample to use in a subsequent analysis of neighborhood selection bias using maternal fixed effects study design.

Study Aim 1b: To describe the differences in sociodemographic and health characteristics between mothers who move between pregnancies and those that do not move.

Hypothesis 1b: We hypothesize movers will be more likely to be younger, have more children, experience lower poverty, and more likely to smoke.

This descriptive analysis is important because it will help us understand whether differences in measured maternal characteristics between mothers that move neighborhoods between pregnancies may lead to bias in neighborhood effects study designs that do not account for these factors, which may also be related to PTB.

Study Aim 1c: Are prior adverse birth outcomes associated with residential mobility changes neighborhoods between pregnancies?

Hypothesis 1c: We hypothesize that a mother is less likely to move if she has an adverse birth outcome, consistent with the healthy migrant theory (Collins, 2011) which postulates that migrants are more likely to be healthy.

Study Aim 2a: Do mothers experience neighborhood poverty trajectory across their successive pregnancies?

Hypothesis 2a: Based on previous studies of neighborhood poverty changes, we expect the mothers in our sample will experience neighborhood poverty trajectory changes across their successive pregnancies, but this change will be limited to a 1-quartile change in poverty level.

Study Aim2b: Do movers experience greater neighborhood poverty trajectory changes than non-movers?

Hypothesis 2b: There has not been enough previous scholarship on this topic to draw a firm hypothesis. We hypothesize that there may be systematic differences between movers and non-movers that warrant this investigation.

Study Aim 2c: Is neighborhood poverty mobility associated with PTB?

Hypothesis2c: Consistent with previous studies of maternal mobility (Lupo et al. 2010; Sundquist et al. 2011; Bell and Belanger 2012; Miller, Siffel, and Correa 2010), we hypothesize that will find a modestly protective association between upward neighborhood poverty trajectory and PTB. We further hypothesize the strongest association will occur with the greatest change in neighborhood poverty trajectory, measured by at least a 3 quartile change in neighborhood poverty, in either direction (downward or upward).

Study Aim 3: To determine the association between neighborhood poverty and PTB using a maternal fixed effects method to control for maternal characteristics, both measured and unmeasured, that may be associated with selection into the neighborhood and PTB.

Hypothesis 3: We hypothesize using a maternal fixed effects approach will yield attenuated association between neighborhood poverty and PTB compared to traditional logistic and random effects approaches.

In summary, in this dissertation we hypothesize that there are characteristics of mothers that determine what neighborhood they live in. Some of those characteristics are measured and can be controlled for – in Study 1, we are characterizing what measured characteristics are associated with moving as a way to begin to address this issue. In Study 2, we are looking at whether the type/direction of move is associated with PTB. In Study 3, we are trying to account for the unmeasured characteristics that might also determine what neighborhood women live in and thus account for some of the relationship between neighborhood and PTB.

REFERENCES

REFERENCES

Anthopolos, Rebecca, Sherman A. James, Alan E. Gelfand, and Marie Lynn Miranda. 2011. "A Spatial Measure of Neighborhood Level Racial Isolation Applied to Low Birthweight, Preterm Birth, and Birthweight in North Carolina." *Spatial and Spatio-Temporal Epidemiology* 2 (4): 235–46. https://doi.org/10.1016/j.sste.2011.06.002.

Barker, D.J.P, K.M Godfrey, P.D Gluckman, J.E Harding, J.A Owens, and J.S Robinson. 1993. "Fetal Nutrition and Cardiovascular Disease in Adult Life." *The Lancet* 341 (8850): 938–41. https://doi.org/10.1016/0140-6736(93)91224-A.

Bell, Michelle L., and Kathleen Belanger. 2012. "Review of Research on Residential Mobility during Pregnancy: Consequences for Assessment of Prenatal Environmental Exposures." *Journal of Exposure Science and Environmental Epidemiology* 22 (5): 429–38. https://doi.org/10.1038/jes.2012.42.

Bergström, Lina, and Maarten Van Ham. 2010. "Understanding Neighbourhood Effects: Selection Bias and Residential Mobility."

Bertin, Mélanie, Jean-François Viel, Christine Monfort, Sylvaine Cordier, and Cécile Chevrier. 2015. "Socioeconomic Disparities in Adverse Birth Outcomes in Urban and Rural Contexts: A French Mother–Child Cohort." *Paediatric and Perinatal Epidemiology* 29 (5): 426–35. https://doi.org/10.1111/ppe.12208.

Blencowe, Hannah, Simon Cousens, Doris Chou, Mikkel Oestergaard, Lale Say, Ann-Beth Moller, Mary Kinney, Joy Lawn, and the Born Too Soon Preterm Birth Action Group (see acknowledgement for full list). 2013. "Born Too Soon: The Global Epidemiology of 15 Million Preterm Births." *Reproductive Health* 10 (1): S2. https://doi.org/10.1186/1742-4755-10-S1-S2.

Bruckner, Tim A., Jennifer B. Kane, and Samantha Gailey. 2019. "Strong Upward Neighborhood Mobility and Preterm Birth: A Matched-Sibling Design Approach." *Annals of Epidemiology* 36 (August): 48-54.e1. https://doi.org/10.1016/j.annepidem.2019.05.005.

Bureau, US Census. n.d. "Geography Program." Accessed November 9, 2019. https://www.census.gov/programs-surveys/geography.html.

Burris, Heather H., and James W. Collins. 2010. "Race and Preterm Birth--the Case for Epigenetic Inquiry." *Ethnicity & Disease* 20 (3): 296–99.

Chetty, Raj, Nathaniel Hendren, and Lawrence F. Katz. 2016. "The Effects of Exposure to Better Neighborhoods on Children: New Evidence from the Moving to Opportunity Experiment." *The American Economic Review* 106 (4): 855–902.

Collins, James W., Allison Mariani, and Kristin Rankin. 2018. “African-American Women’s Upward Economic Mobility and Small for Gestational Age Births: A Population-Based Study.” *Maternal and Child Health Journal* 22 (8): 1183–89. https://doi.org/10.1007/s10995-018-2503-4.

Collins, James W., Kristin M. Rankin, and Richard J. David. 2011. “African American Women’s Lifetime Upward Economic Mobility and Preterm Birth: The Effect of Fetal Programming.” *American Journal of Public Health* 101 (4): 714–19. https://doi.org/10.2105/AJPH.2010.195024.

———. 2015. “Downward Economic Mobility and Preterm Birth: An Exploratory Study of Chicago-Born Upper Class White Mothers.” *Maternal and Child Health Journal* 19 (7): 1601–7. https://doi.org/10.1007/s10995-015-1670-9.

Committee on Practice Bulletins—Obstetrics, The American College of Obstetricians and Gynecologists. 2012. “Practice Bulletin No. 130: Prediction and Prevention of Preterm Birth.” *Obstetrics and Gynecology* 120 (4): 964–73. https://doi.org/10.1097/AOG.0b013e3182723b1b.

Culhane, Jennifer F., and Robert L. Goldenberg. 2011. “Racial Disparities in Preterm Birth.” *Seminars in Perinatology* 35 (4): 234–39. https://doi.org/10.1053/j.semperi.2011.02.020.

Cusack, Leanne, Hind Sbihi, Andrew Larkin, Angela Chow, Jeffrey R. Brook, Theo Moraes, Piush J. Mandhane, et al. 2018. “Residential Green Space and Pathways to Term Birth Weight in the Canadian Healthy Infant Longitudinal Development (CHILD) Study.” *International Journal of Health Geographics* 17 (1): 43. https://doi.org/10.1186/s12942-018-0160-x.

DeFranco, Emily A., David M. Stamilio, Sarah E. Boslaugh, Gilad A. Gross, and Louis J. Muglia. 2007. “A Short Interpregnancy Interval Is a Risk Factor for Preterm Birth and Its Recurrence.” *American Journal of Obstetrics and Gynecology* 197 (3): 264.e1-264.e6. https://doi.org/10.1016/j.ajog.2007.06.042.

Farley, Thomas A., Karen Mason, Janet Rice, Joanna D. Habel, Richard Scribner, and Deborah A. Cohen. 2006. “The Relationship between the Neighbourhood Environment and Adverse Birth Outcomes.” *Paediatric and Perinatal Epidemiology* 20 (3): 188–200. https://doi.org/10.1111/j.1365-3016.2006.00719.x.

Geronimus, Arline T., Margaret Hicken, Danya Keene, and John Bound. 2006. “‘Weathering’ and Age Patterns of Allostatic Load Scores Among Blacks and Whites in the United States.” *American Journal of Public Health* 96 (5): 826–33. https://doi.org/10.2105/AJPH.2004.060749.

Grosse, Scott D., Norman J. Waitzman, Ninee Yang, Karon Abe, and Wanda D. Barfield. 2017. “Employer-Sponsored Plan Expenditures for Infants Born Preterm.” *Pediatrics* 140 (4). https://doi.org/10.1542/peds.2017-1078.

Ha, Sandie, Hui Hu, Liang Mao, Dikea Roussos-Ross, Jeffrey Roth, and Xiaohui Xu. 2016. "Potential Selection Bias Associated with Using Geocoded Birth Records for Epidemiologic Research." *Annals of Epidemiology* 26 (3): 204–11. https://doi.org/10.1016/j.annepidem.2016.01.002.

Ham, Maarten van, Sanne Boschman, and Matt Vogel. 2018. "Incorporating Neighborhood Choice in a Model of Neighborhood Effects on Income." *Demography* 55 (3): 1069–90. https://doi.org/10.1007/s13524-018-0672-9.

Harrison, Margo S., and Robert L. Goldenberg. 2016. "Global Burden of Prematurity." *Seminars in Fetal & Neonatal Medicine* 21 (2): 74–79. https://doi.org/10.1016/j.siny.2015.12.007.

Hedman, Lina, and Maarten van Ham. 2012. "Understanding Neighbourhood Effects: Selection Bias and Residential Mobility." In *Neighbourhood Effects Research: New Perspectives*, edited by Maarten van Ham, David Manley, Nick Bailey, Ludi Simpson, and Duncan Maclennan, 79–99. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-2309-2_4.

Holzman, Claudia, Janet Eyster, Mary Kleyn, Lynne C. Messer, Jay S. Kaufman, Barbara A. Laraia, Patricia O'Campo, Jessica G. Burke, Jennifer Culhane, and Irma T. Elo. 2009. "Maternal Weathering and Risk of Preterm Delivery." *American Journal of Public Health* 99 (10): 1864–1871.

Janevic, T, CR Stein, DA Savitz, JS Kaufman, SM Mason, and AH Herring. 2010. "Neighborhood Deprivation and Adverse Birth Outcomes among Diverse Ethnic Groups." *Annals of Epidemiology* 20 (6): 445–51. https://doi.org/10.1016/j.annepidem.2010.02.010.

Jencks, Christopher, and Susan E. Mayer. 1990. "The Social Consequences of Growing up in a Poor Neighborhood." *Inner-City Poverty in the United States* 111: 186.

Kane, Jennifer B., Gandarvaka Miles, Jennifer Yourkavitch, and Katherine King. 2017. "Neighborhood Context and Birth Outcomes: Going beyond Neighborhood Disadvantage, Incorporating Affluence." *SSM - Population Health* 3 (August): 699–712. https://doi.org/10.1016/j.ssmph.2017.08.003.

Koullali, B., M. A. Oudijk, T. A. J. Nijman, B. W. J. Mol, and E. Pajkrt. 2016. "Risk Assessment and Management to Prevent Preterm Birth." *Seminars in Fetal and Neonatal Medicine*, Prediction and prevention of preterm birth and its sequelae, 21 (2): 80–88. https://doi.org/10.1016/j.siny.2016.01.005.

Kramer, Michael R., Hannah L. Cooper, Carolyn D. Drews-Botsch, Lance A. Waller, and Carol R. Hogue. 2010. "Metropolitan Isolation Segregation and Black-White Disparities in Very Preterm Birth: A Test of Mediating Pathways and Variance Explained." *Social Science & Medicine (1982)* 71 (12): 2108–16. https://doi.org/10.1016/j.socscimed.2010.09.011.

Lhila, Aparna, and Sharon Long. 2012. “What Is Driving the Black–White Difference in Low Birthweight in the US?” *Health Economics* 21 (3): 301–15. https://doi.org/10.1002/hec.1715.

Luo, Zhong-Cheng, Russell Wilkins, Michael S. Kramer, and Fetal and Infant Health Study Group of the Canadian Perinatal Surveillance System. 2006. “Effect of Neighbourhood Income and Maternal Education on Birth Outcomes: A Population-Based Study.” *CMAJ: Canadian Medical Association Journal = Journal de l’Association Medicale Canadienne* 174 (10): 1415–20. https://doi.org/10.1503/cmaj.051096.

Lupo, Philip J., Elaine Symanski, Wenyaw Chan, Laura E. Mitchell, D. Kim Waller, Mark A. Canfield, and Peter H. Langlois. 2010. “Differences in Exposure Assignment between Conception and Delivery: The Impact of Maternal Mobility.” *Paediatric and Perinatal Epidemiology* 24 (2): 200–208. https://doi.org/10.1111/j.1365-3016.2010.01096.x.

MacDorman, Marian F., and T. J. Mathews. 2011. “Understanding Racial and Ethnic Disparities in U.S. Infant Mortality Rates.” *NCHS Data Brief*, no. 74 (September): 1–8.

McKinnon, Britt, Seungmi Yang, Michael S. Kramer, Tracey Bushnik, Amanda J. Sheppard, and Jay S. Kaufman. 2016. “Comparison of Black-White Disparities in Preterm Birth between Canada and the United States.” *CMAJ: Canadian Medical Association Journal = Journal de l’Association Medicale Canadienne* 188 (1): E19-26. https://doi.org/10.1503/cmaj.150464.

Menon, Ramkumar. 2008. “Spontaneous Preterm Birth, a Clinical Dilemma: Etiologic, Pathophysiologic and Genetic Heterogeneities and Racial Disparity.” *Acta Obstetricia Et Gynecologica Scandinavica* 87 (6): 590–600. https://doi.org/10.1080/00016340802005126.

Messer, Lynne C., Lisa C. Vinikoor, Barbara A. Laraia, Jay S. Kaufman, Janet Eyster, Claudia Holzman, Jennifer Culhane, Irma Elo, Jessica G. Burke, and Patricia O’Campo. 2008. “Socioeconomic Domains and Associations with Preterm Birth.” *Social Science & Medicine* 67 (8): 1247–1257.

Messer, Lynne C., Lisa C. Vinikoor-Imler, and Barbara A. Laraia. 2012. “Conceptualizing Neighborhood Space: Consistency and Variation of Associations for Neighborhood Factors and Pregnancy Health across Multiple Neighborhood Units.” *Health & Place* 18 (4): 805–13. https://doi.org/10.1016/j.healthplace.2012.03.012.

Metcalfe, Amy, Parabhdeep Lail, William A. Ghali, and Reg S. Sauve. 2011. “The Association between Neighbourhoods and Adverse Birth Outcomes: A Systematic Review and Meta-Analysis of Multi-Level Studies.” *Paediatric and Perinatal Epidemiology* 25 (3): 236–45. https://doi.org/10.1111/j.1365-3016.2011.01192.x.

Miller, Assia, Csaba Siffel, and Adolfo Correa. 2010. “Residential Mobility during Pregnancy: Patterns and Correlates.” *Maternal and Child Health Journal* 14 (4): 625–34. https://doi.org/10.1007/s10995-009-0492-z.

Miranda, Marie Lynn, Lynne C. Messer, and Gretchen L. Kroeger. 2012. “Associations between the Quality of the Residential Built Environment and Pregnancy Outcomes among Women in North Carolina.” *Environmental Health Perspectives* 120 (3): 471–77. https://doi.org/10.1289/ehp.1103578.

Morris, Tim, David Manley, and Clive E. Sabel. 2018. “Residential Mobility.” *Progress in Human Geography* 42 (1): 112–33. https://doi.org/10.1177/0309132516649454.

Muglia, Louis J., and Michael Katz. 2010. “The Enigma of Spontaneous Preterm Birth.” *The New England Journal of Medicine* 362 (6): 529–35. https://doi.org/10.1056/NEJMra0904308.

Ncube, Collette N., Daniel A. Enquobahrie, Steven M. Albert, Amy L. Herrick, and Jessica G. Burke. 2016. “Association of Neighborhood Context with Offspring Risk of Preterm Birth and Low Birthweight: A Systematic Review and Meta-Analysis of Population-Based Studies.” *Social Science & Medicine (1982)* 153 (March): 156–64. https://doi.org/10.1016/j.socscimed.2016.02.014.

O’Campo, Patricia, Jessica G. Burke, Jennifer Culhane, Irma T. Elo, Janet Eyster, Claudia Holzman, Lynne C. Messer, Jay S. Kaufman, and Barbara A. Laraia. 2008. “Neighborhood Deprivation and Preterm Birth among Non-Hispanic Black and White Women in Eight Geographic Areas in the United States.” *American Journal of Epidemiology* 167 (2): 155–163.

Pearl, Michelle, Jennifer Ahern, Alan Hubbard, Barbara Laraia, Bina Patel Shrimali, Victor Poon, and Martin Kharrazi. 2018. “Life-Course Neighbourhood Opportunity and Racial-Ethnic Disparities in Risk of Preterm Birth.” *Paediatric and Perinatal Epidemiology* 32 (5): 412–19. https://doi.org/10.1111/ppe.12482.

Plunkett, Jevon, and Louis J. Muglia. 2008. “Genetic Contributions to Preterm Birth: Implications from Epidemiological and Genetic Association Studies.” *Annals of Medicine* 40 (3): 167–79. https://doi.org/10.1080/07853890701806181.

Schempf, Ashley H., Jay S. Kaufman, Lynne C. Messer, and Pauline Mendola. 2011. “The Neighborhood Contribution to Black-White Perinatal Disparities: An Example from Two North Carolina Counties, 1999-2001.” *American Journal of Epidemiology* 174 (6): 744–52. https://doi.org/10.1093/aje/kwr128.

Schempf, Ashley, Donna Strobino, and Patricia O’Campo. 2009. “Neighborhood Effects on Birthweight: An Exploration of Psychosocial and Behavioral Pathways in Baltimore, 1995–1996.” *Social Science & Medicine* 68 (1): 100–110. https://doi.org/10.1016/j.socscimed.2008.10.006.

Smith, L. K., E. S. Draper, B. N. Manktelow, J. S. Dorling, and D. J. Field. 2007. “Socioeconomic Inequalities in Very Preterm Birth Rates.” *Archives of Disease in Childhood-Fetal and Neonatal Edition* 92 (1): F11–14. https://doi.org/10.1136/adc.2005.090308.

Sundquist, Jan, Kristina Sundquist, Sven-Erik Johansson, Xinjun Li, and Marilyn Winkleby. 2011. "Mothers, Places and Small for Gestational Age Births: A Cohort Study." *Archives of Disease in Childhood* 96 (4): 380–85. https://doi.org/10.1136/adc.2009.180042.

Thiel de Bocanegra, Heike, Richard Chang, Mike Howell, and Philip Darney. 2014. "Interpregnancy Intervals: Impact of Postpartum Contraceptive Effectiveness and Coverage." *American Journal of Obstetrics and Gynecology* 210 (4): 311.e1-311.e8. https://doi.org/10.1016/j.ajog.2013.12.020.

Thoma, Marie E., Laura B. Drew, Ashley H. Hirai, Theresa Y. Kim, Andrew Fenelon, and Edmond D. Shenassa. 2019. "Black–White Disparities in Preterm Birth: Geographic, Social, and Health Determinants." *American Journal of Preventive Medicine* 57 (5): 675–86. https://doi.org/10.1016/j.amepre.2019.07.007.

Verheij, R. A., H. D. van de Mheen, D. H. de Bakker, P. P. Groenewegen, and J. P. Mackenbach. 1998. "Urban-Rural Variations in Health in The Netherlands: Does Selective Migration Play a Part?" *Journal of Epidemiology & Community Health* 52 (8): 487–93. https://doi.org/10.1136/jech.52.8.487.

Vos, Amber A., Anke G. Posthumus, Gouke J. Bonsel, Eric A. P. Steegers, and Semiha Denktaş. 2014. "Deprived Neighborhoods and Adverse Perinatal Outcome: A Systematic Review and Meta-Analysis." *Acta Obstetricia Et Gynecologica Scandinavica* 93 (8): 727–40. https://doi.org/10.1111/aogs.12430.

Wallace, Maeve, Emily Harville, Katherine Theall, Larry Webber, Wei Chen, and Gerald Berenson. 2013. "Neighborhood Poverty, Allostatic Load, and Birth Outcomes in African American and White Women: Findings from the Bogalusa Heart Study." *Health & Place* 24 (November): 260–66. https://doi.org/10.1016/j.healthplace.2013.10.002.

Yang, Juan, Rebecca J. Baer, Vincenzo Berghella, Christina Chambers, Paul Chung, Tumaini Coker, Robert J. Currier, et al. 2016. "Recurrence of Preterm Birth and Early Term Birth." *Obstetrics and Gynecology* 128 (2): 364–72. https://doi.org/10.1097/AOG.0000000000001506.

STUDY 1

Introduction

There is substantial evidence that neighborhood deprivation is associated with adverse birth outcomes, specifically preterm birth (PTB; <37 weeks gestation) and small-for-gestational age (SGA; <10 percentile birth weight) (Sundquist et al. 2011; Janevic et al. 2010; Arcaya et al. 2012; Schempf and Kaufman 2012; O'Campo et al. 2008; Messer et al. 2008). However, the role of residential mobility, a change in residential address, in this association of neighborhood effects and birth outcomes has received limited consideration.

In order to elucidate the role of maternal selection into neighborhoods we started with a foremost concept of entry and exit into neighborhoods: residential mobility. Mobility represents a change in place of residence based on residential address reported on the birth certificate. Research on mobility and poverty has found that mobility to lower-poverty areas resulted in improved safety, physical health, and mental health (Chetty, Hendren, and Katz 2016). Chetty et al. found residential mobility to better neighborhoods had a causal effect on children's outcomes but that the effect of mobility declines with a child's age at move.

Research on residential mobility and pregnancy suggests there are several demographic features associated with movement. Movers tend to be younger (Canfield et al. 2006; Khoury et al. 1988) with some estimates showing 3.39 OR (95% CI: 2.12-5.4, 20-24 v >30)(Miller, Siffel, and Correa 2010); more likely to be smokers (1.46 OR 95% CI 1.01-2.12)(Miller, Siffel, and Correa 2010) while non-movers tend to have greater household income (Fell, Dodds, and King 2004) and lower parity (Canfield et al. 2006). Characteristics of mobility, such as distance moved, may be an important aspect in understanding the relationship between residential mobility and health (Clark and Huang 2003). Most literature of residential mobility and pregnancy found pregnant women move shorter distances of less than 3 miles (Lupo et al. 2010; Tang et al. 2018). Shorter distance moves represent unintended movement while long distance moves show an upward pattern of mobility and planning (Morris, Manley, and Sabel 2018; Clark and Huang 2003). Having children and employment may actually be constraints to mobility (Lee and Waddell 2010; Kim, Pagliara, and Preston 2003).

Maternal residential mobility is not uncommon but also not well characterized over the life course. For pregnant women there are multiple time periods to consider when evaluating mobility (1) across a single pregnancy, usually measured at trimester time points; or (2) across multiple pregnancies. Presently, evidence estimates between 12-30% of women move during pregnancy (Lupo et al. 2010; Sundquist et al. 2011; Bell and Belanger 2012; Miller, Siffel, and Correa 2010). Studies of residential mobility and pregnancy overwhelmingly focus on the effect of environmental exposure misclassification during a single pregnancy (Bell and Belanger 2012; Chen et al. 2010; Canfield et al. 2006). Two studies which followed women up to the first year of birth reported even higher mobility with up to 42% of women mobility at least once (Saadeh et al. 2013; Urayama et al. 2009). Even less is known about the socioeconomic status (SES) mobility patterns of women postpartum with one study reporting 7% of women move to areas of different SES (Margerison-Zilko et al. 2016) and another reported 24% moved to different SES (Saadeh et al. 2013), similarly split in direction of mobility.

Moreover, no studies to date have specifically looked at the effect of birth outcomes on *subsequent* mobility patterns. Although, other studies have examined motivations for mobility related to birth outcomes. Residential mobility research links childbirth as a “trigger event” for mobility and suggest increased parity is associated with increased likelihood of residential mobility (Kulu and Washbrook 2014), likely due to space needs of a growing family. There is mixed evidence on the effect of children on mobility with some researchers arguing parents are less likely to move in an effort to maintain established neighborhood ties to benefit their children (Morris, Manley, and Sabel 2018). We are unaware of any studies that have investigated the association of adverse prior birth outcome on either (1) mobility or (2) neighborhood poverty mobility.

The objective of this study is to describe residential mobility patterns and birth outcomes among Michigan-resident women between their successive births over multiple years in order to better understand inform our empirical design for testing residual confounding due to selection bias in our subsequent fixed effects analysis. We described study demographics and differences in residential mobility status, while future papers will examine the neighborhood poverty mobility (downward, static, and upward) and PTB. We used maternally-linked data to follow the same woman across multiple pregnancies and evaluated her residential mobility biography, maternal characteristics, mobility correlates, and birth outcomes. We hypothesized that a large proportion of women move between births and that they are demographically distinct compared to non-movers (more likely to smoke, be younger, have lower educational attainment, and have a shorter time in census tract). We hypothesized non-movers would have poorer birth outcomes across all levels of parity with increased occurrence of PTB. Finally, we looked at how prior birth outcomes influence residential mobility changes.

Methods

Data and study population

We used birth certificate data from the Michigan Department of Health and Human Services (MDHHS) Department of Vital Statistics for all births to Michigan-resident women during the period 1989-2012 linked by mother. Birth certificate data was geocoded by MDHHS based on self-reported maternal residence at birth for all births between 1994 to 2012. Births that occurred prior to 1994 were geocoded by the Children's Environmental Health Initiative also using self-reported residence at birth. As shown in **Figure 1**, birth records were included in the study if the women were between 15 and 44 years of age, had a singleton birth, and had geocoded information. Records were excluded if they did not meet the inclusion criteria and if they had any missing covariate information. Our analysis is restricted to the reproductive age of the mother and as such does not capture her movement from childhood. Mothers will be left truncated for births before 1990 and right truncated for births after 2012, although we do evaluate parity and birth year to account for this aspect of study design. In the overall sample, we found almost a quarter of the first recorded births were not nulliparous. As prior PTB has been associated with subsequent PTB (Blencowe et al. 2013) and inter-state birth records were not available, we further restricted our sample to first, second, and third births recorded in Michigan. This study was approved by the MDHHS Institutional Review Board.

Geolytics' Neighborhood Change Database (NCDB) Information on income level was measured from the census tract level poverty data collected from the Geolytics' Neighborhood Change Database for the period 1990-2010. This database collected information from 3 decennial census years 1990, 2000, and 2010 and adjusts data to the 2010 census tract boundaries to allow comparison across multiple census years.

US Census American Community Survey (ACS) Census tract level poverty rates for 2012 were collected from the US Census American Community Survey. They are adjusted to the 2010 Census Tract boundaries and therefore compatible with the boundary definitions from the Geolytics' census tracts.

US Census Tiger/Line Shapefiles The U.S. Census Tiger/Line Shapefiles contain geographic entity codes which can be linked to census tract in the birth certificate data by census year. Longitude and latitude coordinates were extracted from this file and merged with the birth certificate data by census tract id and census year.

Measures

Poverty Neighborhood poverty rates were based on census tract poverty rates collected every 10 years. As we were interested in examining maternally-linked data over a long study time period we used normalized census data, Geolytics' Neighborhood Change Database (NCDB), to account for geographic boundary changes between decennial census years. Intercensal census tract poverty rates were then linearly interpolated across calendar years for the period 1990-2010 using a join method. For the period 2011-2012, poverty rates were extracted from the American Community Survey, Michigan 2012 for each census tract. We then performed a linear interpolation between 2010 and 2012 data for the 2011 census tract poverty rates. Neighborhood poverty rates were merged with data from the birth certificate based on infant's birth year and mother's census tract at the time of delivery using the longitudinal crosswalk reference tool (Logan, Xu, and Stults 2014). Neighborhood poverty rate is reported categorically as quartile distributions, based quartile cut-points from the linearly interpolated NCDB data, and as a continuous mean.

Residential Mobility Status Residential mobility status is measured across two successive births by a change in census tract geocoded to residential address provided on the birth certificate.

Distance moved Information on distance between census tract centroid was computed using latitude and longitude coordinates from the U.S. Census Tiger/Line Shapefiles. In order to compute census tract distance, each census tract was assigned a longitude and latitude for each birth record from the Tiger/Line Shapefiles by census tract and census year resulting in 2 sets of longitude and latitude per women for each analytic sample restricted by parity (Births 1 to 2, and Births 2 to 3). For non-movers there was no difference in distance, but for movers we then used the GEODIST function in SAS to compute the geodetic distance in miles between a mother's two latitude and longitude coordinates using input values in degrees.

Time in census tract The time period of residence in census tract was calculated based on time between births record in the birth certificate files in days.

Adverse birth outcomes Our main outcome was PTB (<37 weeks completed gestation) following recent evidence linking suggesting a protective effect of strong upward neighborhood mobility on PTB outcomes (Bruckner, Kane, and Gailey 2019).

Maternal Characteristics Maternal demographic information from birth certificate data included continuous age; age categorized (<20, 20-24, 25-29, 30-24, 35-40, >40); marital status (married or unmarried); nativity by country (United State or Foreign) and state (Michigan or not Michigan). A previous analysis evaluated maternal education and race/ethnicity for consistency across maternally-linked dataset and excluded improbable observations (for example, negative educational attainment). Maternal race included race/ethnicity using birth certificate date (Non-Hispanic White, Non-Hispanic Black, Hispanic, Non-Hispanic American Indian, Non-Hispanic Asian/Pacific Islander, and Unknown). Maternal educational attainment, also using birth certificate data, was collapsed into 6 categories (less than high school; 9^{th}-12 grade/no diploma; high school Graduate/GED; Some College/Associate; Bachelor's Degree; Professional Degree). Paternal demographic factors are limited to age, race/ethnicity and not reported in this analysis but presented in supplemental tables (Appendix A.3). Maternal risk factor information from birth certificate data included tobacco use during pregnancy recorded as yes/no or unknown. Delivery and birth information from the birth certificate included source of payment (private insurance, Medicaid, self-pay, other, and unknown) that may act as a proxy for individual socioeconomic status.

Statistical Analyses

Women who moved between births (movers) were compared with women who did not move between their births (non-movers). Univariate analysis compared the demographic differences and mean poverty rate between movers and non-movers and tested for statistical significance using X^2 test for general association. Modified Poisson regression with standard robust error variances were used to compute the relative risk of residential mobility by maternal characteristics (Zhao, n.d.). We used Poisson regression to model this risk as outcome was a binary count variable. As Poisson is better suited to count data and does not have as many convergence challenges as a binomial-log model we used this regression strategy. We used a logistic regression to examine the association between prior PTB and odds of mobility adjusted for confounders related to PTB and mobility (maternal age, parity, marital changes, smoking, and maternal race /ethnicity). There were 38,957 PTB outcomes at birth 1 and 14,181 at birth 2. All index births marked the onset of risk for subsequent mobility.

Results

Table 1.1 shows the analytic subsample of births 1 to 2 (n= 895,214 births to 447,607 women), and births 2 to 3 (n=355,912 births to 117,956) where both births occurred in Michigan stratified by residential mobility status (mover and non-mover). Notably, a large percentage of women were classified as movers for both birth samples (50.2% and 51.1%, for births 1 to 2 and births 2 to 3, respectively). Movers were a greater percentage white, younger, and U.S. Born compared to non-movers. Movers had a slightly higher mean poverty rate compared to non-movers (15% compared to 11%; 16% compared to 12%) and the poverty rates increased as parity increased. Among movers, the majority of moves were within the same county and the mean distance moved was 15.9 and 14.5 miles in each birth sample.

Table 1.2a shows the risk ratio of mobility by maternal characteristics for births 1 and 2. **Table 1.2b** shows the risk ratio of mobility by maternal characteristics for births 2 and 3. Movers and non-movers were significantly different for all characteristics except infant sex and educational attainment. The unadjusted risk of mobility among Non-Hispanic Black women was 1.4 times the risk (95% CI: 1.4-1.4) of mobility among Non-Hispanic white women, and after adjusted the risk was 1.2 (95% CI 1.2-1.2). Unmarried women had 1.6 times the risk (95% CI: 1.6-16) of mobility compared to married women and when adjusted for all other covariates in the models was 1.2 times the risk (95%CI 1.2-1.2). Women who smoked also had a high risk of mobility compared to women who did not report smoking during pregnancy (unadjusted RR: 1.3, 95% CI: 1.3-1.3, adjusted RR: 1.1, 95% CI: 1.1-1.2). Finally, Medicaid as the insurance pay source at the time of birth had a higher risk for mobility (RR: 1.5, 95% CI: 1.5-1.5) compared with private payer. The risk of residential mobility by maternal characteristics remained fairly consistent across two levels of parity from births 1 to 2 and from births 2 to 3.

In **Table 1.3** we exploit our data structure to examine the association between prior PTB and subsequent residential mobility using logistic regression. We report on odds ratio for mobility by the time of your successive birth following a prior preterm birth. The odds for mobility after a PTB compared to a term birth at birth 1, after adjustment for race, marital change and age are null (OR: 1.0, 95% CI: 1.0-1.0) at birth 2 and modestly increased at birth 3 (OR: 1.06, 95% CI:1.03 to 1.10). This corresponds to a 6% increase in the odds of mobility between births 2 and 3 given you have a preterm birth at birth 2 compared to a term second birth. Our model of mobility showed a greater magnitude of odds for marital change and race/ethnicity. This suggests that a change in marital status between births may more strongly associated with mobility for divorce (Births 1 to 2 OR: 2.49 , 95% CI:2.37-2.62 ; Births 2 to 3 OR: 3.34 , 95% CI: 3.13-3.55) and for married (Births 1 to 2 OR: 2.79 , 95% CI: 2.71-2.83 ; Births 2 to 3 OR:1.92 , 95% CI: 1.85-2.00). Maternal race/ethnicity also had significant odds, with significant ORs for NHB 1.99 and 2.19 compared to NHW, at births 2 and 3 respectively. All other maternal race ethnicities, except NH Native American had increased odds of mobility compared to NHW, although they were higher at birth 2 compared to birth 3.

Discussion

Our major finding is that a larger percentage of women moved (50%) than we hypothesized (25%). The distribution of maternal characteristics is systematically different between movers and non-movers across demographic, risk factor, birth outcomes, and neighborhood characteristics. The risk of mobility is higher among women who are NHB, smokers, unmarried, and had Medicaid as a source of insurance. The differences between movers and non-movers remain consistent across multiple levels of recorded births. We also looked at across two pairs of births and observe increasing levels of poverty and PTB as parity increased. We found that prior preterm birth had a null association with mobility.

Compared to previous reports which ranged from 12-45% and measured primarily mobility during pregnancy we report almost half of our sample moved between successive births. We found little evidence that prior PTB was associated with mobility by birth 2, contrary to our hypothesis that it would increase the risk of mobility. We found that changes related to marital status, getting divorced or married, were the strongest correlates of mobility and may be important predictors in future studies.

We did not find a significant difference between movers and non-movers for educational attainment, Table 1.2. We would have expected movers to be more likely to have higher educational attainment as that might be related to job opportunity and mobility. Our sample only captures women during the childbearing years. This may indicate that this is not a very dynamic time for changes in educational attainment. Further, this may be due to limitation of a single state capture whereby movers with different educational attainment are more likely to leave the state and not be collected in subsequent Michigan birth records.

The mean poverty status for non-movers was higher than expected and increased with increased parity in our analytic subsamples. Non-movers may therefore experience more poverty change than we anticipated and may also be a viable population of interest in examining residual confounding of neighborhood effects using a continuous poverty measure.

Finally we report that non-movers experience a statistically significant (X^2 test for association p-value <.0001) higher proportion of large-for-gestational age (>90% percentile birthweight) compared to movers (Table 1.1). This was an unexpected finding and we could find no previous reports of this association. This may be due a more proximal mechanism (obesity promoting neighborhood) on the causal pathway. Future investigations may be useful in examining this outcome stratified by mobility status.

Limitations

Our study is one of the first to report on the mobility patterns of women between pregnancies over a partial life-course. While our study provides new information it is important to highlight some of the study limitations. The Michigan singleton birth file is missing 18% of the geocoded census tract data not at random which could bias our results. The data are more missing for earlier years of the study period when geocoding was not as systematically performed at the time of birth. Future studies using this data should conduct a sensitivity analysis of the data using more reliable later years of data (2000-2012) to examine meaningful change in results. However, birth outcomes were not systematically different among the missing and not-missing geocoded data.

The measurement of the poverty variable at the time of birth makes us unable to measure the timing of the mobility *between* births or to have uniform duration of exposure. We therefore must interpret our results as the effect of index birth outcome on mobility patterns at the time of the successive birth. There may be shorter inter-pregnancy mobility patterns that we are not able to capture with our study design. However, we did evaluate the duration of each interval (measured as the time between the index birth and the successive birth in days). The mean time spent in census tract between movers (1,409 days) and non-movers (992 days) showed movers had longer duration of time in census tract. However, this is measurement strictly captures time between births and does not fully detail the duration of time in the census tract irrespective of birth. Our study captures a relatively short period of time for each woman.

There may be some errors in the linkage criterion performed by Michigan Department of Health and Human Services although we did find evidence of successful linkage using the tabulation proposed by Adams and Kirby (Adams and Kirby 2007) (Appendix A).

We were unable to include any information on housing tenure, renting or home ownership status, as it was not included in our data. Previous studies on the effects of population mobility and health control for the home ownership or renting status of individuals as they are likely to influence mobility. This may be particularly useful information as it related to the role of public housing and in relation to one particular risk factor, smoking. In our data we do observe a difference in smoking by residential mobility status with movers having higher risk.

In summary, our study found that a large percentage of women move between pregnancies and they are demographically distinct compared to non-movers. Therefore, studies of neighborhood effects that rely on a single measurement may be capturing a weighted average of non-movers and movers. Future studies, should incorporate multiple time points and residential mobility status to remove the potential for misclassification of neighborhood exposure.

Figure 1 Analytic Sample Flow Chart for Inclusion Michigan Births

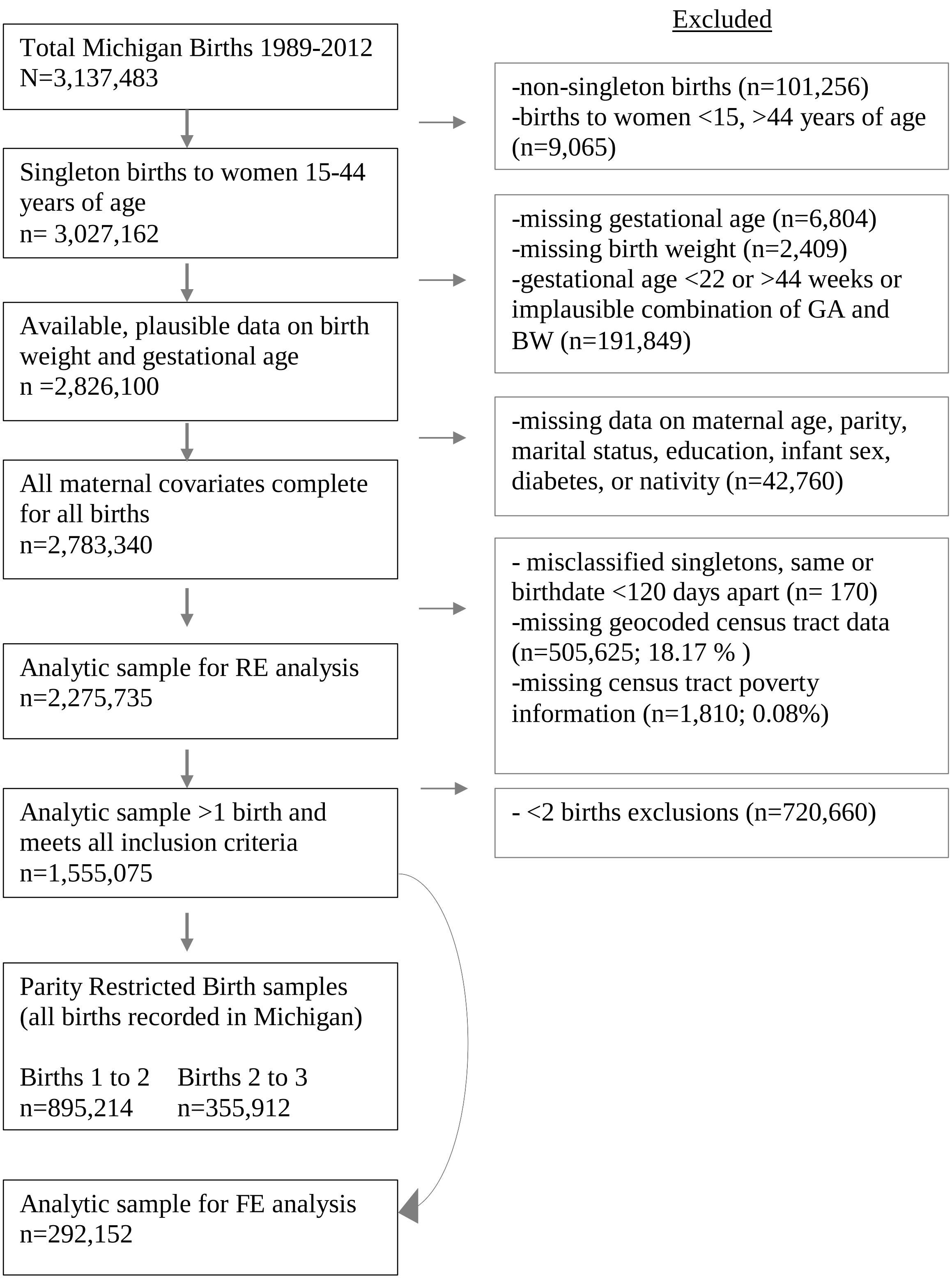

Table 1.1 Maternal characteristics at index birth stratified by residential status (mover vs. non-mover) at successive births restricted by parity, Births 1 to 2 and Births 2 to 3, singleton births recorded in Michigan 1990-2010[a]

	Births 1 to 2					Births 2 to 3				
	Overall n=447,607	Movers n=224,602		Non-Movers n= 223,005		Overall n=177,956	Movers n =90,909		Non-Movers n= 87,047	
Maternal Characteristics at first birth	n	n	%	n	%	n	n	%	n	%
Race										
NHW	333,946	154,388	80.5	179,558	68.7	125,983	58,182	64.0	67,801	77.9
NHB	66,762	44,055	10.2	22,707	19.6	32,358	21,921	24.1	10,437	12.0
Hispanic	22,310	12,845	4.2	9,465	5.7	10,341	5,750	6.3	4,591	5.3
NH AI/AN	673	359	0.1	314	0.2	281	147	0.2	134	0.2
NH A/PI	16,913	8,802	3.6	8,111	3.9	6,389	3,420	3.8	2,969	3.4
Non-Hispanic Mixed race / other/ missing	7,003	4,153	1.3	2,850	1.9	2,604	1,489	1.6	1,115	1.3
Age										
<20	100,578	69,382	30.9	31,196	14.0	18,511	13,148	14.5	5,363	6.2
20-24	129,016	76,995	34.3	52,021	23.3	62,501	39,025	42.9	23,476	27.0
25-29	134,828	52,826	23.5	82,002	36.8	57,284	25,636	28.2	31,648	36.4
30-34	68,264	21,504	9.6	46,760	21.0	33,630	11,481	12.6	22,149	25.4
35-40	14,226	3,747	1.7	10,479	4.7	5,782	1,565	1.7	4,217	4.8
>40	695	148	0.1	547	0.3	248	54	0.1	194	0.2
Nativity										
US born	414,358	209,031	93.1	205,327	92.1	165,513	85,493	94.0	80,020	91.9
Foreign born	33,249	15,571	6.9	17,678	7.9	12,443	5,416	6.0	7,027	8.1
Insurance Payer										
Private	297,402	126,588	56.4	170,814	76.6	109,119	47,102	51.8	62,017	71.3
Medicaid	142,457	93,998	41.9	48,459	21.7	65,428	42,122	46.3	23,306	26.8
Self-pay	2,977	1,483	0.7	1,494	0.7	1,545	748	0.8	797	0.9
Other	430	247	0.1	183	0.1	195	112	0.1	83	0.1

Table 1.1 (cont'd)

Unknown	4,341	2,286	1.0	2,055	0.9	1,669	825	0.9	844	1.0
Infant sex -male	230,113	115,303	51.3*	114,810	51.5*	91,176	46,559	51.2*	44,617	51.3*
Marital Status										
Married	273,956	105,036	46.8	168,920	75.8	115,261	48454	53.3	66807	76.7
Unmarried	173,651	119,566	53.2	54,085	24.3	62,695	42455	46.7	20240	23.3
Education										
Less than HS	11,952	6,027	2.7	5,925	2.7	5,118	2,609	2.9*	2,509	2.9*
Some HS	66,423	33,654	15.0	32,769	14.7	29,008	14,949	16.4*	14,059	16.2*
High School (HS)	137,181	69,881	31.1	67,300	30.2	59,422	30,397	33.4*	29,025	33.3*
Some college	105,353	53,547	23.8	51,806	23.2	42,870	21,958	24.2*	20,912	24.0*
College graduate	68,374	33,966	15.1	34,408	15.4	26,787	13,573	14.9*	13,214	15.2*
Greater than college	36,285	18,260	8.1	18,025	8.1	13,439	6,803	7.5*	6,636	7.6*
Smoke										
No	386,651	187,271	83.4	199,380	89.4	148,943	72,721	80.0	76,222	87.6
Yes	56,497	35,147	15.7	21,350	9.6	27,671	17,513	19.3	10,158	11.7
Successive Birth outcomes										
PTB										
No	408,650	204,051	90.9	206,873	92.8	163,775	82,838	91.1	80,937	93.0
Yes	38,957	20,551	9.2	16,132	7.2	14,181	8,071	8.9	6,110	7.0
SGA										
No	394,039	195,250	86.9	198,789	89.1	162,009	81,497	89.7	80,512	92.5
Yes	53,568	29,352	13.1	24,216	10.9	15,947	9,412	10.4	6,535	7.5
LGA										
No	415,971	209,728	93.4	206,243	92.5	160,773	83,009	91.3	77,764	89.3
Yes	31,636	14,874	6.6	16,762	7.5	17,183	7,900	8.7	9,283	10.7
	Mean (sd)	Mean	(sd)	Mean	(sd)	Mean (sd)	Mean	(sd)	Mean	(sd)

Table 1.1 (cont'd)

Mean neighborhood poverty rate	0.13 (0.12)	0.15	(0.13)	0.11	(0.11)	0.15 (0.13)	0.16	(0.14)	0.12	(0.11)
Mean census tract time in days	1201.8 (803.6)	1410.0	(935.1)	992.1	(572.5)	1240.6 (819.8)	1431.1	935.7	1041.7	618.1
Mean Distance moved in miles	--	15.9	(36.4)	--	--	--	14.5	35.1	--	--
Inter-county Movers	--	56,801	26.0	--	--	--	21,797	24.0		

[a]The analytic sample was restricted to births recorded in Michigan and presented here grouped into first and second birth, and second and third birth.
*Not statistically significant
All other variables significant at p<0.001 using Chi-Square tests

Table 1.2a Associations between maternal characteristics at index birth and residential mobility at successive births restricted to first and second singleton births recorded in Michigan 1990-2010

	Births 1 to 2							
	Non-Movers n=223,005	Movers n=224,602	Unadjusted RR[a] (95% CI)			Adjusted RR [a,b] (95% CI)		
Maternal Characteristics at first birth	%	%	RR	95% CI		RR	95% CI	
Race								
Non-Hispanic White	80.5	68.7	1.0			1.0		
Non-Hispanic Black	10.2	19.6	1.4	1.4	1.4	1.2	1.2	1.2
Hispanic	4.2	5.7	1.3	1.2	1.3	1.1	1.1	1.1
Non-Hispanic American Indian/ Alaska Native	0.1	0.2	1.2	1.1	1.2	1.0	0.9	1.0
Non-Hispanic Asian/ Pacific Islander	3.6	3.9	1.1	1.1	1.1	1.2	1.1	1.2
Non-Hispanic Mixed race / other/ missing	1.3	1.9	1.3	1.3	1.3	1.2	1.1	1.2
Age								
<20	30.9	14.0	0.9	0.9	1.0	0.9	0.8	0.9
20-24	34.3	23.3	1.0			1.0		
25-29	23.5	36.8	0.8	0.8	0.8	0.9	0.9	0.9
30-34	9.6	21.0	0.6	0.6	0.6	0.8	0.8	0.8
35-40	1.7	4.7	0.6	0.6	0.6	0.8	0.8	0.8
>40	0.1	0.3	0.6	0.6	0.6	0.8	0.7	0.8
Nativity								
US born	93.1	92.1	1.0			1.0		
Foreign born	6.9	7.9	0.9	0.9	0.9	1.0	0.9	1.0
Insurance Payer								
Private	56.4	76.6	1.0			1.0		
Medicaid	41.9	21.7	1.5	1.5	1.5	1.2	1.2	1.2
Self-pay	0.7	0.7	1.2	1.1	1.2	1.1	1.0	1.1
Other	0.1	0.1	1.4	1.4	1.5	1.2	1.1	1.3
Unknown	1.0	0.9	1.1	1.0	1.1	0.9	0.9	1.0
Infant sex -male	51.3	51.5	1.0	1.0	1.0	1.0	1.0	1.0
Marital Status								
Married	46.8	75.8	1.0			1.0		
Unmarried	53.2	24.3	1.6	1.6	1.6	1.2	1.2	1.2
Education								
Less than HS	2.7	2.7	1.0	1.0	1.0	1.0	1.0	1.0
Some HS	15.0	14.7	1.0	1.0	1.0	1.0	1.0	1.0
High School (HS)	31.1	30.2	1.0	1.0	1.0	1.0	1.0	1.0
Some college	23.8	23.2	1.0	1.0	1.0	1.0	1.0	1.0

Table 1.2a (cont'd)

College graduate	15.1	15.4	1.0	1.0	1.0	1.0	1.0	1.0
Greater than college	8.1	8.1	1.0			1.0		
Smoke								
No	83.4	89.4	1.0			1.0		
Yes	15.7	9.6	1.3	1.3	1.3	1.1	1.1	1.2
Hypertension								
No	90.9		1.0			1.0		
Yes	9.2		1.0	1.0	1.0	1.1	1.0	1.1

[a] RR calculated using modified Poisson regression with robust error variances (Zhao, K.)
[b] Adjusted for all other covariates listed.

Table 1.2b Associations between maternal characteristics at index birth and residential mobility at successive births restricted to second and third singleton births recorded in Michigan 1990-2010

	Births 2 to 3							
	Non-Movers n= 87,047	Movers n= 90,909	Unadjusted RR[a] (95% CI)			Adjusted RR[a,b] (95% CI)		
Maternal Characteristics at first birth	%	%	RR	95% CI		RR	95% CI	
Race								
Non-Hispanic White	77.9	64	1.0			1.0		
Non-Hispanic Black	12.0	24.11	1.5	1.5	1.5	1.2	1.2	1.2
Hispanic	5.3	6.33	1.2	1.2	1.2	1.1	1.1	1.1
Non-Hispanic American Indian/ Alaska Native	0.2	0.16	1.1	1.0	1.1	1.0	0.9	1.1
Non-Hispanic Asian/ Pacific Islander	3.4	3.76	1.2	1.1	1.2	1.1	1.1	1.2
Non-Hispanic Mixed race / other/ missing	1.3	1.64	1.2	1.2	1.2	1.1	1.1	1.2
Age								
<20	6.2	14.5	1.0	1.0	1.1	0.9	0.9	1.0
20-24	27.0	42.9				1.0		
25-29	36.4	28.2	0.9	0.9	0.9	1.0	1.0	1.0
30-34	25.4	12.6	0.7	0.7	0.7	0.9	0.9	0.9
35-40	4.8	1.7	0.7	0.7	0.7	0.9	0.9	0.9
>40	0.2	0.1	0.7	0.7	0.7	1.0	0.9	1.0
Nativity								
US born	91.9	94.0	1.0			1.0		
Foreign born	8.1	6.0	0.8	0.8	0.9	0.9	0.9	0.9
Insurance Payer								
Private	71.3	51.8	1.0			1.0		
Medicaid	26.8	46.3	1.4	1.4	1.5	1.2	1.2	1.2
Self-pay	0.9	0.8	1.1	1.0	1.1	1.0	1.0	1.1
Other	0.1	0.1	1.4	1.3	1.5	1.2	1.1	1.3
Unknown	1.0	0.9	1.0	1.0	1.1	1.0	0.9	1.0
Infant sex -male	51.3	51.2	1.0	1.0	1.0	1.0	1.0	1.0
Marital Status								
Married	76.75	53.3	1.0			1.0		
Unmarried	23.25	46.7	1.6	1.6	1.6	1.3	1.3	1.3
Education								
Less than HS	2.9	2.9	1.0	1.0	1.0	1.0	1.0	1.0
Some HS	16.2	16.4	1.0	1.0	1.0	1.0	1.0	1.0
High School (HS)	33.3	33.4	1.0	1.0	1.0	1.0	1.0	1.0
Some college	24.0	24.2	1.0	1.0	1.0	1.0	1.0	1.0
College graduate	15.2	14.9	1.0	1.0	1.0	1.0	1.0	1.0
Greater than college	7.6	7.5	1.0			1.0		

Table 1.2b (cont'd)

Smoke								
No	87.6	80.0	1.0			1.0		
Yes	11.7	19.3	1.3	1.3	1.4	1.2	1.1	1.2
Hypertension								
No						1.0		
Yes			1.0	1.0	1.1	1.0	1.0	1.1

[a]RR calculated using modified Poisson regression with robust error variances (Zhao, K.)
[b]Adjusted for all other covariates listed.

Table 1.3 Estimates from adjusted logistic model of association between prior PTB and residential change for mothers at successive birth[a]

	Birth 2			Birth 3		
	OR	95% CI		OR	95% CI	
PTB At Index Birth	1.0	1.0	1.0	1.1	1.0	1.1
Age						
<20	0.8	0.8	0.8	1.0	0.9	1.0
20-24 (ref)	1.0			1.0		
25-29	0.7	0.7	0.7	0.8	0.8	0.9
30-34	0.5	0.5	0.6	0.7	0.6	0.7
35-40	0.5	0.5	0.5	0.6	0.6	0.7
>40	0.5	0.5	0.5	0.7	0.6	0.7
Race/Ethnicity						
NHW	1.0			1.0		
NHB	2.0	2.0	2.0	2.2	2.1	2.3
Hispanic	1.4	1.4	1.5	1.4	1.3	1.4
NH Native American	1.0	0.9	1.2	0.9	0.7	1.2
NH Asian/Pacific Is.	1.4	1.4	1.4	1.3	1.3	1.4
Mixed/Other/Missing	1.5	1.5	1.6	1.4	1.3	1.5
Marital Change from Index Birth						
No change (ref)	1.0			1.0		
Divorce	2.5	2.4	2.6	3.3	3.1	3.6
Married	2.8	2.7	2.8	1.9	1.9	2.0
Smoke						
No	1.0			1.0		
Yes	1.6	1.6	1.7	1.7	1.7	1.7
Unknown	1.0	0.9	1.1	1.1	1.0	1.3

[a] ORs derived using logistic regression models adjusted for all other covariates in the model

APPENDIX

Table A.1 Maternal characteristics at index birth stratified by geocoded status among singleton births in Michigan Birth File 1990-2012

	Geocode Complete n= 2,277,545		Geocode not complete[a] n= 505,625	
Maternal Characteristics at first birth	n	%	n	%
Race				
Non-Hispanic White	1,643,120	72.1	408,827	80.9
Non-Hispanic black	432,728	19.0	63,462	12.6
Hispanic	103,006	4.5	17,323	3.4
Non-Hispanic American Indian/ Alaska Native	10,343	0.5	4,373	0.9
Non-Hispanic Asian/Pacific Islander	60,698	2.7	10,572	2.1
Non-Hispanic Mixed race / other/ missing	27,650	1.2	1,068	0.2
Age				
<20	239,525	10.6	59,988	11.9
20-24	547,415	24.2	139,347	27.7
25-29	670,769	29.7	155,810	31.0
30-34	548,042	24.3	106,687	21.2
35-40	229,105	10.1	37,927	7.5
>40	24,966	1.1	3,269	0.7
Nativity				
US born	2,073,456	91.0	485,620	96.0
Foreign born	204,089	9.0	20,005	4.0
Insurance Payer				
Private	1,427,744	62.7	321,967	63.7
Medicaid	802,473	35.2	165,960	32.8
Self-pay	22,589	1.0	9,313	1.8
Other	3,837	0.2	567	0.1
Missing	20,902	0.9	7,818	1.6
Infant sex -male	1,166,988	51.2	259,474	51.3
Marital Status				
Married	1469135	64.5	369,931	73.2
Unmarried	808410	35.5	135,694	26.8
Education				
Less than HS	59,854	2.6	11,350	2.2
Some HS	329,160	14.5	76,480	15.1
High School (HS)	733,860	32.2	197,159	39.0
Some college	593,514	26.1	124,462	24.6
College graduate	354,419	15.6	62,515	12.4
Greater than college	206,738	9.1	33,659	6.7
Parity				
Nulliparous (0 live births)	908,095	39.9	210,833	42
Primiparous (1 previous live birth)	733,341	32.2	165,697	33

Table A.1 (cont'd)

Multiparous (>1 previous live births)	636,109	27.9	129,095	26
Birth outcomes				
PTB				
No	2,065,969	90.7	460,844	91.1
Yes	211,576	9.3	44,781	8.9
SGA				
No	2,029,387	89	455,150	90.0
Yes	248,158	11	50,475	10.0
LGA				
No	2,071,814	91.0	454,698	89.9
Yes	205,731	9.0	50,927	10.1

[a] census tract missing, not Michigan, or incomplete

Table A.2 Geocoded missing status by infant year of birth in singleton Michigan births 1989-2012

	Geocoded		Missing Geocode	
Infant Birth Year	n	%	n	%
1989	-	0	131,357	100
1990	96,169	70.2	40,782	29.8
1991	93,784	70.4	39,481	29.6
1992	90,833	70.6	37,768	29.4
1993	88,145	70.5	36,901	29.5
1994	83,220	68.8	37,819	31.3
1995	102,232	87.0	15,293	13.0
1996	78,613	67.8	37,331	32.2
1997	77,323	67.1	37,995	33.0
1998	81,727	70.8	33,666	29.2
1999	80,437	69.8	34,740	30.2
2000	114,292	97.8	2,565	2.2
2001	113,455	97.9	2,467	2.1
2002	111,098	98.1	2,153	1.9
2003	111,276	98.0	2,275	2.0
2004	109,054	98.0	2,175	2.0
2005	107,908	97.9	2,266	2.1
2006	109,461	98.3	1,941	1.7
2007	108,327	98.2	1,964	1.8
2008	109,860	99.0	1,085	1.0
2009	102,232	99.2	842	0.8
2010	100,068	99.3	745	0.7
2011	104,089	99.0	1,059	1.0
2012	103,942	99.1	955	0.9
Total	2,277,545	81.8	505,625	18.2

Table A.3 Paternal characteristics overall and stratified by maternal PTB outcomes among singleton Michigan Births 1990-2012

Paternal Characteristics	Overall	PTB			
		No		Yes	
		n	%	n	%
Race					
Non-Hispanic White	1,452,507	1,345,472	92.6	107,035	7.4
Non-Hispanic black	224,592	195,235	86.9	29,357	13.1
Hispanic	90,021	82,350	91.5	7,671	8.5
Non-Hispanic American Indian/ Alaska Native	9,196	8,413	91.5	783	8.5
Non-Hispanic Asian/Pacific Islander	53,407	49,476	92.6	3,931	7.4
Non-Hispanic Mixed race / other/ missing	446,012	383,356	86.0	62,656	14.1
Age					
Missing	34,776	31,784	91.4	2,992	8.6
<20	57,065	50,506	88.5	6,559	11.5
20-24	276,403	250,963	90.8	25,440	9.2
25-29	513,948	473,898	92.2	40,050	7.8
30-34	561,571	519,529	92.5	42,042	7.5
35-40	314,991	289,401	91.9	25,590	8.1
>40	516,981	448,221	86.7	68,760	13.3

Table A.4 Maternal characteristics and poverty exposure by ordering of preterm birth outcomes across two pregnancies, births 1 to 2, and births 2 to 3 among singleton births in Michigan 1990-2010

	PTB Outcomes							
	Births 1 to 2				Births 2 to 3			
	Term - Term	Preterm - Term	Term - Preterm	Preterm - Preterm	Term - Term	Preterm - Term	Term - Preterm	Preterm - Preterm
Maternal Characteristics at first birth	n	n	n	n	n	n	n	n
Total	762,954	62,494	54,346	15,420	151,747	11,102	12,028	3,079
Race								
NHW	290,891	21,012	17,383	4,660	110,856	6,443	7,177	1,507
NHB	50,920	6,842	6,739	2,261	24,388	3,357	3,368	1,245
Hispanic	18,870	1,646	1,427	367	8,702	667	809	163
NH AI/AN	576	47	44	6	237	25	18	1
NH A/PI	14,344	1,210	1,072	287	5,380	440	455	114
Non-Hispanic Mixed race / other/ missing	5,876	490	508	129	2,184	170	201	49
Age								
<20	80,733	9,135	8,344	2,366	14,163	2,033	1,708	607
20-24	110,209	8,621	8,085	2,101	52,081	4,404	4,751	1,265
25-29	118,716	7,935	6,366	1,811	50,389	2,754	3,421	720
30-34	59,264	4,396	3,467	1,137	29,837	1,578	1,809	406
35-40	11,992	1,099	856	279	5,062	319	321	80
>40	563	61	55	16	215	14	18	1
Nativity								
US born	352,561	29,198	25,312	7,287	140,893	10,386	11,286	2,948
Foreign born	28,916	2,049	1,861	423	10,854	716	742	131
Insurance Payer								
Private	257,753	19,204	15,868	4,577	95,531	5,853	6,254	1,481
Medicaid	117,168	11,443	10,861	2,985	53,294	5,029	5,577	1,528
Self-pay	2,499	252	159	67	1,327	106	86	26
Other	362	34	25	9	167	11	13	4
Unknown	3,695	314	260	72	1,428	103	98	40
Infant sex -male	194,878	16,940	14,095	4,200	77,436	5,997	6,107	1,636

Table A.4 (cont'd)

Marital Status								
Married	240,252	16,492	13,395	3,817	102,062	5,646	6,230	1,323
Unmarried	141,225	14,755	13,778	3,893	49,685	5,456	5,798	1,756
Education								
Less than HS	10,119	887	730	216	4,361	323	340	94
Some HS	56,578	4,730	3,950	1,165	24,689	1,850	1,964	505
High School (HS)	116,695	9,623	8,491	2,372	50,627	3,771	4,008	1,016
Some college	89,970	7,370	6,181	1,832	36,522	2,656	2,951	741
College graduate	58,352	4,759	4,125	1,138	22,937	1,622	1,759	469
Greater than college	31,006	2,538	2,123	618	11,553	775	898	213
Smoke								
No	330,665	26,746	22,756	6,484	128,048	8,929	9,546	2,420
Yes	47,059	4,133	4,162	1,143	22,578	2,085	2,376	632
Birth outcomes								
SGA								
no	338,127	27,471	21,916	6,525	138,991	10,237	10,076	2,705
yes	43,350	3,776	5,257	1,185	12,756	865	1,952	374
LGA								
no	354,003	28,760	25,823	7,385	136,866	9,758	11,261	2,888
yes	27,474	2,487	1,350	325	14,881	1,344	767	191
Mean neighborhood poverty rate	0.13	0.15	0.16	0.16	0.14	0.18	0.18	0.20
	(0.12)	(0.13)	(0.14)	(0.14)	(0.13)	(0.14)	(0.14)	(0.15)

Table A.5 Residential mobility status[a] (mover, non-mover) and percent neighborhood poverty by ordering of preterm birth outcomes across two pregnancies, births 1 to 2, and births 2 to 3 among singleton births in Michigan 1990-2010

	PTB Outcomes							
	Births 1 to 2				Births 2 to 3			
	Term - Term	Preterm - Term	Term - Preterm	Preterm - Preterm	Term - Term	Preterm - Term	Term - Preterm	Preterm - Preterm
Movers	189,375	16,476	14,676	4,075	189,375	16,476	14,676	4,075
Mean poverty rate birth 1	0.143 (0.124)	0.166 (0.136)	0.174 (0.138)	0.182 (0.142)	0.143 (0.124)	0.166 (0.136)	0.174 (0.138)	0.182 (0.142)
Mean poverty rate birth 2	0.143 (0.126)	0.167 (0.136)	0.175 (0.141)	0.180 (0.146)	0.143 (0.126)	0.167 (0.136)	0.175 (0.141)	0.180 (0.146)
Mean poverty rate change	0.000 (0.123)	0.001 (0.135)	0.001 (0.137)	-0.001 (0.139)	0.000 (0.123)	0.001 (0.135)	0.001 0.137)	-0.001 (0.139)
Non-Movers	192,102	14,771	12,497	3,635	192,102	189,375	14,771	3,635
Mean poverty rate Birth 1	0.110 (0.103)	0.127 (0.117)	0.140 (0.127)	0.139 (0.127)	0.110 (0.103)	0.127 (0.117)	0.140 (0.127)	0.139 (0.127)
Mean poverty rate birth 2	0.117 (0.107)	0.133 (0.120)	0.147 (0.129)	0.145 (0.130)	0.117 (0.107)	0.133 (0.120)	0.147 (0.129)	0.145 (0.130)
Mean poverty rate change	0.007 (0.030)	0.006 (0.033)	0.006 0.033	0.006 (0.032)	0.007 (0.030)	0.006 (0.033)	0.006 (0.033)	0.006 (0.032)

[a]Determined from geocoded residential address census tract change between births

Table A.6 Table poverty variable derivation and missing poverty values

NCDB	Ncdb.sas7bdat					
Variable	Year	Decisions	Missing code	N Missing	Total Census Tracts	Percent Missing
POVRAT9	1990	--	0	65	2813	2.0%
POVRATA	2000	--	0	62	2813	2.0%
POVRAT1A	2010	--	-999	65	2813	2.0%
Total		--		200	8439	2.0%

NCDB recode	ncdbrecode.sas7bdat					
POV90	1990	if povrat9=**0** and nintiesD=**0** then pov90=**.**; else pov90=povrat9; if povrat9=**0** and povrata>**0** then pov90=povrata	.	51	2813	1.8%

POV00	2000	if povrata=**0** and aughtsD=**0** then pov00=**.**;
		else if povrata=**0** and povrat9>**0** then pov00=povrat9;
		else pov00=povrata;
			.	53	2813	1.8%

POV10	2010	if povrat1a=**-999** and povrata<=**0** then pov10=**.**;
		else if povrat1a=**-999** and povrata>**0** then pov10=povrata;
		else pov10=povrat1a;
			.	52	2813	1.8%

Total					8439	1.8%
ACS 2012	acs2012.sas7bdat					
pov	2012	--	.	68	2813	2.4%

Table A.6 (cont'd)

Linear Interpolation	interpolatedpov.sas7bdat					

pov	1990-2012	**Proc expand**
		data=work.addyear2
		out=work.year
		from=year10 to=year
		method=join;
		by geo2010 notsorted;
		id yearD;
		run;
		
		proc expand data=pov2
		out=pova method=join;
		by geo2010;
		ID BXYEAR;
		run;
			.	1,254	64,699	1.9 %

Full eligible dataset	NPfinal.sas7dbat					
pov		**proc sql**; create table poverty as select L.*, R. pov from normalizedcensus L left join interpolatedpov R on l.nbxyear=r.bx and l.long10=r.geo; **quit**;	.	1,810 Birth records missing poverty	2,277,545 total Birth Records	0.08 %

Final Eligible Births		NPmibirths.sas7bdat			2275735	
pov	1990-2012	>1 birth after poverty missing and all other inclusion criteria		0		0%

REFERENCES

REFERENCES

Adams, Melissa M., and Russell S. Kirby. 2007. “Measuring the Accuracy and Completeness of Linking Certificates for Deliveries to the Same Woman.” *Paediatric and Perinatal Epidemiology* 21 Suppl 1 (July): 58–62. https://doi.org/10.1111/j.1365-3016.2007.00838.x.

Arcaya, Mariana, Mark Brewster, Corwin M. Zigler, and S. V. Subramanian. 2012. “Area Variations in Health: A Spatial Multilevel Modeling Approach.” *Health & Place* 18 (4): 824–831.

Bell, Michelle L., and Kathleen Belanger. 2012. “Review of Research on Residential Mobility during Pregnancy: Consequences for Assessment of Prenatal Environmental Exposures.” *Journal of Exposure Science and Environmental Epidemiology* 22 (5): 429–38. https://doi.org/10.1038/jes.2012.42.

Blencowe, Hannah, Simon Cousens, Doris Chou, Mikkel Oestergaard, Lale Say, Ann-Beth Moller, Mary Kinney, Joy Lawn, and the Born Too Soon Preterm Birth Action Group (see acknowledgement for full list). 2013. “Born Too Soon: The Global Epidemiology of 15 Million Preterm Births.” *Reproductive Health* 10 (1): S2. https://doi.org/10.1186/1742-4755-10-S1-S2.

Bruckner, Tim A., Jennifer B. Kane, and Samantha Gailey. 2019. “Strong Upward Neighborhood Mobility and Preterm Birth: A Matched-Sibling Design Approach.” *Annals of Epidemiology* 36 (August): 48-54.e1. https://doi.org/10.1016/j.annepidem.2019.05.005.

Canfield, Mark A., Tunu A. Ramadhani, Peter H. Langlois, and D. Kim Waller. 2006. “Residential Mobility Patterns and Exposure Misclassification in Epidemiologic Studies of Birth Defects.” *Journal of Exposure Science & Environmental Epidemiology* 16 (6): 538–43. https://doi.org/10.1038/sj.jes.7500501.

Chen, Lei, Erin M. Bell, Alissa R. Caton, Charlotte M. Druschel, and Shao Lin. 2010. “Residential Mobility during Pregnancy and the Potential for Ambient Air Pollution Exposure Misclassification.” *Environmental Research* 110 (2): 162–68. https://doi.org/10.1016/j.envres.2009.11.001.

Chetty, Raj, Nathaniel Hendren, and Lawrence F. Katz. 2016. “The Effects of Exposure to Better Neighborhoods on Children: New Evidence from the Moving to Opportunity Experiment.” *The American Economic Review* 106 (4): 855–902.

Clark, William A V, and Youqin Huang. 2003. “The Life Course and Residential Mobility in British Housing Markets.” *Environment and Planning A: Economy and Space* 35 (2): 323–39. https://doi.org/10.1068/a3542.

Fell, Deshayne B., Linda Dodds, and Will D. King. 2004. “Residential Mobility during Pregnancy.” *Paediatric and Perinatal Epidemiology* 18 (6): 408–14. https://doi.org/10.1111/j.1365-3016.2004.00580.x.

Janevic, T, CR Stein, DA Savitz, JS Kaufman, SM Mason, and AH Herring. 2010. “Neighborhood Deprivation and Adverse Birth Outcomes among Diverse Ethnic Groups.” *Annals of Epidemiology* 20 (6): 445–51. https://doi.org/10.1016/j.annepidem.2010.02.010.

Khoury, M. J., W. Stewart, A. Weinstein, S. Panny, P. Lindsay, and M. Eisenberg. 1988. “Residential Mobility during Pregnancy: Implications for Environmental Teratogenesis.” *Journal of Clinical Epidemiology* 41 (1): 15–20.

Kim, Jae-Hong, Francesca Pagliara, and John Preston. 2003. “An Analysis of Residential Location Choice Behaviour in Oxfordshire, Uk: A Combined Stated Preference Approach.” *International Review of Public Administration* 8 (1): 103–14. https://doi.org/10.1080/12294659.2003.10805021.

Kulu, Hill, and Elizabeth Washbrook. 2014. “Residential Context, Migration and Fertility in a Modern Urban Society.” *Advances in Life Course Research* 21 (September): 168–82. https://doi.org/10.1016/j.alcr.2014.01.001.

Lee, Brian H. Y., and Paul Waddell. 2010. “Residential Mobility and Location Choice: A Nested Logit Model with Sampling of Alternatives.” *Transportation* 37 (4): 587–601. https://doi.org/10.1007/s11116-010-9270-4.

Logan, John R., Zengwang Xu, and Brian J. Stults. 2014. “Interpolating U.S. Decennial Census Tract Data from as Early as 1970 to 2010: A Longitudinal Tract Database.” *The Professional Geographer* 66 (3): 412–20. https://doi.org/10.1080/00330124.2014.905156.

Lupo, Philip J., Elaine Symanski, Wenyaw Chan, Laura E. Mitchell, D. Kim Waller, Mark A. Canfield, and Peter H. Langlois. 2010. “Differences in Exposure Assignment between Conception and Delivery: The Impact of Maternal Mobility.” *Paediatric and Perinatal Epidemiology* 24 (2): 200–208. https://doi.org/10.1111/j.1365-3016.2010.01096.x.

Margerison-Zilko, Claire, Catherine Cubbin, Jina Jun, Kristen Marchi, and Paula Braveman. 2016. “Post-Partum Residential Mobility Among a Statewide Representative Sample of California Women, 2003-2007.” *Maternal and Child Health Journal* 20 (1): 139–48. https://doi.org/10.1007/s10995-015-1812-0.

Messer, Lynne C., Lisa C. Vinikoor, Barbara A. Laraia, Jay S. Kaufman, Janet Eyster, Claudia Holzman, Jennifer Culhane, Irma Elo, Jessica G. Burke, and Patricia O’Campo. 2008. “Socioeconomic Domains and Associations with Preterm Birth.” *Social Science & Medicine* 67 (8): 1247–1257.

Miller, Assia, Csaba Siffel, and Adolfo Correa. 2010. "Residential Mobility during Pregnancy: Patterns and Correlates." *Maternal and Child Health Journal* 14 (4): 625–34. https://doi.org/10.1007/s10995-009-0492-z.

Morris, Tim, David Manley, and Clive E. Sabel. 2018. "Residential Mobility: Towards Progress in Mobility Health Research." *Progress in Human Geography* 42 (1): 112–33. https://doi.org/10.1177/0309132516649454.

O'Campo, Patricia, Jessica G. Burke, Jennifer Culhane, Irma T. Elo, Janet Eyster, Claudia Holzman, Lynne C. Messer, Jay S. Kaufman, and Barbara A. Laraia. 2008. "Neighborhood Deprivation and Preterm Birth among Non-Hispanic Black and White Women in Eight Geographic Areas in the United States." *American Journal of Epidemiology* 167 (2): 155–163.

Saadeh, Frances B., Melissa A. Clark, Michelle L. Rogers, Crystal D. Linkletter, Maureen G. Phipps, James F. Padbury, and Patrick M. Vivier. 2013. "Pregnant and Moving: Understanding Residential Mobility during Pregnancy and in the First Year of Life Using a Prospective Birth Cohort." *Maternal and Child Health Journal* 17 (2): 330–43. https://doi.org/10.1007/s10995-012-0978-y.

Schempf, Ashley H., and Jay S. Kaufman. 2012. "Accounting for Context in Studies of Health Inequalities: A Review and Comparison of Analytic Approaches." *Annals of Epidemiology* 22 (10): 683–90. https://doi.org/10.1016/j.annepidem.2012.06.105.

Sundquist, Jan, Kristina Sundquist, Sven-Erik Johansson, Xinjun Li, and Marilyn Winkleby. 2011. "Mothers, Places and Small for Gestational Age Births: A Cohort Study." *Archives of Disease in Childhood* 96 (4): 380–85. https://doi.org/10.1136/adc.2009.180042.

Tang, Zhongfeng, Hanru Zhang, Haiya Bai, Ya Chen, Nan Zhao, Min Zhou, Hongmei Cui, et al. 2018. "Residential Mobility during Pregnancy in Urban Gansu, China." *Health & Place* 53 (September): 258–63. https://doi.org/10.1016/j.healthplace.2018.08.021.

Urayama, Kevin Y., Julie Von Behren, Peggy Reynolds, Andrew Hertz, Monique Does, and Patricia A. Buffler. 2009. "Factors Associated with Residential Mobility in Children with Leukemia: Implications for Assigning Exposures." *Annals of Epidemiology* 19 (11): 834–40. https://doi.org/10.1016/j.annepidem.2009.03.001.

Zhao, Kechen. n.d. "Proper Estimation of Relative Risk Using PROC GENMOD in Population Studies," 14.

STUDY 2

Introduction

Neighborhood poverty at the time of delivery is considered a risk factor for adverse birth outcomes (David and Messer 2011; Croteau, Marcoux, and Brisson 2007; Braveman et al. 2010; Meyer, Warren, and Reisine 2007). Neighborhood poverty may also be increasing over time. Using U.S. census data, one study reported that in the U.S. between 1980 and 2014, a combination of growing income segregation and muted economic performance have increased the risk for living in high-poverty neighborhoods (Iceland and Hernandez 2017). Alarmingly, the extreme poverty has grown at a disproportionate rate meaning a greater percentage of people are experiencing the highest levels of neighborhood poverty (Jargowsky 1998).

The association between neighborhood poverty and birth outcomes have been extensively studied (Messer et al. 2006; O'Campo et al. 2008; Holzman et al. 2009a; Schempf et al. 2011; J. W. Collins, Rankin, and David 2015; Pearl et al. 2018; Bruckner, Kane, and Gailey 2019). The associations between neighborhood poverty trajectories, changes in level of poverty over time, have studied less. Primarily, this type of socioeconomic trajectory has been studied as an individual trajectory in relation to small for gestational age (Love et al. 2010; Osypuk et al. 2016; Slaughter-Acey et al. 2016; J. W. Collins, Mariani, and Rankin 2018) and low birth weight (Spencer 2004; Colen CG et al. 2006; Love et al. 2010; Osypuk et al. 2016). Fewer studies measure neighborhood poverty trajectory and PTB (Love et al. 2010; J. J. Collins et al. 2007; Collins, Rankin, and David 2015; Kramer, Dunlop, and Hogue 2014). One study (Collins, Rankin, and David 2011) used inter-generationally linked records of African American women comparing economic trajectory from childhood to adulthood in the association of PTB. They reported decreased risk for PTB among African American women who experienced neighborhood poverty in childhood with strong upward trajectory as adults (0.7 RR (95% CI:0.6, 0.8)) and modest upward trajectory (0.8 RR (95% CI: 0.7, 0.9) and weak upward trajectory (0.9 RR (95% CI: 0.8, 0.9)) compared to those who stayed in high neighborhood poverty. They report increased risk of PTB for white women who experience downward poverty trajectory, starting from low neighborhood poverty in childhood and experienced slight 1.2 (95% CI: 1.0, 4.0), moderate RR 1.6 (95% CI: 1.3, 1.9), and extreme RR 1.9 (95% CI 1.3, 2.6) downward poverty, respectively, compared to white women who continued in low neighborhood poverty (J. W. Collins, Rankin, and David 2015). Another study that used longitudinally linked births in Georgia to evaluate cumulative neighborhood deprivation reported a modest association between neighborhood deprivation, using the Neighborhood Deprivation Index (NDI) and PTB (adjusted RD 0.95 (95% CI: 0.79—1.12) with strong effect modification by history of prior PTB and significant differences by race for black but not white women with increasing age (Kramer, Dunlop, and Hogue 2014). Though limited, increasingly studies of neighborhood poverty based trajectory consistently show that large changes in neighborhood poverty, in either direction, are associated with PTB. Upward trajectory, moving away from poverty, has been associated with a modest reduction in preterm birth although this has not been consistent for all race/ethnicities and may be subject to effect modification by mother's own birth history (Collins, Rankin, and David 2011). One potential explanation for the paucity of this type of investigation is the need for longitudinally data linked in order to evaluate changes measured over multiple time points.

We previously reported on residential mobility in Michigan using a maternally-linked longitudinal dataset (Study 1) where we found that approximately half of women in the Michigan birth data move between pregnancies. As this type of investigation may be increasingly utilized as more longitudinal datasets become available with area-based geocoding, we were interested in investigating how residential mobility would modify the association between neighborhood poverty trajectory and PTB. In that sense, neighborhood poverty trajectory occurred either as a result of moving to a neighborhood with a different level of poverty or as the neighborhood poverty conditions either deteriorated or improved.

We aimed to determine whether mothers experienced neighborhood poverty trajectory changes between successive pregnancies and if those changes are different for movers compared to non-movers. We aimed to address if poverty trajectory changes were driven more by the act of moving or by the neighborhoods changing in order to evaluate how these changes related to preterm birth outcomes. We hypothesized that the poverty changes, measured by at least a quartile change in neighborhood poverty status across births, will be greater for movers than non-movers. We then aimed to examine the association between neighborhood poverty trajectory and PTB. We hypothesized consistent with previous finding there will be a modest association between upward trajectory and a reduction in PTB. We then further controlled for individual-level characteristics associated with adverse birth outcomes and evaluate the role of poverty trajectory in these relationships.

Methods

Study Data and Population

Birth data files were linked by the Michigan Department of Health and Human Services to create maternally-linked births files that include a mother and all of her successive pregnancies in the state of Michigan during the study time period, 1990-2012. Women who had a previous birth outside of Michigan were excluded from this analysis as we did not have access to inter-state birth records. We further restrict our analysis to at least 2 births to compare across birth time points. As a final restriction we limit birth records including up to the third birth to control for confounding of the association between neighborhood poverty and PTB by parity and as this captures the majority of our full eligible sample had three or less births.

We used a normalized dataset as the source for our poverty rate, the Neighborhood Change Database. This dataset allowed comparisons of census tract poverty rates across different census years by normalizing tract boundary changes to the 2010 decennial census tract boundaries. For our purposes, the NCDB allows comparison across 3 decennial census years in our study period: 1990, 2000, and 2010. Census tracts are designed to be stable statistical groupings that reflect natural geographic boundaries and homogenous groups that encompass the "neighborhood" (Geography n.d.) However, they do evolve over time and may be split due to population growth or merged as a result of substantial population decline. In Michigan there were 2,552 census tracts recorded in the 1990 census, 2,717 census tracts in the 2000 census, and 2,813 census tracts recorded in the American Community Survey and 2010 census (Bureau n.d.; n.d.). We performed linear interpolation of census tract poverty rate for each infant birth year between decennial census periods and using American Community Survey data. We used a longitudinal database as a crosswalk reference between the 1990 to 2010 and 2000 to 2010 to allow linkage between the normalized poverty data and Michigan Birth files for census tracts that had been merged or split (Logan, Xu, and Stults 2014).

Measures

Residential Mobility We define residential mobility as successive changes in census tract based on geocoding of maternal residence at live birth. Residential mobility is categorized as mover (changed census tract) or non-mover (did not change census tract) at the time of the successive live birth.

Neighborhood Poverty Trajectory Previous studies have examined changes in neighborhood poverty rates across multiple time points as a determinant in birth outcomes. There is however no standard approach for how to measure these socioeconomic changes. The use of cut points to define socioeconomic changes vary from relative definitions such as quartiles

(Janevic et al. 2010; J. W. Collins, Rankin, and David 2015; Slaughter-Acey et al. 2016; Bruckner, Kane, and Gailey 2019), absolute poverty levels (Margerison-Zilko et al. 2015) or dichotomous high/low (Pearl et al. 2018; Heinonen et al. 2013). The measurement of socioeconomic change range from individual socioeconomic position (Osypuk et al. 2016; Slaughter-Acey et al. 2016) to occupational status (Heinonen et al. 2013) to neighborhood deprivation indices (O'Campo et al. 2008; Holzman et al. 2009b; Bruckner, Kane, and Gailey 2019), or neighborhood poverty rate (Margerison-Zilko et al. 2015). The defined study periods for examining socioeconomic changes vary as well depending on the hypothesis being tested, but are conceptually within the individual (e.g., childhood to adulthood, birth 1 to birth 2) or intergenerational (e.g., grandmother to grandchild). For this study, we seek to understand the relationship between socioeconomic change, measured as changes in neighborhood poverty rate that we term 'neighborhood poverty trajectory', and birth outcomes for an individual during a mother's adulthood (years 15-44) over successive births, or times. This type of change has been previously examined in relation to PTB using intergenerational births(Pearl et al. 2018; J. W. Collins, Mariani, and Rankin 2018; J. W. Collins, Rankin, and David 2015) and across an individual mother's successive births(Bruckner, Kane, and Gailey 2019).

Based on previous studies, we calculated a neighborhood poverty trajectory score based a mother's level of neighborhood poverty trajectory away from, or into poverty. We first compared neighborhood poverty rates of maternal address at each birth (census tract) based on quartile cut points from the linearly interpolated neighborhood poverty (Q1: $\leq$0.05, Q2: >=0.05 and <0.09, Q3: >=0.09 and <0.017, Q4: $\geq$0.17). These quartile categories represent neighborhoods with the least percentage of poverty (Q1) to those with the highest percentage of poverty (Q4). We then compared changes in neighborhood poverty rates across time points between two successive pregnancies restricted to within state migration. We defined neighborhood poverty trajectory as any quartile change in census tract poverty between two successive pregnancies in Michigan based on quartile cut points from the linearly interpolated poverty data (Q1,: 0.05, Q2: >=0.05 and <0.09, Q3: >=0.09 and <0.017, Q4: ≥0.17). We created neighborhood poverty trajectory categorical variables representing these changes: strong downward (Q1 to Q4), moderate downward (a 2-quartile move into higher percentage poverty), and weak downward (a 1-quartile move into higher poverty), strong upward (Q4 to Q1), moderate upward (a 2-quartile move to away from poverty), weak upward (a 1-quartile move away from poverty), and static mobility. Again consistent with previous studies(Bruckner, Kane, and Gailey 2019), the static trajectory category serves as a reference category for neighborhood poverty trajectory but represents both women who did not move and did not experience a quartile change in neighborhood poverty rate and women who moved to neighborhood with similar (within the same poverty quartile) neighborhood poverty rate. Finally, women who did not move could be classified in an upward or downward trajectory if the neighborhood changed poverty levels between her successive live births.

Maternal characteristics Maternal characteristics included age (<20, 20-24, 25-29, 30-34, 35-40, >40), race/ethnicity (non-Hispanic white [NHW], non-Hispanic black [NHB], Hispanic, non-Hispanic American Indian / Alaska Native [AI/AN], non-Hispanic Asian/Pacific Islander [A/PI], and non-Hispanic mixed race/other), nativity (US born, foreign born), parity (nulliparous, primiparous, multiparous), marital status (married, not married), educational attainment (some high school, high school, some college, college, greater than college), insurance pay source at birth (private, Medicaid, self-pay, other, unknown), smoking during pregnancy (yes, no, unknown) and hypertension during pregnancy (yes, no).

Preterm Birth PTB is our dependent variable, defined as less than 37 completed weeks at delivery. This is a binary (yes/no) variable and is reported at index, or initial, birth and successive, or subsequent, births for a mother. The gestational age is listed on the birth certificate based on clinical estimate of gestation. We also examine gestational age of PTB (<32, 32-36, 37) and fetal growth (SGA: infants with $<10^{th}$ percentile birthweight, AGA: infants with between 10-90^{th} percentile birthweight, and LGA: infants with $>90^{th}$ percentile birthweight) in a sensitivity analysis but these are not in our main analysis as there may be distinct etiologies related to mechanistic pathway.

Statistical Analysis

We first reported univariate and bivariate analysis for neighborhood poverty trajectory and residential mobility. Our strategy was to understand how much of neighborhood poverty trajectory was driven by residential mobility. We calculated unadjusted relative risk and 95% confidence intervals for the relationship between neighborhood trajectory and residential mobility, using static trajectory as the reference group similar to previous work. Successive PTB rates were then calculated within each quartile of poverty. Crude PTB rate per 1000 live births were calculated by neighborhood poverty trajectory.

We then performed modified Poisson regression with robust standard error multivariable adjusted models and neighborhood poverty trajectories and PTB. The models were adjusted for a priori covariates (maternal age, parity, educational attainment and smoking during pregnancy) thought to confound the association between neighborhood mobility trajectory and PTB. We also adjusted for PTB at the index birth which may cause an issue with selection if it influences the women's neighborhood poverty mobility. For example, if a heathier mother who has a lower risk of PTB shows stronger upward mobility compared with a mother at higher risk for PTB then we may expect our model to be confounded by not including PTB at the index birth. This is also consistent with the healthy migrant theory which postulates that healthier women are more likely to move, however in our study we focused on health relative to prior PTB.

In sensitivity analyses we performed modified Poisson regression with robust standard error adjusted models to assess the association between neighborhood poverty quartile and PTB. We then tested the static trajectory group for association of poverty quartile category and PTB using chi-square test for general association and using Mantel-haenszal chi-square test for trend. Although this group represents no change in neighborhood mobility trajectory it also represents varying levels of neighborhood poverty by quartile. We sought to examine if there was increasing PTB with increasing neighborhood poverty among this group as it serves as the reference group for neighborhood trajectory. We then examined the associations between our neighborhood poverty trajectory categories using only static trajectory of the lowest poverty group (Q1) as the reference. Finally, we also examined PTB by levels of gestational age (<28, 28-<32, 32-<34, 34-<37).

Results

Table 2.1 shows the distribution of neighborhood poverty trajectories stratified by residential mobility. Most women in both birth samples (births 1 to 2, n=447,607; births 2 to 3, n=117,956) experienced static neighborhood poverty trajectory. Of the static trajectory category, 65.1% were non-movers compared to 34.9% movers. Movers experienced greater risk of both upward and downward poverty trajectory (compared to static trajectory) than non-movers. The relative risk of moving mirrored in either direction, where movers had 2.8 times the risk compared to non-movers for both strong upward and downward poverty trajectory. This mirror pattern remained consistent across all measured levels of parity, although the risk was slightly reduced by the 3rd birth (RR: 2.6).

Table 2.2 arrays the percent PTB births at the successive birth by quartile of neighborhood poverty at index birth (horizontal) and successive birth (vertical) across births 1 to 2 and births 2 to 3. The bold diagonal on these arrays shows women whose neighborhood poverty stayed in the same quartile of poverty across both births and includes both lateral movers, in that the residence changed but the poverty quartile did not, and non-movers who did not experience a quartile change in poverty. The remaining values show neighborhood poverty trajectory, which accounts for approximately 36% of women at birth 2 and 35% of women at birth 3. The quartile representing the static trajectory (Q4 and Q4) with the highest poverty rate also has the highest rate of PTB in both birth samples (11.4% births 1 to 2; 12.3% births 2 to 3). Only 7.4% of women experienced PTB who exhibited strong upward trajectory (Q4 to Q1) from births 1 to 2, and 8.7% of women who had strong upward trajectory experience PTB from birth 2 to 3. In comparison, women who had strong downward trajectory (Q1 to Q4) experienced 8.6% of PTB from births 1 to 2, and 10.6% for births 2 to 3.

Table 2.3 shows the crude PTB rates per 100 live births by level of mother's trajectory from previous live birth (Appendix tables B.5 and B.6 present the PTB rates per 100 live births per calendar year). Strong downward trajectory was associated with the highest rate of PTB per live birth at both the second (8.65 cases/100 live births) and third birth (10.60 cases/live births). Strong upward trajectory did not show a reduction in the crude rate of PTB. The lowest crude rate of PTB at the second birth occurred in the weak downward trajectory category while at the third birth it occurred in the weak upward category. The majority of cases of PTB occurred in the static trajectory category, representing no change in neighborhood poverty.

Table 2.4 shows the multivariable adjusted association of neighborhood poverty trajectories with PTB at the successive birth. In crude and adjusted models, strong upward poverty trajectory was modestly associated with a slight reduction in odds of PTB but the association was not significant (Crude OR 0.93, 95% CI: 0.83-1.03; Adjusted OR: 0.94, 95% CI: 0.84-1.06). Weak downward trajectory between births was significantly associated with a 10% decrease in the odds of PTB at the successive birth (OR: 0.90, 95% CI: 0.87 -0.93) in crude models and adjusted models (OR: 0.90, 95% CI: 0.87-0.93). In the adjusted model, the direction of the association is inconsistent with the direction of trajectory. For example, weak upward trajectory showed slightly decreased odds of PTB at successive birth (OR: 0.96, 95% CI: 0.93-0.99), while moderate upward trajectory had an increased odds of PTB (OR: 1.05, 95% CI: 1.00-1.12), and strong upward trajectory was again protective. The strongest association was seen in the strong downward trajectory between births 2 and 3 with a 27% increase in the odds of PTB (OR: 1.27, 95%CI 1.07-1.50).

Discussion

We had previously reported a large percentage of women move between pregnancies, but we find here that there is limited trajectory across poverty levels (movers move to similar levels of poverty) and that there is only a modest association between neighborhood poverty trajectory and PTB during our study time period. The majority of PTB cases occurred in the static trajectory category (table 2.1) which is comprised of more non-movers than movers (63.0% versus 37.0%). This is consistent with our findings that the majority of women experience static trajectory and that neighborhood poverty trajectory was only modestly related to PTB. However, we also saw the highest rates of PTB among the poorest quartile of neighborhood poverty. Overall, women who started in low poverty had a lower percentage of PTB compared to women who started in high poverty. Our findings were similar across two levels of birth parity.

We hypothesized that upward trajectory would be associated with a reduction in PTB consistent with other published results. We found evidence of a modest protective association between strong upward neighborhood poverty trajectory and PTB between birth 1 and 2. We also found a significant protective association with PTB among women who experienced weak downward neighborhood poverty trajectory between birth 1 and 2. As this group is comprised of more non-movers than any other level of neighborhood poverty trajectory there may be some confounding by residential mobility status. We may also have measured two simultaneous associations between moving itself and a change in poverty level. It may be useful to examine this further by stratifying by moving status in the association between poverty trajectory and PTB. We might also examine women who had the same change (e.g., Q1 to Q3) who moved and who did not move. In the association between neighborhood poverty trajectory and PTB we found the strongest association with strong downward trajectory between birth 2 and 3 with OR 1.2 (95%CI: 1.0-1.3). As downward poverty trajectory represents an unfavorable poverty condition and this group represents an increase in the total number of children we suspect this may represent a more unexpected downturn or stress pathway.

We also used a static neighborhood poverty trajectory as our reference group, consistent with another study of neighborhood poverty trajectory (Bruckner, 2019). However, our choice in reference group may have introduced confounding into our model as it static included all levels of neighborhood poverty that did not change. In sensitivity analysis we compare the association of neighborhood poverty trajectory using a restricted reference group. This group is comprised of the lowest risk group, the static Q1 low poverty group. We found increased odds of PTB for births 1 to 2 with strong downward neighborhood trajectory (OR 1.2, 95% CI 1.0-1.3) but also increased odds of PTB among strong upward neighborhood poverty trajectory (OR 1.1, 95%CI: 1.1- 1.2) compared to the static trajectory group of lowest neighborhood poverty quartile(Table

B.4). This is more consistent with the estimation methods used by Collins et al. when they used reference groups of lowest risk.

Limitations

While this study offers important contributions to our understanding of neighborhood poverty trajectories and PTB, there are several important limitations to interpreting and generalizing our results. First, our sample excludes women with only one birth. This limits the generalizability of our study and may not truly define the PTB risk if mothers with a first PTB delayed or discontinued subsequent childbearing.

We reported the proportion of PTB by quartile of neighborhood poverty rate at the index and successive births. However, we did not investigate the distribution of maternal characteristics by quartile of neighborhood poverty rate. We therefore cannot conclusively determine the role of structural confounding in our model (Messer, Oakes and Mason, 2010). If for example, our Q4 category, the highest poverty level, also disproportionately represents white women or women with high educational attainment, such that their exposure differs within the covariate strata then we may have structural confounding associated with social stratification. Future investigations using this poverty quartile structure should delineate the categorical distribution of maternal characteristics. This is necessary in order to allow for meaningful causal contrasts by level of poverty exposure, or exchangeability (Greenland and Robins, 2009; Messer, Oakes and Mason, 2010), Previous studies measured neighborhood poverty trajectory across a larger time period from childhood to adulthood for early-life exposure to poverty which may bias our results if, for example, women in our study were born into high poverty but now reside in low poverty. We do not have information in our study about childhood poverty exposure. Our study period may not be early enough to measure critical windows of exposure for subsequent

PTB outcomes related to poverty trajectory. While our study time frame is broad it may represent too acute a time period for change in trajectory to be associated with PTB. We also do not have information on the mother's own birth histories which may be relevant as a previous report suggest women who had adverse birth events as infants may be more likely to have PTB with increased neighborhood poverty exposure (J. W. Collins, Rankin, and David 2011). Further examination of this potential for residual confounding is warranted. We also do not have detailed socioeconomic data on the mother or her family unit, such as her employment and partner's socioeconomic status. We therefore cannot make inference about the motivations for trajectory and the relationship to birth outcomes. Finally, we used a relative measure of poverty trajectory, quartiles based on the population neighborhood poverty rate, but an alternate specification, such as absolute poverty levels, may be more informative as it relates to policy decisions (such as the U.S. Census guidelines for high poverty >20% (Bureau n.d.)).

In summary, this study extends the work on associations between neighborhood poverty trajectories and adverse birth outcomes using a large sample of maternally-linked births in Michigan during the period 1990-2012. We find that non-movers experience some poverty change through neighborhood changes but the majority of poverty trajectory comes in the form of moving. Even among movers, there is limited trajectory across poverty groups with the majority of women remaining in the same quartile of poverty across successive births. PTB is associated with high levels of neighborhood poverty, but not with neighborhood poverty trajectory across poverty quartiles.

Table 2.1 Neighborhood poverty trajectories at successive birth (upward, downward, static) stratified by residential status (mover, non-mover) in singleton maternally-linked Michigan births1990-2012

Births 1 to 2 (n=895,214)

Neighborhood Trajectory[a]	Overall		Residential Mobility						
			Non-Movers		Movers				
	n	%	n	%	n	%	RR[b]	95%CI	
Total Mothers	447,607	100	223,005	49.8	224,602	50.2			
Strong Downward	3,955	0.9	144	3.6	3,811	96.4	2.8	2.7	2.8
Moderate Downward	17,133	3.8	950	5.5	16,183	94.5	2.7	2.7	2.7
Weak Downward	69,421	15.5	26,119	37.6	43,302	62.4	1.8	1.8	1.8
Static	285,662	63.8	186,094	65.1	99,568	34.9	1.0		
Weak Upward	50,265	11.2	9,188	18.3	41,077	81.7	2.3	2.3	2.4
Moderate Upward	16,567	3.7	424	2.6	16,143	97.4	2.8	2.8	2.8
Strong Upward	4,604	1.0	86	1.9	4,518	98.1	2.8	2.8	2.8

Births 2 to 3 (n=355,912)

Neighborhood Trajectory[a]	Overall		Residential Mobility						
			Non-Movers		Movers				
	n	%	n	%	n	%	RR[b]	95% CI	
Total Mothers	177,956	100	87,047	48.9	90,909	51.1			
Strong Downward	1,405	0.8	51	1.9	1,354	98.1	2.6	2.5	2.6
Moderate Downward	6,337	3.6	463	2.6	5,874	97.4	2.5	2.4	2.5
Weak Downward	27,556	15.5	10,927	17.8	16,629	82.3	1.6	1.6	1.6
Static	115,193	64.7	71,971	62.5	43,222	37.5	1.0		
Weak Upward	19,375	10.9	3,440	39.7	15,935	60.4	2.2	2.2	2.2
Moderate Upward	6,265	3.5	161	7.3	6,104	92.7	2.6	2.6	2.6
Strong Upward	1,825	1.0	34	3.6	1,791	96.4	2.6	2.6	2.6

[a] Quartile cut points from linearly interpolated census data 1990-2012: 0.05, 0.09, and 0.17. Neighborhood poverty Trajectories are categories of change away, or into poverty based on a quartile change. The strongest change represents Strong Downward (Q1 to Q4) and Strong Upward (Q4 to Q1).

[b] Modified Poisson regression of movers versus non-movers by neighborhood poverty trajectory with static mobility as reference group

Table 2.2 Percentage of PTB births at successive birth among singleton Michigan births by neighborhood poverty quartile[a] at index and successive births

Births 1 to 2 (n=447,607)									
		Birth 1 (Index Birth)							
Neighborhood Poverty		Q1		Q2		Q3		Q4	
	Q1	**6.1%**	**(4,735/78,159)**	6.3%	(1,164/18,427)	7.2%	(573/7,979)	7.4%	(340/4,604)
Birth 2 (Successive Birth)	Q2	6.2%	(1,438/23,089)	**6.6%**	**(4,443/67,439)**	7.3%	(1,164/15,963)	9.3%	(795/8,588)
	Q3	6.6%	(543/8,197)	6.9%	(1,727/25,193)	**6.2%**	**(4,425/70,865)**	9.4%	(1,488/15,875)
	Q4	8.6%	(342/3,955)	9.0%	(802/8,936)	8.7%	(1,836/21,139)	**11.4%**	**(9,068/79,199)**
Births 2 to 3 (n=177,956)									
		Birth 2 (Index birth)							
Neighborhood Poverty		Q1		Q2		Q3		Q4	
	Q1	**5.6%**	**(1,537/27,252)**	6.5%	(438/6,771)	7.8%	(226/2,880)	8.7%	(159/1,825)
Birth 3 (Successive Birth)	Q2	6.9%	(570/8,228)	**6.8%**	**(1,660/24,337)**	8.1%	(478/5,906)	10.4%	(352/3,385)
	Q3	7.9%	(222/2,823)	7.8%	(792/10,101)	**7.6%**	**(1,844/24,384)**	9.7%	(652/6,698)
	Q4	10.6%	(149/1,405)	9.5%	(333/3,514)	9.5%	(875/ 9,227)	**12.3%**	**(4,820/39,220)**

[a]Neighborhood Poverty Quartiles: Q1 Very Low: <0.05 Q2 Low: >=0.05 and <0.09 Q3 High: >=0.09 and <0.017 Q4 Very High: >=0.17

Table 2.3 Risk per 100 live births of preterm birth (<37 weeks completed gestation) at birth 2 and birth 3 by mother's neighborhood poverty trajectory from previous index birth, singleton Michigan Births 1990-2012

	Preterm Births at Birth 2 (n=447,607)		Preterm Births at Birth 3 (n=177,956)	
Neighborhood Poverty Trajectory	Cases	Cases per 100 live births	Cases	Cases per 100 live births
Strong downward	342	8.7	149	10.6
Moderate Downward	1,345	7.9	555	8.8
Weak Downward	5,001	7.2	2,237	8.1
Static	22,671	7.9	9,861	8.6
Weak upward	3,816	7.6	1,568	8.1
Moderate upward	1,368	8.3	578	9.2
Strong upward	340	7.4	159	8.7

Table 2.4 Associations of Improved Neighborhood Trajectory Trajectories and Successive Birth Outcomes, Bivariate and Multivariate Models in Singleton Michigan Births 1990-2012 (n=895,214)

Neighborhood Poverty Trajectory	PTB					
	Crude[a]			Adjusted[b]		
	OR	(95% CI)		OR	(95% CI)	
Poverty Trajectory Birth 1 to 2						
Strong Downward	1.1	1.0	1.2	1.0	0.9	1.2
Moderate Downward	1.0	0.9	1.1	1.0	0.9	1.1
Weak Downward	0.9*	0.9	0.9	1.0	0.9	1.0
Static (ref)	1.0			1.0		
Weak Upward	1.0	0.9	1.0	1.0	1.0	1.0
Moderate Upward	1.0	1.0	1.1	1.1	1.0	1.1
Strong Upward	0.9	0.8	1.0	0.9	0.8	1.0
Poverty Trajectory Birth 2 to 3						
Strong Downward	1.3	1.1	1.5	1.2	1.0	1.5
Moderate Downward	1.0	0.9	1.1	1.1	1.0	1.2
Weak Downward	0.9	0.9	1.0	1.0	1.0	1.1
Static (ref)	1.0			1.0		
Weak Upward	0.9	0.9	1.0	1.0	1.0	1.1
Moderate Upward	1.1	1.0	1.2	1.1	1.0	1.2
Strong Upward	1.0	0.9	1.2	1.1	0.9	1.2

[a]Crude is bivariate model. [b]Adjusted for a priori covariates age, parity, maternal education, race/ethnicity, smoking and prior PTB. PTB preterm birth <37 weeks *significant p<.0001

APPENDIX

Table B.1 Datasets Mean, SD and Quartile Cut-points of Neighborhood Poverty

Dataset	Mean	SD	Quartile Cut-point 1	Quartile Cut-point 2	Quartile Cut-point 3
NCDB Linear Interpolated*	0.137120	0.13092	0.0492723	0.0919302	0.1736361
All births	0.145801	0.12861	0.0527120	0.0991436	0.1992184
All births >1	0.146822	0.12975	0.0525170	0.0990175	0.2020000
MI births 1 to 2	0.132156	0.11947	0.0494155	0.0893607	0.1724290
MI births 2 to 3	0.147351	0.12925	0.0537776	0.1005618	0.2020000

* Used as Quartile cut points for all analyses

Table B.2 Bivariate Associations of Quartiles of Neighborhood Poverty[a] and PTB across all births, Singleton Michigan Births 1990-2012

	Births 1 to 2			Births 2 to 3		
Quartiles	PTB Odds Ratio	95% CI		PTB Odds Ratio	95% CI	
Q2 vs Q1	1.1	1.1	1.1	1.2	1.1	1.2
Q3 vs Q1	1.2	1.2	1.2	1.3	1.3	1.4
Q4 vs Q1	1.6	1.6	1.7	2.0	2.0	2.1

[a]Neighborhood Poverty Quartiles:Q1 Very Low: <0.05 Q2 Low: >=0.05 and <0.09 Q3 High: >=0.09 and <0.017 Q4 Very High: >=0.17

Table B.3 Poverty quartile of static neighborhood poverty trajectory (no change) and PTB, and residential mobility at birth 2 (n= 285,662)

Quartile of Neighborhood Poverty[a] at index and successive births	PTB at Successive Birth						Residential Mobility					
	No		YES		X^2	M-H X^2	Non-Mover		Mover		X^2	M-H X^2
	n	%	n	%			n	%	n	%		
Q1-Q1 (n=78,159)	73,424	93.9	56,675	6.1	<.0001	<.0001	56,675	72.5	21,484	27.5	<.0001	<.0001
Q2-Q2 (n=67,439)	62,996	93.4	48,354	6.6			48,354	71.7	19,085	28.3		
Q3-Q3 (n=60,865)	56,440	92.7	41,970	7.3			41,970	69.0	18,895	31.0		
Q4-Q4 (n=79,199)	70,131	88.6	39,095	11.5			39,095	49.4	40,104	50.6		

[a]Neighborhood Poverty Quartiles: Q1 Very Low: <0.05 Q2 Low: >=0.05 and <0.09 Q3 High: >=0.09 and <0.017 Q4 Very High: >=0.17
[b]X^2 test for general association
[c]Mantel-haenszel test for trend

Table B.4 Associations of Improved Neighborhood Trajectory Trajectories and Successive Birth Outcomes, Bivariate and Multivariate Models in Singleton Michigan Births 1990-2012 (n=146,518) Q1 Static Reference Group

Neighborhood Poverty Trajectory	PTB					
	Crude[a]			Adjusted[b]		
	OR	(95% CI)		OR	(95% CI)	
Poverty Trajectory Birth 1 to 2						
Strong Downward	1.5	1.3	1.7	1.2	1.0	1.3
Moderate Downward	1.3	1.2	1.4	1.1	1.0	1.2
Weak Downward	1.3	1.2	1.4	1.1	1.0	1.1
Static (ref) **Q1 only**	1.0			1.0		
Weak Upward	1.3	1.2	1.4	1.1	1.1	1.2
Moderate Upward	1.4	1.3	1.5	1.2	1.1	1.3
Strong Upward	1.2	1.1	1.4	1.0	0.9	1.1

[a]Crude is bivariate model. [b]Adjusted for a priori covariates age, parity, maternal education, race/ethnicity, smoking and prior PTB. PTB preterm birth <37 weeks *significant p<.0001

Table B.5 Risk per 100 live births by calendar year of preterm birth (<37 weeks completed gestation) at birth 2 by level of mother's trajectory from birth 1, Singleton Michigan Births 1990-2012

	Neighborhood Poverty Trajectory by Quartile Change[a]								
Birth Year	No change	Downward (inclusive)	Strong Downward	Moderate Downward	Weak Downward	Upward (inclusive)	Weak Upward	Moderate Upward	Strong Upward
1990	47.83	66.67	.	66.67	.	0.00	0.00	.	.
1991	12.56	10.66	6.67	13.04	10.71	16.14	17.49	9.26	23.53
1992	8.52	7.03	17.74	4.73	6.43	8.47	8.38	10.63	4.35
1993	8.72	10.05	14.04	13.78	8.74	7.38	6.98	8.15	9.43
1994	8.10	6.84	12.24	5.86	6.55	6.44	6.02	7.09	9.90
1995	8.06	6.64	5.75	6.08	6.83	7.53	6.94	8.49	10.99
1996	8.33	7.41	5.62	9.58	6.94	7.46	6.90	8.87	9.38
1997	8.15	7.39	6.67	8.57	7.16	8.34	8.60	8.23	5.92
1998	8.39	8.89	9.43	8.67	8.91	7.89	7.49	8.25	11.23
1999	8.14	9.90	7.69	7.43	10.76	8.87	8.43	11.44	5.58
2000	8.39	8.36	8.20	8.83	8.24	7.82	7.48	8.89	7.55
2001	9.15	7.79	13.14	8.88	7.27	7.37	7.00	8.82	5.81
2002	7.93	7.74	6.52	7.17	7.93	8.25	8.08	8.33	9.70
2003	8.58	8.50	8.76	8.22	8.55	9.24	9.47	9.33	6.07
2004	6.87	6.53	7.07	7.88	6.24	7.83	7.70	8.44	6.83
2005	7.47	6.77	8.75	7.11	6.60	7.62	7.40	8.67	5.65
2006	7.19	6.21	9.41	7.06	5.85	7.09	6.76	8.57	5.02
2007	6.66	6.81	7.54	6.71	6.80	7.36	7.13	7.82	8.00
2008	7.33	7.11	8.98	7.82	6.84	7.44	7.07	8.52	6.92
2009	6.92	6.69	8.14	7.25	6.47	7.80	8.29	6.94	6.29
2010	6.41	6.39	7.08	6.50	6.30	6.27	6.46	6.48	3.65
2011	8.92	8.58	9.09	9.43	8.31	7.84	7.84	7.07	10.76
2012	9.26	7.69	9.11	8.42	7.40	7.81	8.09	6.90	7.61
Total	7.94	7.39	8.65	7.85	7.20	7.73	7.59	8.26	7.38

[a]Quartile Q1 Very Low: <0.05; Q2 Low: >=0.05 and <0.09 ; Q3 High: >=0.09 and <0.017; Q4 Very High: >=0.17

Table B.6 Risk per 100 live births by calendar year of preterm birth (<37 weeks completed gestation) at birth 3 by level of mother's trajectory from birth 2, Singleton Michigan Births 1990-2012

	Neighborhood Poverty Trajectory by Quartile Change[a]								
Birth Year	No change	Downward (inclusive)	Strong Downward	Moderate Downward	Weak Downward	Upward (inclusive)	Weak Upward	Moderate Upward	Strong Upward
1990	0	.	.	.	.	.	.	.	.
1991	22.17	6.67	0.00	0.00	10.00	0.00	0.00	0.00	0.00
1992	13.86	11.70	33.33	5.56	11.43	11.11	10.23	17.39	0.00
1993	10.26	11.41	7.69	14.29	11.19	9.72	11.43	5.45	5.88
1994	8.74	11.00	5.88	13.33	10.92	6.28	6.42	2.74	13.79
1995	7.30	8.37	8.33	8.70	8.29	6.99	6.16	9.15	10.00
1996	8.52	6.44	12.00	6.06	6.17	7.19	5.38	10.29	16.98
1997	8.87	10.29	16.67	12.22	9.64	8.16	7.26	10.81	9.80
1998	8.77	9.60	9.38	10.48	9.38	7.61	8.44	6.42	2.67
1999	9.46	8.54	6.25	8.89	8.51	8.51	7.75	12.30	4.94
2000	8.72	8.97	10.81	5.88	9.62	8.16	7.85	8.72	9.52
2001	8.62	8.46	11.29	7.47	8.57	8.70	8.14	9.71	10.00
2002	9.71	8.04	12.31	7.07	8.04	11.36	12.16	10.29	6.67
2003	9.11	9.27	12.66	11.42	8.68	7.39	7.75	7.08	3.70
2004	8.41	8.52	12.22	8.52	8.35	7.40	7.17	8.52	5.75
2005	8.10	8.09	6.82	5.67	8.65	9.53	8.97	10.44	12.77
2006	7.30	7.87	12.09	9.26	7.38	8.04	8.16	7.57	8.65
2007	7.80	6.87	4.21	8.44	6.66	9.16	8.12	12.17	8.57
2008	7.67	7.87	9.00	8.68	7.63	8.50	8.28	9.05	8.61
2009	7.58	7.63	12.75	7.87	7.30	7.02	6.59	7.43	9.63
2010	7.48	7.01	7.25	8.86	6.50	8.09	8.03	9.13	4.63
2011	9.48	9.65	13.64	9.76	9.34	8.71	8.25	9.19	12.17
2012	9.64	9.09	12.40	10.32	8.59	8.92	8.32	10.34	11.71
Total	8.56	8.33	10.60	8.76	8.12	8.39	8.09	9.23	8.71

[a]Quartile Q1 Very Low: <0.05; Q2 Low: >=0.05 and <0.09 ; Q3 High: >=0.09 and <0.017; Q4 Very High: >=0.17

Table B.7 Gestational age of preterm births among singleton Michigan births 1990-2012

Gestational age (weeks)		PTB			
		Births 1 to 2 (n= 73,840)		Births 2 to 3 (n=29,288)	
		n	%	n	%
Extreme Preterm	<28	2,940	4.0	971	3.3
Very Preterm	≥28 to 32	5,572	7.6	2,028	6.9
Moderate Preterm	≥32 to 34	8,624	11.7	3,418	11.7
Late Preterm	≥34 to 37	56,704	76.8	22,871	78.1

Table B.8 Mother's (N=447,607) Neighborhood Poverty Trajectories by MSA (Metropolitan, Micropolitan, Rural) Change, Singleton Michigan Births 1 to 2, 1990-2012

Neighborhood Poverty Trajectories	MSA Change from Birth 1 to Birth 2				
	Micro to Metro	Metro to Rural	No change	Rural to Metro	Metro to Micro
Strong Downward	4	189	3,723	77	36
Moderate Downward	33	922	15,820	544	253
Weak Downward	142	1,978	66,469	1,508	1,171
Static	141	2,461	283,603	2,529	2,911
Weak Upward	59	1,227	47,733	1,683	804
Moderate Upward	6	406	15,725	687	125
Strong Upward	1	57	4,508	114	12

REFERENCES

REFERENCES

Braveman, Paula A., Catherine Cubbin, Susan Egerter, David R. Williams, and Elsie Pamuk. 2010. “Socioeconomic Disparities in Health in the United States: What the Patterns Tell Us.” *American Journal of Public Health* 100 Suppl 1 (April): S186-196. https://doi.org/10.2105/AJPH.2009.166082.

Bruckner, Tim A., Jennifer B. Kane, and Samantha Gailey. 2019. “Strong Upward Neighborhood Mobility and Preterm Birth: A Matched-Sibling Design Approach.” *Annals of Epidemiology* 36 (August): 48-54.e1. https://doi.org/10.1016/j.annepidem.2019.05.005.

Bureau, US Census. n.d. “About.” Accessed March 4, 2019a. https://www.census.gov/topics/income-poverty/poverty/about.html.
———. n.d. “American Community Survey (ACS).” Accessed October 24, 2016b. https://www.census.gov/programs-surveys/acs.
———. n.d. “Geography Program.” Accessed November 9, 2019c. https://www.census.gov/programs-surveys/geography.html.

Colen CG, Geronimus AT, Bound J, and James SA. 2006. “Research and Practice. Maternal Upward Socioeconomic Mobility and Black-White Disparities in Infant Birthweight.” *American Journal of Public Health* 96 (11): 2032–39. https://doi.org/10.2105/AJPH.2005.076547.

Collins, James W., Allison Mariani, and Kristin Rankin. 2018. “African-American Women’s Upward Economic Mobility and Small for Gestational Age Births: A Population-Based Study.” *Maternal and Child Health Journal* 22 (8): 1183–89. https://doi.org/10.1007/s10995-018-2503-4.

Collins, James W., Kristin M. Rankin, and Richard J. David. 2011. “African American Women’s Lifetime Upward Economic Mobility and Preterm Birth: The Effect of Fetal Programming.” *American Journal of Public Health* 101 (4): 714–19. https://doi.org/10.2105/AJPH.2010.195024.

———. 2015. “Downward Economic Mobility and Preterm Birth: An Exploratory Study of Chicago-Born Upper Class White Mothers.” *Maternal and Child Health Journal* 19 (7): 1601–7. https://doi.org/10.1007/s10995-015-1670-9.

Collins, Jr JW, R. J. David, D. M. Simon, and N. G. Prachand. 2007. “Preterm Birth among African American and White Women with a Lifelong Residence in High-Income Chicago Neighborhoods: An Exploratory Study.” *Ethnicity & Disease* 17 (1): 113–17.

Croteau, Agathe, Sylvie Marcoux, and Chantal Brisson. 2007. “Work Activity in Pregnancy, Preventive Measures, and the Risk of Preterm Delivery.” *American Journal of Epidemiology* 166 (8): 951–65. https://doi.org/10.1093/aje/kwm171.
David, Richard, and Lynne Messer. 2011. “Reducing Disparities: Race, Class and the Social Determinants of Health.” *Maternal and Child Health Journal* 15 Suppl 1 (September): S1-3. https://doi.org/10.1007/s10995-011-0878-6.

Geography, US Census Bureau. n.d. “Guide to State and Local Geography - Michigan.” Accessed January 11, 2017. https://www.census.gov/geo/reference/guidestloc/st26_mi.html.

Greenland, Sander, and James M Robins. 2009. “Identifiability, Exchangeability and Confounding Revisited.” *Epidemiologic Perspectives & Innovations : EP+I*6 (September): 4. https://doi.org/10.1186/1742-5573-6-4.

Heinonen, Kati, Johan G. Eriksson, Eero Kajantie, Anu-Katriina Pesonen, David J. Barker, Clive Osmond, and Katri Raikkonen. 2013. “Late-Preterm Birth and Lifetime Socioeconomic Attainments: The Helsinki Birth Cohort Study.” *Pediatrics* 132 (4): 647–55. https://doi.org/10.1542/peds.2013-0951.

Holzman, Claudia, Janet Eyster, Mary Kleyn, Lynne C. Messer, Jay S. Kaufman, Barbara A. Laraia, Patricia O’Campo, Jessica G. Burke, Jennifer Culhane, and Irma T. Elo. 2009a. “Maternal Weathering and Risk of Preterm Delivery.” *American Journal of Public Health* 99 (10): 1864–1871.

———. 2009b. “Maternal Weathering and Risk of Preterm Delivery.” *American Journal of Public Health* 99 (10): 1864–71. https://doi.org/10.2105/AJPH.2008.151589.

Iceland, John, and Erik Hernandez. 2017. “Understanding Trends in Concentrated Poverty: 1980 to 2014.” *Social Science Research* 62 (February): 75–95. https://doi.org/10.1016/j.ssresearch.2016.09.001.

Janevic, T, CR Stein, DA Savitz, JS Kaufman, SM Mason, and AH Herring. 2010. “Neighborhood Deprivation and Adverse Birth Outcomes among Diverse Ethnic Groups.” *Annals of Epidemiology* 20 (6): 445–51. https://doi.org/10.1016/j.annepidem.2010.02.010.

Jargowsky, Paul A. 1998. *Poverty and Place: Ghettos, Barrios, and the American City*. New York: Russell Sage Foundation.

Kramer, Michael R., Anne L. Dunlop, and Carol J. R. Hogue. 2014. “Measuring Women’s Cumulative Neighborhood Deprivation Exposure Using Longitudinally Linked Vital Records: A Method for Life Course MCH Research.” *Maternal and Child Health Journal* 18 (2): 478–87. https://doi.org/10.1007/s10995-013-1244-7.

Logan, John R., Zengwang Xu, and Brian J. Stults. 2014. “Interpolating U.S. Decennial Census Tract Data from as Early as 1970 to 2010: A Longitudinal Tract Database.” *The Professional Geographer* 66 (3): 412–20. https://doi.org/10.1080/00330124.2014.905156.

Love, Catherine, Richard J. David, Kristin M. Rankin, and James W. Collins. 2010. “Exploring Weathering: Effects of Lifelong Economic Environment and Maternal Age on Low Birth Weight, Small for Gestational Age, and Preterm Birth in African-American and White Women.” *American Journal of Epidemiology* 172 (2): 127–34. https://doi.org/10.1093/aje/kwq109.

Margerison-Zilko, Claire, Catherine Cubbin, Jina Jun, Kristen Marchi, Kathryn Fingar, and Paula Braveman. 2015. "Beyond the Cross-Sectional: Neighborhood Poverty Histories and Preterm Birth." *American Journal of Public Health* 105 (6): 1174–80. https://doi.org/10.2105/AJPH.2014.302441.

Messer, Lynne C., Jay S. Kaufman, Nancy Dole, David A. Savitz, and Barbara A. Laraia. 2006. "Neighborhood Crime, Deprivation, and Preterm Birth." *Annals of Epidemiology* 16 (6): 455–62. https://doi.org/10.1016/j.annepidem.2005.08.006.

Messer, Lynne C., J. Michael Oakes, and Susan Mason. 2010. "Effects of Socioeconomic and Racial Residential Segregation on Preterm Birth: A Cautionary Tale of Structural Confounding." *American Journal of Epidemiology*171 (6): 664–73. https://doi.org/10.1093/aje/kwp435.

Meyer, John D., Nicholas Warren, and Susan Reisine. 2007. "Job Control, Substantive Complexity, and Risk for Low Birth Weight and Preterm Delivery: An Analysis from a State Birth Registry." *American Journal of Industrial Medicine* 50 (9): 664–75. https://doi.org/10.1002/ajim.20496.

O'Campo, Patricia, Jessica G. Burke, Jennifer Culhane, Irma T. Elo, Janet Eyster, Claudia Holzman, Lynne C. Messer, Jay S. Kaufman, and Barbara A. Laraia. 2008. "Neighborhood Deprivation and Preterm Birth among Non-Hispanic Black and White Women in Eight Geographic Areas in the United States." *American Journal of Epidemiology* 167 (2): 155–163.

Osypuk, Theresa L., Jaime Slaughter-Acey, Rebecca Kehm, and Dawn P. Misra. 2016. "Life Course Social Mobility and Reduced Risk of Adverse Birth Outcomes." *American Journal of Preventive Medicine* 51 (6): 975–82. https://doi.org/10.1016/j.amepre.2016.09.008.

Pearl, Michelle, Jennifer Ahern, Alan Hubbard, Barbara Laraia, Bina Patel Shrimali, Victor Poon, and Martin Kharrazi. 2018. "Life-Course Neighbourhood Opportunity and Racial-Ethnic Disparities in Risk of Preterm Birth." *Paediatric and Perinatal Epidemiology* 32 (5): 412–19. https://doi.org/10.1111/ppe.12482.

Schempf, Ashley H., Jay S. Kaufman, Lynne C. Messer, and Pauline Mendola. 2011. "The Neighborhood Contribution to Black-White Perinatal Disparities: An Example from Two North Carolina Counties, 1999-2001." *American Journal of Epidemiology* 174 (6): 744–52. https://doi.org/10.1093/aje/kwr128.

Slaughter-Acey, Jaime C., Claudia Holzman, Danuelle Calloway, and Yan Tian. 2016. "Movin' on Up: Socioeconomic Mobility and the Risk of Delivering a Small-for-Gestational Age Infant." *Maternal and Child Health Journal* 20 (3): 613–22. https://doi.org/10.1007/s10995-015-1860-5.

Spencer, N. 2004. "Accounting for the Social Disparity in Birth Weight: Results from an Intergenerational Cohort." *Journal of Epidemiology & Community Health* 58 (5): 418–19. https://doi.org/10.1136/jech.2003.012757.

STUDY 3

Introduction

Individuals who live in high-poverty areas fare worse compared to individuals who live in low-poverty neighborhoods on a broad range of outcomes not just limited to health but including economic and educational outcomes (Sampson 2013; Leventhal and Brooks-Gunn 2000). Evidence from neighborhood associations examining deprivation suggests a persistent association with adverse birth outcomes that remains even after adjustment for neighborhood-level and individual-level covariates. Increasingly, there is evidence of an association between upward mobility, moving away from higher poverty areas, and a modest protective effect on PTB (Kramer 2016; Collins, Mariani, and Rankin 2018; Pearl et al. 2018). However, this protective effect is not consistent across racial groups and may be modified by early-life poverty status (Collins, Mariani, and Rankin 2018; Collins, Rankin, and David 2015). Further, neighborhoods are not discrete entities but reflect larger societal patterns such that Non-Hispanic Black women are more likely than Non-Hispanic White women to reside in neighborhoods with high deprivation, increased crime, and diminished housing quality (Culhane and Goldenberg 2011). As we previously reported, there is a large amount of residential mobility among women between pregnancies with approximately 50% of women in our previous study changing residence between births. In the estimation of the association between neighborhood poverty and birth outcomes, it is therefore important to evaluate these residential mobility patterns as a potential source for bias, particularly if they are also related to the successive birth outcome. Even non-movers may be subject to selection bias if they have unobserved confounding that selects them into their original neighborhood and impacts PTB outcomes.

These observed societal patterns may challenge the validity of causal inference in the association between neighborhood poverty and preterm birth if there are conditions that select a woman into a neighborhood which also influence her pregnancy outcome. The resulting selection bias, when there are maternal characteristics which differentially select a woman into a neighborhood, are associated with her pregnancy outcomes, is then incorrectly attributed as neighborhood exposure. Prior studies have recognized the potential for neighborhood compositional changes due to maternal selection and controlled for maternal covariates such as race/ethnicity, age and parity. However, there may be unmeasured factors, such as stressors, health, prenatal practices, which also impact selection into neighborhoods. Maternal factors – both measured and unmeasured – can either be time-invariant, where they do not substantially vary over time such as gender, race/ethnicity, or time-varying, when there is a change in value over time such as parity or marital status. Prior studies of neighborhood associations with birth outcomes have adjusted for measured confounders by including measured maternal covariates. Prior studies of neighborhood associations with birth outcomes have also focused on adjustments for confounding by unmeasured neighborhood-level characteristics using multi-level modeling or time-varying area-level characteristics. However, to our knowledge there have been scant studies that have addressed confounding by unmeasured maternal characteristics (Margerison, Luo, and Li 2019; Bruckner, Kane, and Gailey 2019).

One such method that addresses unmeasured factors inherent to the mother that do not vary substantially over time is a maternal fixed effects analysis, analogous to a case crossover study where a mother is used as her own control to account for stable maternal characteristics, both observed and unobserved. This is also termed a within-mother analysis or matched sibling design as it examines the variation within the mother while discarding the between person variation that is likely contaminated by the unmeasured maternal characteristics resulting in unbiased estimates (Allison 2005).

We utilized a longitudinal dataset linked by a mother's recorded births in Michigan during the study period 1990 to 2012 to examine the association between neighborhood poverty and preterm birth (PTB) using a maternal fixed effects analysis. We examined changes in neighborhood poverty between successive pregnancies measured at the time of infant birth and PTB. We then compared these findings to conventional applications of neighborhood associations of poverty and PTB, logistic regression and a random effects approach using data from the full maternally-linked Michigan births data 1990-2012.

Methods

Study Population and Data

We used birth certificate data from the State of Michigan linked by the mother during the study time period 1990-2012. Figure 1.1 shows the study inclusion and exclusion criteria. The final study sample includes a total of 2,199,206 births to 1,181,640 unique mothers.

We then linked yearly neighborhood poverty rates obtained from linearly interpolated Neighborhood Change Database (NCDB) poverty rates at the census tract level. NCDB information is taken from 3 decennial census years 1990, 2000, and 2010 all normalized to census tract boundaries of 2010 to allow for longitudinal comparisons.

In order to use a maternal fixed effects (FE) analysis we further limited the sample to mothers who had a least two births and had discordant PTB outcomes. This left 279,150 births to 103,180 mothers in the FE analytic sample. Previous research using the Michigan Birth file reported recoding inconsistent maternal data, such as race/ethnicity differed across births, when available or excluding inconsistent data that did not meet recoding criteria. We use the corrected covariates in our analysis using the methodology detailed in (Margerison, Luo, and Li 2019).

Measures

Neighborhood poverty rate We measured area-level poverty conditions using census tract poverty rates (i.e. the number of poor persons divided by the number of persons in a census tract) measured at the time of birth by residential address linked to geocoded census tract. Neighborhood poverty rates were merged with data from the birth certificate based on infant's birth year and mother's census tract at the time of delivery. Neighborhood poverty rates are a frequently used proxy for area-level socioeconomic conditions in research on birth outcomes, and in neighborhood effects in general. One of our primary objectives in utilizing a fixed effects analysis is to compare with traditional logistic associations used in previous studies of neighborhood deprivation and PTB. Thus our primary analyses uses neighborhood poverty rate. There are 2,813 census tracts and 83 counties in the state of Michigan.

Our analyses focused on poverty conditions at the time of birth because 1) they have been previously associated with adverse birth outcomes and 2) they represent a critical window of exposure for the child, which may be considered for future analysis.

Adverse birth outcomes Our primary outcome was PTB (<37 weeks completed gestation) following recent evidence (Bruckner, Kane, and Gailey 2019) that strong upward neighborhood poverty were associated with decreased PTB. We completed secondary analysis of small-for-gestational age (SGA: <10^{th} percentile) and large-for-gestational-age (LGA :> 10th percentile) outcomes but did not develop a priori hypotheses about the relationship with neighborhood poverty other than it would be inverse of the PTB association (downward mobility is associated with increased SGA).

Maternal characteristics Maternal characteristics included age (<20, 20-24, 25-29, 30-34, 35-40, >40), race/ethnicity (non-Hispanic white [NHW], non-Hispanic black [NHB], Hispanic, non-Hispanic American Indian / Alaska Native [AI/AN], non-Hispanic Asian/Pacific Islander

[A/PI], and non-Hispanic mixed race/other), nativity (US born, foreign born), parity (nulliparous, primiparous, multiparous), marital status (married, not married), educational attainment (some high school, high school, some college, college, greater than college), insurance pay source at birth (private, Medicaid, self-pay, other, unknown), smoking during pregnancy (yes, no, unknown) and hypertension during pregnancy (yes, no). Inter-pregnancy interval period was calculated between the conception date and the previous birth date of birth. Conception date was calculated based on gestational days estimation and date of birth.

Statistical Analyses

Primary Analyses First, we first conducted a traditional logistic regression for the association between the neighborhood poverty rate and PTB (logistic). We adjusted these for race/ethnicity and nativity.

Second, we conducted a random effects analysis with a mother specific random effect that accounts for differences in maternal outcomes with a random distribution. The RE model is as follows:

$$g\{E[Y_{ij}|e_{1ij}\alpha_i X_{ij}]\} = \alpha_i + \beta_{1e_{ij}} + X_{ij}\gamma$$

Here γ_{ij} is the outcome for mother i's birth j. e_{1ij} is the neighborhood poverty variable of interest for birth j. X_{ij} is a vector of control variables that include the month and year of birth, and maternal characteristics.α_i is a mother-specific random intercept that is independent of x_{ij}, ε_{ij} *and* z_i but could possible covary with α_i. G is a logit link function for the outcome, PTB. The parameter of interest is β_1, presented as a transformation for odds ratio (Allison 2005).

For the RE model this type of mixed effect works well with our longitudinal data for several reasons. First, time is treated as a continuous variable allowing for variations in time across subjects, useful when inter-birth intervals vary for each woman in the data set. Both time and time-varying covariates can be included in the model. Therefore the outcome is modelled due both the mother's stable characteristics (e.g., race or gender) and those that changes over time (e.g., number of children).

We controlled for observed maternal characteristics hypothesized to influence and woman's likelihood PTB – maternal age, race/ethnicity, nativity, marital status, marital status, parity, education, and infant sex. These variables can be included as birth-specific controls in the model. We included indicator variables seasonality (birth month) and secular trends (year of birth).

Third, we conducted fixed analysis using a maternal fixed effect model (conditional logistic model) adjusted for the same maternal characteristics as the RE model. The FE model, in contrast to the RE model, controls for unobserved heterogeneity of time-invariant maternal covariates (measured and unmeasured). We added an indicator variable for each birth record to control for increasing parity. The FE (within mother) analysis controls for time-invariant characteristics shared by the mothers across births. The FE model is similar to the RE model except that the variable α_i is not independent and does not follow a specific distribution. This parameter then represents the unobserved confounding factors that do not change over time for the mother i. It may be correlated with the exposure e_{1ij} and $\boldsymbol{X}_{ij}$. The fixed effects logit model uses the conditional maximum likelihood method to eliminate the nuisance parameter, α_i , and estimate other coefficients $(\beta_1 \gamma)$.

We considered the use of a lagged preterm birth control in our fixed effects model as prior PTB is considered a risk factor for subsequent PTB There are multiple ways to conceptualize the risk of prior PTB. The risk may be due to inherent characteristics of the mother, which our model would capture, or the risk may be due to the impact of a non-term pregnancy on the gestational term of a subsequent pregnancy, which our model would not capture. We are currently not aware of a consensus on the mechanism of the risk of prior PTB on subsequent birth, but to the extent that is related to the mother it would be possible to include a covariate to control for prior PTB. However, this may introduce some bias related to our fixed effect model. In fixed effects analysis we chose not to include a lagged dependent PTB variable primarily because it introduced a form of bias, Nickell's bias, into the models (Nickell 1981). This occurs particularly when there is a small time T, large N as in our case with a large sample size (N) but each individual woman contributes only a few births (T). The estimate of the coefficient of the lagged dependent variable, lagged prior PTB, is biased the first birth because observations are always 0 (T-1 observations are always 0) and which mean the mean error contains bias as it is subtracted from each ε_{ij}. Increasing births do not mitigate this error and the result is termed Nickell's bias. Including these poorly specified variable lagged variables in the model comes at a risk of introducing this bias. In our primary analysis we excluded prior, or lagged, PTB but in secondary analysis we included models with a lagged PTB variable to evaluate the covariate specification and the effect on our poverty variable in our models.

We then performed a RE model using the FE sample to determine if differences in the measure of association are due to differences in our analytic sampling or modeling.

All data management was conducted using SAS 9.4 (Cary, NC) and analyses were performed using Stata 15 (College Station, TX).

Secondary Analyses In supplementary analyses, we replicated models 1 and 2 replacing continuous poverty with poverty mobility calculated based on three cut points from the interpolated poverty source data and differences in poverty quartiles across births. We did this in an effort to replicate recent findings that strong upward trajectory of quartile-based neighborhood deprivation was protective for PTB using a sibling-based, or maternal effects, design (Bruckner, Kane, and Gailey 2019). We also examine the differences in neighborhood poverty scale in an effort to in part examine the susceptibility of our data to Modifiable Areal Unit Problem (MAUP) (Openshaw and Taylor, 1979). This occurs when spatial measures are aggregated into spatial boundaries which group the population into observed associations that depend on the boundary location and scale of aggregation, introducing statistical bias.

We tested for maternal race/ethnicity effect modification by including an interaction with race and neighborhood poverty in our FE model. While you cannot adjust for time invariant maternal characteristics in this model, such as gender or race, as they will be omitted but you can include the covariate as an interaction term with time or a time-varying variable. We also examine residential moving status in a stratified analysis.

We perform robustness checks on our model in several ways. First, we compare our fully adjusted results to those that do not include positively correlated monotonic covariates such as age and parity, which only increase with each birth. We then also compare our model to one that is restricted to 2000-2012 to control for the period effects of our missing geographical data, which is more missing for the 1990-1999 census years.

Results

Primary Analyses

Table 3.1 describes analytic samples for the RE analysis (n= 2,199,206 births) and the FE analysis (n=279,150 births) of discordant PTB outcomes. 1,223,040 mothers (1,920,056 births) did not have discordant outcomes and were not included in the fixed effects analysis. In the RE sample, approximately 70.4% of births were to Non-Hispanic White mothers and 18.5% were to Non-Hispanic Black mothers. The maternal FE analytic sample consists of mothers with at least one PTB and thus differs from the RE sample. In the FE sample, approximately 56.1 %

of births were to NHW mothers and 31.7 were to NHB mothers. Overall, mothers in the FE sample were more likely to be NHB, and have Medicaid as an insurance pay source and more likely to have an inter-pregnancy interval of <18 month (38.7% versus 14.2%) on average. The mean neighborhood poverty rate was higher in the FE sample 18.4% (14.6 SD) compared with 14.6% (12.9 SD) in the RE sample of all births. PTB births in the FE sample were higher 41.3% compared to the RE sample 9.3%.

Table 3.2 compares the odds ratios for the variable of interest, neighborhood poverty rate percentage using different model specifications (logistic, random effect, fixed effect, and random effect in the fixed effect sample) and adjustments (crude, adjusted for year and month of birth, maternal age, parity, marital status, education, infant sex, and additionally adjusted for a lagged term of prior PTB). The Hausman test results rejected the null hypothesis that the Random Effects model is preferred in favor of using the Fixed Effects model (X^2 P<.0001). In all models there was a null or modest effect. In the random effects models there was a modest OR of 1.01 (95% CI: 1.07-1.12) meaning that for a one percentage point increase in neighborhood poverty between births there is a 1% increase in the odds of preterm birth. The fixed effects model did not show a change in the odds for a one percentage point change in poverty (OR: 1.00, 95% CI: 1.00-1.00). Estimates from the RE model using the smaller FE sample were identical to those of the FE model.

Secondary Analyses

Table 3.3 shows the association of poverty and PTB with an interaction covariate for poverty and maternal race/ethnicity. This adjustment allows us to model the effect of a stable maternal characteristic, i.e., race/ethnicity. Overall we did not find strong statistical interaction between neighborhood poverty rate and maternal race/ethnicity. Native American/Alaska Native maternal race/ethnicity has a slightly reduced odds of PTB for a 1 percentage point increase in neighborhood poverty between births (OR: 0.99 95% CI: 0.96-1.02) but it is not significant. Asian/Pacific Islander maternal race/ethnicity had a 1% increase in the odds of PTB for a one percentage point increase in the neighborhood poverty rate between births (OR: 1.01, 95% CI: 1.00-1.01).

Table 3.4 shows fixed effects analysis with a different exposure classification by using neighborhood poverty trajectory across quartiles of poverty, similar to recently published studies. Here the effect of poverty is captured over a larger change (quartile change versus a single percentage point change). We also exclude the birth year and birth month adjustments to allow for comparison to a recently published maternal fixed effects analysis. We see slightly stronger associations of neighborhood poverty trajectory level and PTB compared to the continuous poverty measure. There is a modest protective association with PTB of the most extreme decline in poverty quartile, strong upward mobility moving from >17% neighborhood poverty to <5% neighborhood poverty, which is associated with a decrease in odds of PTB of 7% (OR: 0.93, 95%CI: 0.84 to 1.03). Similarly, an extreme incline in neighborhood poverty is associated with an increased in the odds for PTB (OR: 1.09, 95% CI: 0.98 to 1.20). That is, for a strong downward change in poverty quartile from the lowest level of poverty to the highest level of neighborhood poverty the odds of PTB increased by 9% between births. Increasing maternal age lead to increased odds of PTB with women who were greater than 40 having the highest odds of PTB (OR 1.40, 95% CI: 1.28 to 1.51).

Table 3.5 shows the covariates for poverty and lagged-PTB (PTB at previous birth, 0 for all first births). We demonstrate the potential limitation of including the lagged-dependent covariate in a fixed effects model by comparing the estimate to alternate models. In the logistic model, the poverty variable is unchanged but the lagged-PTB OR is significant and has a large magnitude (OR: 2.88, 95% CI: 2.83-2.93). We then control for the effect of the lagged variable equal to zero at the first birth by removing those births from the model and still find a strong, significant association (OR 3.03 , 95% CI:2.97-3.09). This suggests in both these models the odds of PTB is much more related to prior PTB events than to neighborhood poverty. The same is true, although with a reduction in the magnitude of the odds of prior PTB for the Random Effects model. However, when we included the lagged term as an explanatory variable in the Fixed Effects Models the Prior PTB variable had an OR: 0.4, 95% CI 0.4 - 0.5) which would suggest a strong protective effect of prior preterm birth in the association of poverty and PTB. This table shows the association between prior PTB and PTB diminishes across the model. The problem we highlighted here including or not including a lagged PTB estimate in the model. The association between neighborhood poverty and PTB does not seem to be affected by controlling for prior PTB by including it in the model, but it may introduce bias due to the fixed effects method and we chose not to include it.

In our robustness checks (Table 3.6) we see no evidence that parity and age, which both increase as our number of births increase, influence the association of the model. The estimates using a restricted data sample that includes only 2000-2012 data, eliminating the 1990 census poverty variables also did not change the association. We see no significant difference in our associations when we stratify by movers and non-movers (Table 3.7).

Discussion

Our results showed that using a fixed effects method shows little to modest association between neighborhood poverty and PTB. However, we also see this null or modest association in the crude logistic model and random effects models. Unlike our hypothesis, which stated that the results would be attenuated in fixed effects compared to logistic and random effects models, we see a consistent null association. We modeled our exposure as a continuous 1 percentage point change in poverty.

This approach used a maternal fixed effects analysis to examine the association between neighborhood poverty conditions and preterm birth using a large dataset that included all the births in the state of Michigan over the study period. We aimed to use this approach to reduce the problem of differential selection bias into neighborhoods in the association of neighborhood poverty and birth outcomes. This approach allows control for time-invariant maternal characteristics (both measured and unmeasured) that are associated with adverse birth and neighborhood poverty exposure. Previous studies have used this approach to examine macroeconomic conditions during preconception and adverse pregnancy outcomes in this study population (Margerison, Luo, and Li 2019). We also reported our results using a similar parametrization of poverty mobility (quartile changes downward, static, and upward) for another study using California birth data using a maternal fixed effects (Bruckner, Kane, and Gailey 2019).However, our studies are not entirely comparable as they employ a lagged PTB variable while computing a fixed effects difference model, which we chose not to do given the introduction of bias. Interestingly, when we include a lagged PTB term in our models of poverty mobility (Secondary analysis Appendix Table) we find increased odds of PTB but at all levels of mobility in both directions. This is not advisable as we hypothesize the lagged PTB covariate in the fixed effects analysis to be biased. Finally, we observed different sized odds of PTB given different scale of aggregation for the poverty variable (quartile versus continuous). This may indicate that our data is susceptible to the MAUP. Further analysis that incorporates re-zoning of the data by changing the boundary lines and adjusts for spatial autocorrelation would be warranted in order to more definitively determine the effect of MAUP.

There are important limitations to the maternal fixed effects models to consider. Both the RE and FE models assume the coefficients of the same covariate remain equal across all numbers of birth. Another restriction is that the unexplained variance stays the same over time; even if an individual changes over time the error variance does not. The latent time-invariant variables must either correlated with all the covariates (FE) or be uncorrelated with all the covariates (RE). This means that we assume the latent time invariant variables are uncorrelated with the observed covariates (Bollen and Brand 2010). Finally, the RE and FE models do not report any test statistics to allow identification of overall fit (the Hausman test just compares the two models). FE allows for latent time-invariant variables to correlate to time-varying variables but the analysis does not report any information on the magnitude of the correlations. One potential model to consider for future work would be a structural equation modeling framework using fixed effects. This is particularly salient given the prior birth history of preterm birth. Previous models have either used a lagged-PTB in their model or shown a strong association between a prior PTB and subsequent PTB. A possible test for this association is in the RE model by seeing if RE model shows similarities to the logistic model estimates, after controlling for the previous PTB. This means that after controlling for the woman's unobserved characteristics, as in the random effects model, the odds ratio for the previous PTB is strongly reduced from 2.83 to 1.4, with a significant p value ($p<0.000$). The magnitude of the logistic model may instead represent the omission of her time-constant characteristics the affect the probability of PTB at all of her pregnancies.

Our primary analyses focused on neighborhood poverty at the time of birth. There is evidence that early pregnancy exposure may be the most strongly associated with birth outcomes (Margerison, Luo, and Li 2019) and that would only be captured in our analysis if the women resided in the same census tract for the duration of her pregnancy and during the preconception period. It stands to reason that among non-movers between pregnancies we can estimate this exposure, but not for the remainder of our sample.

In summary, our findings suggest that 1) increases in neighborhood poverty rate between pregnancies are not associated with increases in the odds of PTB, and 2) this association does not change when using a maternal fixed effect analysis to control for time-invariant and time-varying characteristics and 3) the use of lagged-dependent variables in one-way fixed analysis is inappropriate and introduces bias into models that are specifically designed to remove bias.

Table 3.1 Comparison of Samples for All Singleton Michigan Births 1990-2012

Maternal Characteristics	Random Effects Sample N	%	Fixed Effects Sample N	%
Number of Births	2,199,206	100	279,150	100
Race				
Non-Hispanic White	1,546,767	70.3	156,602	56.1
Non-Hispanic black	409,412	18.6	88,407	31.7
Hispanic	118,627	5.4	17,139	6.1
Non-Hispanic American Indian/ Alaska Native	5,434	0.3	410	0.2
Non-Hispanic Asian/Pacific Islander	87,988	4.0	12,533	4.5
Non-Hispanic Mixed race / other/ missing	30,978	1.4	4,059	1.5
Age				
<20	230,135	10.5	39,907	14.3
20-24	525,803	23.9	77,228	27.7
25-29	647,576	29.5	77,161	27.6
30-34	530,767	24.1	57,063	20.4
35-40	223,224	10.2	23,648	8.5
>40	41,701	1.9	4,143	1.5
Nativity				
US born	2,003,503	91.1	259,141	92.8
Foreign born	195,703	8.9	20,009	7.2
Insurance Payer				
Private	1,393,352	63.4	149,205	53.5
Medicaid	780,460	35.5	126,630	45.4
Self-pay	21,774	1.0	2,834	1.0
Other	3,620	0.2	481	0.2
Infant sex -male	1,126,803	51.2	144,950	51.9
Marital Status				
Married	1,417,529	64.5	145,067	52.0
Unmarried	781,677	35.5	134,083	48.0
Education				
Less than HS	59,801	2.7	8,180	2.9
Some HS	334,941	15.2	46,181	16.5
High School (HS)	732,080	33.3	94,260	33.8
Some college	555,673	25.3	66,950	24.0
College graduate	338,449	15.4	42,981	15.4
Greater than college	178,262	8.1	20,598	7.4
Parity				
Nulliparous (0 live births)	874,597	39.8	80,634	28.9
Primiparous (1 previous live birth)	701,943	31.9	85,595	30.7
Multiparous (>1 previous live births)	622,666	28.3	112,921	40.5

Table 3.1 (cont'd)

Smoke				
No	1,809,509	82.3	219,740	78.7
Yes	369,576	16.8	57,090	20.5
Unknown	20,121	0.9	2,320	0.8
Pregnancy Hypertension				
No	2,110,892	96.0	265,084	95.0
Yes	88,314	4.0	14,066	5.0
Delivery				
Vaginal	1,656,945	75.3	211,489	75.8
Caesarean	542,261	24.7	67,661	24.2
Birth outcomes				
PTB				
No	1,994,585	90.7	163,876.0	58.7
Yes	204,621	9.3	115,274.0	41.3
SGA				
No	1,959,489	89.1	239,885	85.9
Yes	239,717	10.9	39,265	14.1
LGA				
No	2,000,154	91.0	257,022	92.1
Yes	199,052	9.1	22,128	7.9
Inter-pregnancy Interval <18 Months				
No	1,886,752	85.8	107,933	61.3
Yes	312,454	14.2	68,037	38.7
Mean Gestational Age in Weeks	39.0	2.3	37.2	3.2
Mean neighborhood poverty rate	14.6	12.9	18.4	14.6

The FE sample was different from the RE sample with respect to having a higher percentage of NHB women, Medicaid payers, and greater number of women with an inter-pregnancy interval of <18 months and higher PTB and SGA outcomes.

Table 3.2 Comparison of multivariable-adjusted[a] associations between neighborhood poverty rate[b] and preterm birth (PTB) using logistic regression and maternal fixed-effects analyses among singleton births in Michigan, 1990-2012

All Michigan Births												
	Logistic Full Model			RE			FE			RE using FE sample		
Neighbor-hood Poverty Percentage	OR	95% CI	OR	95% CI	OR		95% CI	OR		95% CI	OR	
Model 1 Crude	1.00	1.02	1.02	1.02	1.02	1.02	1.00	1.00	1.00	1.00	1.00	1.00
Model 2 Adjusted[1]	1.00	1.00	1.01	1.01	1.07	1.12	1.00	1.00	1.00	1.00	1.00	1.00
Hausman Test: H_o: Random Effects is better				X^2 Pr<.0001, Reject H_o (Fixed Effects better model)								
							X^2 Pr<.0001, Reject H_o (Fixed Effects better model)					

[a]All analyses adjusted for year of birth, month of birth, maternal age, parity, marital status, education, and infant sex. Logistic regression models additionally adjusted for maternal race/ethnicity. [b]Linearly interpolated Neighborhood poverty percentage from Neighborhood Change Database.

Table 3.3 Maternal Fixed Effects Models of PTB with Interaction between Maternal Race/Ethnicity and Poverty

FE Sample (n=279,150)	OR	95% CI	
Maternal Race/Ethnicity*poverty			
Non-Hispanic White	1.00	1.00	1.00
Non-Hispanic black	1.00	1.00	1.00
Hispanic	1.00	1.00	1.01
Non-Hispanic American Indian/ Alaska Native	0.99	0.96	1.02
Non-Hispanic Asian/Pacific Islander	1.01	1.00	1.01
Non-Hispanic Mixed race / other/ missing	1.00	0.99	1.01

All analyses adjusted for year of birth, month of birth, maternal age, parity, marital status, education, and infant sex.

Table 3.4 Maternal Fixed Effects Odds Ratios (OR)[a] and 95% Confidence Intervals (CI) predicting the probability of preterm birth (PTB), maternal poverty quartile mobility levels (vs. no change) and covariates

	OR	95% CI	
Mobility			
Strong Upward (Q4 to Q1)	0.93	0.84	1.03
Modest Upward	1.03	0.98	1.09
Weak Upward	0.99	0.96	1.02
Static (ref)	1.00		
Weak Downward	0.97	0.94	1.00
Modest Downward	1.00	0.95	1.05
Strong Downward (Q1 to Q4)	1.09	0.98	1.20
Insurance			
Private (ref)	1.00		
Medicaid	0.99	0.97	1.01
Self-pay	1.31	1.20	1.42
Other	1.16	0.95	1.40
Parity			
1 birth	0.85	0.79	0.90
2 births	0.72	0.68	0.77
3 births	0.79	0.74	0.83
4 births	0.89	0.84	0.94
5 births	0.94	0.89	0.99
6+ births (ref)	1.00		
Infant male	1.12	1.10	1.14
Not Married	1.05	1.02	1.09
Foreign Born	0.89	0.79	1.01
Maternal Age			
<20	1.07	1.04	1.10
20-24 (ref)	1.00		
25-29	1.02	0.99	1.04
30-34	1.09	1.05	1.13
35-40	1.20	1.15	1.27
>40	1.39	1.28	1.51
Education			
Less than HS	1.03	0.96	1.11
Some HS	1.04	0.99	1.09
High School (HS)	1.00	0.96	1.05
Some college	1.01	0.97	1.06
College graduate	1.01	0.97	1.06
Greater than college	1.00		

[a]All odds ratios in the table are adjusted for every other variable in the model. Not adjusted as previous models for seasonal and period effects.

Table 3.5 Comparison of Mutlivariable-Adjusted[a] Odds Ratios for Lagged Preterm Birth Covariate in Models (Logistic and Fixed Effects)

All Births (N=279,150 births to 103,180 mothers)									
	Logistic[a]			RE Model[a]			FE model[b]		
Covariates of interest	OR	95% CI		OR	95% CI		OR	95% CI	
Poverty	1.00	1.00	1.00	1.01	1.00	1.01	1.00	1.00	1.00
Lagged PTB	2.88	2.83	2.93	1.41	1.36	1.46	0.04	0.04	0.05
Births >1 (N=88,325 births to 33,562 mothers)									
	Logistic[a]			RE Model[a]			FE model[b]		
Covariates of interest	OR	95% CI		OR	95% CI		OR	95% CI	
Poverty	1.00	1.00	1.01	1.00	1.00	1.01	1.00	1.00	1.00
Lagged PTB	3.03	2.97	3.09	2.93	2.87	3.00	0.08	0.08	0.08

[a] Adjusted for lagged PTB, race/ethnicity, year of birth, month of birth, maternal age, parity, marital status, education, and infant sex.
[b] Adjusted for lagged PTB, year of birth, month of birth, maternal age, parity, marital status, education, and infant sex.

Table 3.6 Table Robustness Checks for positive monotonic covariates and study time period

Fixed Effects All Michigan Births						
	No Parity or Age[a] N=279,150 births (103,180 mothers)			Fully Adjusted[b] 2000-2012 N= 140,185 births (54,820 mothers)		
	OR	95% CI		OR	95% CI	
Neighborhood Poverty[c]	1.00	1.00	1.00	1.00	1.00	1.00

[a]Adjusted for year of birth, month of birth, marital status, education, and infant sex.
[b]Fully adjusted for year of birth, month of birth, maternal age, parity, marital status, education, and infant sex. Logistic regression models additionally adjusted for maternal race/ethnicity
[c]Neighborhood poverty rates from Neighborhood Change Database.

Table 3.7 Comparison of multivariable-adjusted[a] associations between neighborhood poverty rate[b] by birth and preterm birth (PTB) using logistic regression and maternal fixed-effects analyses among singleton births in Michigan, 1990-2012

All Michigan Births									
Neighborhood Poverty	Logistic Full Model			RE			FE		
	OR	95% CI		OR	95% CI		OR	95% CI	
Movers	1.00	1.00	1.00				1.00	1.00	1.00
Non-Movers	1.00	1.00	1.00				0.99	0.99	1.00

[a]All analyses adjusted for year of birth, month of birth, maternal age, parity, marital status, education, and infant sex. Logistic regression models additionally adjusted for maternal race/ethnicity. [b]Neighborhood poverty rates from Neighborhood Change Database.

APPENDIX

Table C.1 Crude Logistic Association of Neighborhood Poverty Mobility and PTB

Mobility	OR	95% CI	
Strong Upward (Q4 to Q1)	0.90	0.83	0.96
Modest Upward	0.98	0.94	1.02
Weak Upward	0.90	0.88	0.92
Static (ref)			
Weak Downward	0.87	0.85	0.89
Modest Downward	0.95	0.91	0.98
Strong Downward (Q1 to Q4)	1.10	1.02	1.19

Table C.2 Associations with Poverty Mobility Trajectories and PTB using a Prior PTB (lagged) dependent variable in model, Michigan Births 1990-2012

	OR	95% CI	
Mobility			
Strong Upward (Q4 to Q1)	1.2	1.1	1.4
Modest Upward	1.3	1.2	1.4
Weak Upward	1.3	1.2	1.3
Static (ref)			
Weak Downward	1.2	1.2	1.3
Modest Downward	1.3	1.2	1.3
Strong Downward (Q1 to Q4)	1.3	1.2	1.5
Prior PTB (lagged)			

Table C.3 Comparison of multivariable-adjusted[a] associations between quartiles of neighborhood poverty rate[b] by birth and preterm birth (PTB) using logistic regression, random effects and maternal fixed-effects analyses among singleton births in Michigan, 1990-2012

All Michigan Births												
Quartiles of Neighborhood Poverty [1]	Logistic Full Model			RE			FE			RE using FE sample		
	OR	95% CI		OR	95% CI		OR	95% CI		OR	95% CI	
Q2	1.1	1.1	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0
Q3	1.1	1.1	1.1	1.1	1.1	1.2	1.0	1.0	1.1	1.0	1.0	1.1
Q4	1.2	1.2	1.2	1.2	1.2	1.2	1.0	1.0	1.1	1.0	1.0	1.0

[a] Q1 referent. All analyses adjusted for year of birth, month of birth, maternal age, parity, marital status, education, and infant sex. Logistic and Random Effects regression models additionally adjusted for maternal race/ethnicity. [b]Linearly interpolated Neighborhood poverty percentage from Neighborhood Change Database.

Table C.4 Crude FE Model Response Patterns

Response Patterns	PTB		Strata	Frequency
	1	0		
1	0	1	640,461	640,461
2	1	0	68,715	68,715
3	0	2	342,839	685,678
4	1	1	54,974	109,948
5	2	0	7,946	15,892
6	0	3	111,446	334,338
7	1	2	25,185	75,555
8	2	1	5,267	15,801
9	3	0	947	2,841
10	0	4	26,293	105,172
11	1	3	8,017	32,068
12	2	2	2,352	9,408
13	3	1	591	2,364
14	4	0	136	544
15	0	5	5,454	27,270
16	1	4	2,385	11,925
17	2	3	817	4,085
18	3	2	283	1,415
19	4	1	109	545
20	5	0	28	140
21	0	6	1,462	8,772
22	1	5	689	4,134
23	2	4	341	2,046
24	3	3	119	714
25	4	2	44	264
26	5	1	19	114
27	6	0	4	24
28	0	7	439	3,073
29	1	6	220	1,540
30	2	5	115	805
31	3	4	42	294
32	4	3	19	133
33	5	2	11	77
34	6	1	6	42
35	7	0	1	7
36	0	8	156	1,248
37	1	7	81	648
38	2	6	50	400
39	3	5	27	216
40	4	4	10	80
41	5	3	6	48

Table C.4 (cont'd)

42	6	2	3	24
43	7	1	1	8
44	0	9	55	495
45	1	8	23	207
46	2	7	15	135
47	3	6	6	54
48	4	5	4	36
49	5	4	5	45
50	6	3	2	18
51	7	2	1	9
52	8	1	1	9
53	0	10	18	180
54	1	9	9	90
55	2	8	5	50
56	3	7	3	30
57	4	6	2	20
58	5	5	2	20
59	6	4	1	10
60	0	11	10	110
61	1	10	5	55
62	2	9	1	11
63	3	8	3	33
64	10	1	1	11
65	0	12	3	36
66	1	11	1	12
67	0	14	1	14
68	1	15	1	16

REFERENCES

REFERENCES

Allison, Paul D. 2005. *Fixed Effects Regression Methods for Longitudinal Data Using SAS*. Sas Institute. https://books.google.com/books?hl=en&lr=&id=OIPExEh-tcMC&oi=fnd&pg=PA1&dq=fixed+effects+regression+methods+for+longitudinal+data+using+sas&ots=HpFkcTQAph&sig=eMEB4_irtoTbbRUw_Fd8MI_5_gE.

Bollen, Kenneth A., and Jennie E. Brand. 2010. "A GENERAL PANEL MODEL WITH RANDOM AND FIXED EFFECTS: A STRUCTURAL EQUATIONS APPROACH." *Social Forces; a Scientific Medium of Social Study and Interpretation* 89 (1): 1–34. https://doi.org/10.1353/sof.2010.0072.

Bruckner, Tim A., Jennifer B. Kane, and Samantha Gailey. 2019. "Strong Upward Neighborhood Mobility and Preterm Birth: A Matched-Sibling Design Approach." *Annals of Epidemiology* 36 (August): 48-54.e1. https://doi.org/10.1016/j.annepidem.2019.05.005.

Collins, James W., Allison Mariani, and Kristin Rankin. 2018. "African-American Women's Upward Economic Mobility and Small for Gestational Age Births: A Population-Based Study." *Maternal and Child Health Journal* 22 (8): 1183–89. https://doi.org/10.1007/s10995-018-2503-4.

Collins, James W., Kristin M. Rankin, and Richard J. David. 2015. "Downward Economic Mobility and Preterm Birth: An Exploratory Study of Chicago-Born Upper Class White Mothers." *Maternal and Child Health Journal* 19 (7): 1601–7. https://doi.org/10.1007/s10995-015-1670-9.

Culhane, Jennifer F., and Robert L. Goldenberg. 2011. "Racial Disparities in Preterm Birth." *Seminars in Perinatology* 35 (4): 234–39. https://doi.org/10.1053/j.semperi.2011.02.020.

Kramer, Michael R. 2016. "Race, Place, and Space: Ecosocial Theory and Spatiotemporal Patterns of Pregnancy Outcomes." In *Recapturing Space: New Middle-Range Theory in Spatial Demography*, 275–299. Springer. http://link.springer.com/chapter/10.1007/978-3-319-22810-5_14.

Leventhal, T., and J. Brooks-Gunn. 2000. "The Neighborhoods They Live in: The Effects of Neighborhood Residence on Child and Adolescent Outcomes." *Psychological Bulletin* 126 (2): 309–37. https://doi.org/10.1037/0033-2909.126.2.309.

Margerison, Claire E., Zhehui Luo, and Yu Li. 2019. "Economic Conditions during Pregnancy and Preterm Birth: A Maternal Fixed-Effects Analysis." *Paediatric and Perinatal Epidemiology* 33 (2): 154–61. https://doi.org/10.1111/ppe.12534.

Nickell, Stephen. 1981. "Biases in Dynamic Models with Fixed Effects." *Econometrica* 49 (6): 1417–26. https://doi.org/10.2307/1911408.

Openshaw, Stan, and Peter J. Taylor. 1979. “A Million or so Correlation Coefficients: Three Experiments on the Modifiable Areal Unit Problem.” Statistical Applications in the Spatial Sciences21: 127–144.

Pearl, Michelle, Jennifer Ahern, Alan Hubbard, Barbara Laraia, Bina Patel Shrimali, Victor Poon, and Martin Kharrazi. 2018. “Life-Course Neighbourhood Opportunity and Racial-Ethnic Disparities in Risk of Preterm Birth.” *Paediatric and Perinatal Epidemiology* 32 (5): 412–19. https://doi.org/10.1111/ppe.12482.

Sampson, Robert J. 2013. *Great American City: Chicago and the Enduring Neighborhood Effect*. Reprint edition. Chicago; London: University of Chicago Press.

CONCLUSION

Our studies examined the residential movement, poverty mobility, and maternal fixed effects in associations with PTB using a maternally-linked sample of singleton births in Michigan during the period 1990-2012. We hypothesized that movement would change neighborhood composition and lead to misclassification bias in the association between poverty and PTB. However, we observed that most women do not change poverty levels, even those who change residence. There are extreme movers across levels of poverty, but they represent a select minority of our study population. The static trajectory group encompasses the most women, although at varying poverty levels from low to high poverty. We find there is a modest association between downward neighborhood poverty trajectory and increased PTB. However, there may be unobserved maternal characteristics that lead a woman to select her neighborhood that may also be associated with her risk of PTB. We therefore examine the association with neighborhood poverty and PTB using a maternal fixed effect approach that allows for control of both measure and unmeasured maternal characteristics. We find a null association. We highlight the need for careful selection of covariates in this model by showing how a prior PTB control may introduce bias. This does raise concerns for how much a prior PTB itself is a risk versus due to the mothers own characteristics. Future models to consider include dynamic panel models and structural equations modeling with fixed effects which can better account for both the maternal characteristics and the prior PTB events (as a time-varying covariate) (Gunasekara et al. 2014).

Our study used neighborhood poverty as an exposure variable because we hypothesized it would have a strong association with PTB in conventional models and because it has been used in previous research. However, we did not observe a strong association. This may be due to our time period of study, a mother’s adulthood during her period of fertility. Previous work that observed strong associations did so over the life course from childhood to adulthood (Collins, Rankin, and David 2015; Pearl et al. 2018). In our study we are not able to do that for the mothers. However, this work could be foundational to a study that examines the birth outcomes of the infants in this study. Such inter-generational linkage has been previously done in select populations(Spencer 2004; Collins, Rankin, and David 2011). This would afford an opportunity for a state wide study and Michigan is an ideal state to capture this information as there is limited out-migration.

Previous research also found the strongest associations between neighborhood disadvantage and adverse birth events among mothers who had adverse births as infants (Collins, Rankin, and David 2011). This suggests a component of heritability in the association, and one of the reasons a fixed effects analysis may be most appropriate. Another way to test this would be to examine epigenetic effects among the future inter-generational sample.

One challenge of modeling large data stems from the absence of changes in the significance level of covariates. These significance levels are typically used in model building and evaluation to inform the model design. However, when working with a large sample size there is ample power to make most covariates significant. We relied on covariates chosen based on our a priori hypothesis and reference groups but additional covariates or different reference groups may be warranted for future analysis.

Finally, in our study population we report high levels of poverty that increased over the study period. In a study examining birth outcomes, we would be remiss to not remark that not only are these infants born into poverty but they may experience limited mobility out of poverty without intervention. Alarmingly, we also observe increasing rates of poverty over our study period. We hypothesize that while the mothers may not experience a critical window during our study period, the data captured in our studies reflects a critical window for the infants whose birth outcomes we include. We see our current work as foundational and future research efforts would be wise to focus on this group and make every effort to work towards appropriate interventions in the reduction of poverty conditions.

REFERENCES

REFERENCES

Collins, James W., Kristin M. Rankin, and Richard J. David. 2015. “Downward Economic Mobility and Preterm Birth: An Exploratory Study of Chicago-Born Upper Class White Mothers.” *Maternal and Child Health Journal* 19 (7): 1601–7. https://doi.org/10.1007/s10995-015-1670-9.

Gunasekara, Fiona Imlach, Ken Richardson, Kristie Carter, and Tony Blakely. 2014. “Fixed Effects Analysis of Repeated Measures Data.” International Journal of Epidemiology43 (1): 264–69. https://doi.org/10.1093/ije/dyt221.

Pearl, Michelle, Jennifer Ahern, Alan Hubbard, Barbara Laraia, Bina Patel Shrimali, Victor Poon, and Martin Kharrazi. 2018. “Life-Course Neighbourhood Opportunity and Racial-Ethnic Disparities in Risk of Preterm Birth.” *Paediatric and Perinatal Epidemiology* 32 (5): 412–19. https://doi.org/10.1111/ppe.12482.