The Role of Neighborhood in Individual and Disparity-Level Factors and Birth Weight in Dane County, Wisconsin

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ABSTRACT

Introduction: There are significant disparities in the rates of maternal and infant morbidity and mortality in the United States—a discrepancy of particular importance in Wisconsin, where Non-Hispanic Black women experience the highest mortality rates in the country. The adverse effects of neighborhood socioeconomic status and geographical distance to obstetrical care outcomes have been demonstrated previously, with poor neighborhood socioeconomic status having been linked to higher rates of preterm births and low birth weight infants, which both increase the risk of neonatal morbidity and mortality. The objective of this study was to investigate the contributions of Area Deprivation Index and geographic location on age-matched birth weight z-scores.

Methods: We conducted a retrospective cohort study of all singleton births >22 weeks' gestation in Dane County, Wisconsin, from January 2016 through June 2018. Generalized additive models were adjusted for race/ethnicity, cigarette use, delivery route, pregnancy-related or chronic hypertension, pregestational and gestational diabetes, number of prenatal visits, maternal age, total weight gain, and pre-pregnancy body mass index.

Results: There is evidence of an association between birth weight z-score and spatial location (median *P* value 0.006). With area deprivation, we found no evidence of an association with birth weight z-score (-0.01; 95% CI, -0.03 to 0.01; $P = 0.109$). Mean birth weight z-scores were lowest (-0.72) in the urban center of Madison, while mean birth weight z-score was highest (0.18) in rural areas near the northeast, southeast, and southwest county borders. We found an effect of race/ethnicity on birth weight.

Conclusions: We identified geographic variations in birth weight at a granular level using census block groups and a holistic measure of deprivation, which can inform targeted public health interventions. The lack of evidence of area deprivation on birth outcomes but significant spatial trends demonstrated continued geographic disparities in our health care systems.

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INTRODUCTION

Maternal and infant morbidity and mortality is higher in the United States than other developed countries.[1] Additionally, there are significant disparities noted by race and ethnicity. This discrepancy is of particular importance in the state of Wisconsin, where the highest mortality rates in the country have been seen in non-Hispanic Black women at 14.28 per 1000 births, which is 3 times higher than rates quoted for White infants.[2-4] Looking at health disparities with a particular focus on modifiable risk factors for neonatal morbidity, a birth person's location of residence during pregnancy matters. The adverse effects of neighborhood socioeconomic status and geographical distance to obstetrical care outcomes have been demonstrated in previous literature.[2,5-6] Poor neighborhood socioeconomic status has been linked to higher rates of preterm births and low birth weight infants, both outcomes which increase the risk of neonatal morbidity and mortality.[5,7]

Though previous studies have pointed to both individual-level factors[8] and area-level factors,[9] birth and obstetric outcomes have not been explored previously at fine spatial resolution using the Area Deprivation Index (ADI).[10] ADI ranks census block groups by socioeconomic disadvantage at the state or national level. The index is a composite measure comprised of factors across the domains of income, education, employment, and housing quality. The objective of this study was to investigate the association between birth weight and ADI after accounting for known individual-level covariates.

We sought to identify and map spatial differences in Dane County, Wisconsin associated with poorer neonatal outcomes. We hypothesized that there would be an association between birth weight and ADI after accounting for known individual-level confounders. We use a generalized additive model with tensor product smooths to account for spatial dependence and adjust for individual-level covariates. We show that while area deprivation is not related to birth weight, we do still identify a significant spatial trend that is not explained by area-level factors.

METHODS

Study Population

Dane County is the second most populous county in Wisconsin and is where the state capitol of Madison is located. It has an area of 3100.84 km^2 and has an estimated population of 568203 as of 2022. Residents in the county are mostly White (84.1%), over half (53%) have a bachelor's degree or higher, and approximately 11.3% of the county population is estimated to be living in poverty.[11] According to the 2017 Wisconsin Public Health Profiles, Dane County had a crude live birth rate of 11.3 per 1000, and approximately 7% of infants were born as low birth weight (< 2499 gm) regardless of gestational age.[12]

Peridata, a web-based prospective database available to hospitals in Wisconsin, was used to obtain birth record data and birth outcomes from the 2 delivering hospitals in Dane County, Wisconsin. Patients giving birth at 2 tertiary care centers, St Mary's Hospital Medical Center (n = 4927) and UnityPoint Health - Meriter Hospital (n = 8345), from January 2016 to June 2018 were included. These hospitals are the only 2 designated birthing centers in the county. For inclusion into our study, patients must have been (1) pregnant people > 15 years old and (2) carrying a singleton pregnancy. Analysis was limited to singletons because the etiology of preterm birth is different in multiple pregnancies. Exclusion criteria included (1) multiple gestations, (2) gestational age at delivery < 22 weeks, (3) residence outside of Dane County, and (4) maternal age < 15 years. The populations were pooled for the remaining data analysis, with a goal of capturing data from deliveries in Dane County, rather than comparing outcomes at the 2 locations. This study was approved by the Institutional Review Board at UnityPoint Hospital (IRB # 2018-017).

Primary Outcome and Covariates

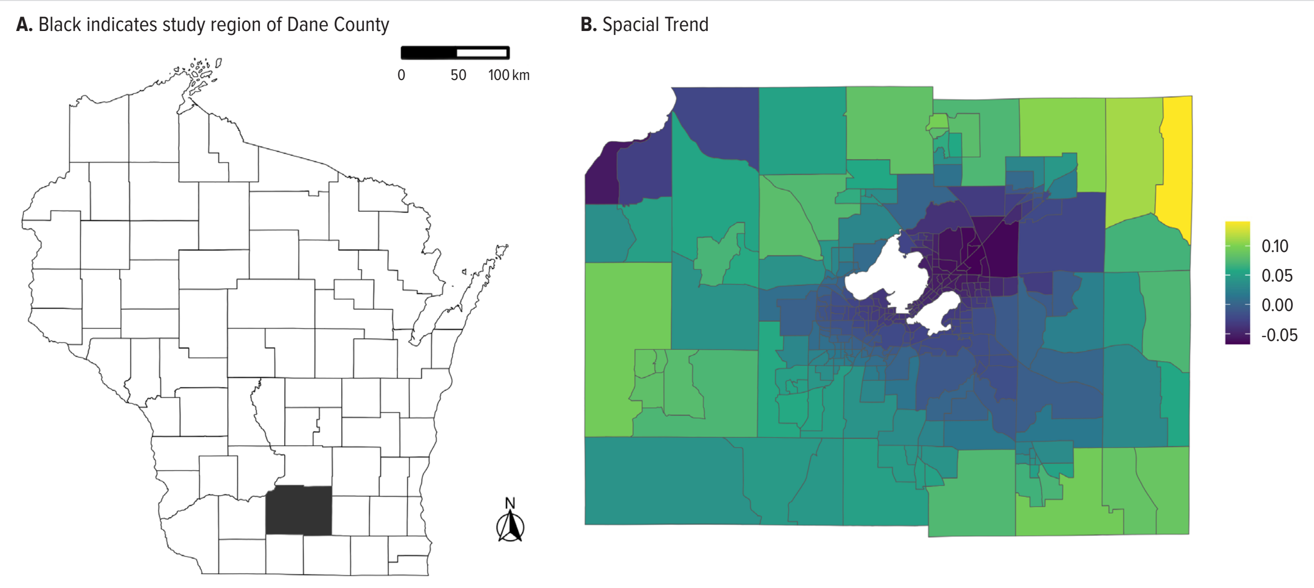
The primary outcome was birth weight, which was adjusted for by infant sex and gestational age based on Fenton growth charts (in grams) and converted to z-scores (standardized units).[13] The primary exposure is ADI. For analysis, the ADI was operationalized as the rank of the census block group at the state level (higher ranks indicate greater socioeconomic disadvantage). We also included the following covariates: cigarette use (yes/no [referent]), delivery route (spontaneous vaginal [referent], operative vaginal,

Table 1. Analytic Sample Demographics

	Mean (SD) or %	Missing (%)
Birth place facility (%)		0.00%
St Mary's Hospital Medical Center	4927 (37.1)	
Meriter	8345 (62.9)	
ADI-State rank (mean [SD])	3.16 (2.42)	0.13%
Mother's age (mean [SD])	31.13 (5.00)	0.00%
Pre-pregnancy BMI (mean [SD])	26.60 (8.46)	0.00%
Total weight gain (mean [SD])	30.48 (14.19)	1.88%
Gestational age (mean [SD])	39.15 (1.86)	0.00%
Infant sex (%)		8.79%
Female	5945 (44.8)	
Male	6161 (46.4)	
Birth weight (g) (mean [SD])	3366.83 (557.80)	0.05%
Race/ethnicity (%)		0.00%
White	9337 (70.4)	
Black	1245 (9.4)	
Latinx	1108 (8.3)	
Asian/Pacific Islander	1250 (9.4)	
Multiracial/other races	139 (1.0)	
Unknown	193 (1.45)	
Mother's education (%)		1.48%
No high school diploma	762 (5.7)	
High school diploma	1849 (13.9)	
Some college or associate degree	2678 (20.2)	
Bachelor's degree	4547 (34.3)	
Master's degree or higher	3239 (24.4)	
Cigarette use (%)		0.85%
No	12386 (93.3)	
Yes	773 (5.8)	
Insurance		0.04%
Private/government insurance	10129 (76.3)	
Medicaid	3119 (23.5)	
Self pay	19 (0.1)	
Number of prenatal visits (mean [SD])	12.68 (3.26)	3.16%
Pregnancy-related hypertension (%)		0.01%
No	12304 (92.7)	
Yes	967 (7.3)	
Chronic hypertension (%)		0.01%
No	13120 (98.9)	
Yes	151 (1.1)	
Gestational diabetes (%)		0.01%
No	12818 (96.6)	
Yes	453 (3.4)	
Pregestational diabetes (%)		0.01%
No	12673 (95.5)	
Yes	598 (4.5)	
Delivery route (%)		0.05%
Vaginal spontaneous	9280 (69.92)	
Cesarean	3312 (24.95)	
Operative vaginal	673 (5.07)	

Abbreviation: ADI, area deprivation index.

Figure 1. County-level Map of Wisconsin (A) and Map of the Predicted Spatial Trend in Birth Weight (B)



cesarean), pregestational diabetes (yes/no [referent]), gestational diabetes (yes/no [referent]), total weight gain (continuous), race/ethnicity (White [referent], Black, Latinx, Asian/Pacific Islander, multiracial/other), patient's education (no high school diploma, high school diploma, some college or associate degree, bachelor's degree [referent], master's degree or higher), and payment type (private/government insurance [referent], Medicaid/BadgerCare, self-pay).

Statistical Analysis

Patients were geocoded and aggregated to a census block group, then linked to the neighborhood ADI. Multiple imputation using additive regression, bootstrapping, and predictive mean matching as implemented in the aregImpute function in the Hmisc[14] package in R was used to account for potential biases due to missing data and is valid under a missing-at-random assumption. Associations between ADI and birth weight adjusted for spatial location and other covariates were assessed using generalized additive regression models (GAM),[15] which allow for parsimonious representations of potentially nonlinear effects of quantitative predictors, including spatial trends and/or autocorrelation.

Quantitative predictors (number of prenatal care visits, maternal age at birth, total weight gain during pregnancy, and pre-pregnancy body mass index [BMI]) were modeled using penalized cubic regression spline smooths. The effect of spatial location was modeled using a tensor product smooth of the census block group centroid coordinates (using the Wisconsin Transverse Mercator [WTM] coordinate system[16]). Point estimates and standard errors were pooled across analyses of the 38 imputed datasets using Rubin's method.[17] Median *P* values across imputations were used for multiparameter hypothesis tests.[18] Statistical analysis was performed using the mgcv[19] package in R version 4.0.2.[20]

RESULTS

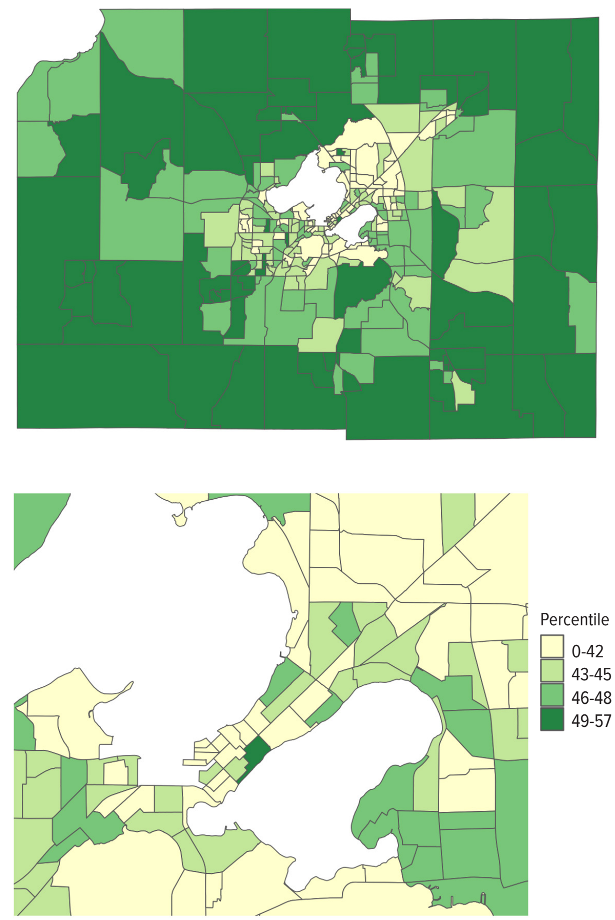
A total of 13 272 patients were included in this study. Both mean and median state-ranked ADI did not differ across the 2 hospitals, nor did all other demographic variables (Table 1). Individual socioeconomic and prenatal factors were then explored for our outcomes. In the sample (Table 1), patients were, on average, in their early thirties, slightly overweight (BMI 26.60 m^2), had gained about 30 pounds throughout their pregnancy, and had birthed infants at approximately 39 weeks. Most patients were White (70.4%), had attained a bachelor's degree (34.3%), were on private or government insurance (76.3%), and had spontaneous vaginal births (69.92%).

Though we found no evidence of an association between birth weight and ADI (adjusted estimate [adj est] -0.01; 95% CI, -0.01 to 0.00), we did find evidence of a statistically significant spatial trend ($P = 0.006$) indicating other spatial information not captured by ADI or covariates. The smoothness of the spatial trend indicates spatial dependence in birth weight not captured by any of the factors explored in our model (Figure 1). The spatial trend was lowest near the center of the county and along the isthmus (between the 2 lakes) near the capitol. Further from the county center, the spatial trend was increasing and highest in the top right corner along the border with the neighboring county (Dodge County), indicating stronger spatial dependence in this area. Interestingly, the top left corner had some of the lowest trend values near the border with Sauk County, indicating lower spatial dependence. Overall, we observed less spatial dependence in birth weight in the more urban county center and stronger dependence along the county border in the more rural cities.

We used our model to predict birth weight in standardized units for each participant. We then aggregated those predicted values by taking the mean birth weight in each census block group. For ease of interpretation, we converted the predicted mean birth weights from z-scores to percentiles (Figure 2). The predicted birth weight percentiles ranged from 24th to 57th percentile (mean 45th percentile, SD 5). The spatial trend from Figure 1B can be seen in the predicted birth weight percentiles. Most of the lower percentile birth weights were found in the center of the county near the downtown area and state capitol between the 2 lakes (0%-42% range). Higher predicted mean birth weight percentiles were found further outside the center of the county nearer the county border.

We also found that Black (adj est -0.31; 95% CI, -0.37 to -0.25) and Asian/Pacific Islander (adj est -0.26; 95% CI, -0.32 to -0.21) patients had lower birth weights compared to White patients after adjusting for known covariates (Supplemental Table 1). Nonlinear relationships with maternal age, number of prenatal care visits, pre-pregnancy BMI, and total weight gain are visualized in Supplemental Figure 2.

Figure 2. Predicted Percentiles for Birth Weight in Dane County (top); Zoomed-in View of Predicted Percentiles Along the Downtown Area (bottom)



DISCUSSION

In our study, we found no association between ADI and birth weight. Dane County is an overall affluent county (mean ADI of 3.16) with variability within census blocks, so it is possible that we are not able to detect the effect of area deprivation. Given the relationship between low socioeconomic status and adverse neonatal outcomes demonstrated in previous literature,[21-24] we hypothesize that investigating ADI in a larger population would possibly highlight a relationship between ADI and these maternal and neonatal outcomes. We found a statistically significant spatial trend in birth weight. This may be driven by other socioeconomic factors not encompassed in the ADI index or other spatially dependent variables that we did not have available in our data. We also found a consistent association between these birth outcomes and patients' race, despite the relative affluence of the county. This may be driven by racial disparities at the individual level that are independent of socioeconomic status. This speaks to the need for continued investigation into the systemic drivers of these disparities.

This study has several limitations. Our ADI measure is at the census block group level which, though very small, may still be masking some spatial effects due to data aggregation. This may be why we observed spatial trends in birth weight but no association with ADI. There also may be other aspects of socioeconomic disadvantage not captured by the ADI that we did not explore. Though our sample size is large, our data are limited to a window of 2016 to 2018, so it may be possible that we need a longer time period and larger sample size to identify effects of ADI. Finally, our analysis is limited to Dane County, Wisconsin, which has a relatively high socioeconomic status and may not be generalizable to other counties that differ in their populations, demographics, and health care services.

Despite these limitations, this study has several strengths. First, the 2 hospitals explored are the only birthing hospitals in the county. Aside from home births or other alternative births, we captured the population of Dane County birthing patients from January 2016 to June 2018. Second, we use a flexible modeling strategy that allowed for nonlinearity in certain continuous covariates and, importantly, allowed for flexibility in capturing the spatial patterns in the data. Finally, we used multiple imputation to impute missing data instead of deleting those individuals from the data, reducing bias and improving precision in our estimates.

CONCLUSIONS

This exploratory study identified the feasibility of using a spatial model to examine neonatal outcomes. Assessments such as this could be used on a larger spectrum to identify areas in need of improved access to high quality obstetrics care and to create a model for reallocation of prenatal services. Furthermore, we found a consistent association between race and birth outcomes even after adjustment for area deprivation and other individual-level factors. This indicates a continued need to investigate health disparities as well as promote the education of health care providers regarding bias to improve maternal and neonatal outcomes. In future work, this approach could be taken across a larger geographic area, such as multiple neighboring counties. This could help highlight locations that would benefit most from targeted public health interventions or even targeted physician recruitment, ultimately improving neonatal outcomes.

Funding/Support: This work was supported by Research and Development Funds from the University of Wisconsin School of Medicine and Public Health Department of Obstetrics and Gynecology.

Financial Disclosures: None declared.

Appendix: Visit www.wmjonline.org to access supplemental materials.

REFERENCES

1. Chinn JJ, Eisenberg E, Artis Dickerson S, et al. Maternal mortality in the United States: research gaps, opportunities, and priorities. A*m J Obstet Gynecol.* 2020;223(4):486-492.e6. doi:10.1016/j.ajog.2020.07.021

2. Infant mortality. Centers for Disease Control and Prevention. Updated September 16, 2024. Accessed April 30, 2020. https://www.cdc.gov/maternal-infant-health/infant-mortality/

3. Matthews TJ, Ely DM, Driscoll AK. State variations in infant mortality by race and Hispanic origin of mother, 2013-2015. N*CHS Data Brief.* 2018;(295):1-8. https://www.cdc.gov/nchs/data/databriefs/db295.pdf

4. Byrd DR, Katcher ML, Peppard P, Durkin M, Remington PL. Infant mortality: explaining Black/White disparities in Wisconsin. *Matern Child Health J.* 2007;11(4):319-326. doi:10.1007/s10995-007-0183-6

5. Ncube CN, Enquobahrie DA, Albert SM, Herrick AL, Burke JG. Association of neighborhood context with offspring risk of preterm birth and low birthweight: a systematic review and meta-analysis of population-based studies. *Soc Sci Med.* 2016;153:156-164. doi:10.1016/j.socscimed.2016.02.014

6. Grzybowski S, Stoll K, Kornelsen J. Distance matters: a population based study examining access to maternity services for rural women. *BMC Health Serv Res.* 2011;11:147. doi:10.1186/1472-6963-11-147

7. Giurgescu C, Zenk SN, Templin TN, Engeland CG, Kavanaugh K, Misra DP. The impact of neighborhood conditions and psychological distress on preterm birth in African-American women. *Public Health Nurs.* 2017;34(3):256-266. doi:10.1111/phn.12305

8. Nagahawatte NT, Goldenberg RL. Poverty, maternal health, and adverse pregnancy outcomes. *Ann N Y Acad Sci*. 2008;1136:80-85. doi:10.1196/annals.1425.016

9. DeFranco EA, Lian M, Muglia LA, Schootman M. Area-level poverty and preterm birth risk: a population-based multilevel analysis. *BMC Public Health.* 2008;8:316. doi:10.1186/1471-2458-8-316

10. Kind AJH, Buckingham WR. Making neighborhood-disadvantage metrics accessible - the Neighborhood Atlas. *N Engl J Med.* 2018;378(26):2456-2458. doi:10.1056/NEJMp1802313

11. QuickFacts: Dane County, Wisconsin. United States Census Bureau. Updated June 27, 2024. Accessed July 13, 2023. https://www.census.gov/quickfacts/danecountywisconsin

12. Wisconsin Department of Health Services. Wisconsin Public Health Profiles 2017. Wisconsin Department of Health Services; 2021. P-45358-21. February 2021. Accessed July 13, 2023. https://www.dhs.wisconsin.gov/publications/p45358-21.pdf

13. Fenton TR, Kim JH. A systematic review and meta-analysis to revise the Fenton growth chart for preterm infants. *BMC Pediatr.* 2013;13:59 doi:10.1186/1471-2431-13-59

14. Harrell FE Jr. Harrell Miscellaneous, version 5.1.1. CRAN; 2020. Accessed July 15, 2024. https://hbiostat.org/R/Hmisc/

15. Hastie T, Tibshirani R. Generalized additive models for medical research. Stat Methods Med Res. 1995;4(3):187-196. doi:10.1177/096228029500400302

16. Danielsen, D, Kock, T, ed. *Wisconsin: Coordinate Reference Systems*. 2nd ed. Wisconsin State Cartographer's Office; 2009. Updated June 2015. Accessed July 15, 2024. https://www.sco.wisc.edu/wp-content/uploads/2017/07/WisCoordRefSys_June2015.pdf

17. Rubin, D. *Multiple Imputation for Nonresponse in Surveys*. John Wiley & Sons, Inc; 1987.

18. Eekhout I, van de Wiel MA, Heymans MW. Methods for significance testing of categorical covariates in logistic regression models after multiple imputation: power and applicability analysis. *BMC Med Res Methodol*. 2017;17(1):129. doi:10.1186/s12874-017-0404-7

19. Wood, S. Mixed GAM Computation Vehicle with Automatic Smoothness Estimation, version 1.9.0. CRAN; 2018. Accessed July 15, 2024. https://cran.r-project.org/web//packages//mgcv/index.html

20. R Core Team. *R: A Language and Environment for Statistical Computing*. Version 4.0.2. The R Foundation; 2021. Accessed July 15, 2024. https://www.r-project.org/

21. Ruth CA, Roos N, Hildes-Ripstein E, Brownell M. The influence of gestational age and socioeconomic status on neonatal outcomes in late preterm and early term gestation: a population based study. *BMC Pregnancy Childbirth.* 2012;12:62. doi:10.1186/1471-2393-12-62

22. Bohanon FJ, Nunez Lopez O, Adhikari D, et al. Race, income and insurance status affect neonatal sepsis mortality and healthcare resource utilization. *Pediatr Infect Dis J*. 2018;37(7):e178-e184. doi:10.1097/INF.0000000000001846

23. Pabayo R, Cook DM, Harling G, Gunawan A, Rosenquist NA, Muennig P. State-level income inequality and mortality among infants born in the United States 2007-2010: a cohort study. *BMC Public Health.* 2019;19(1):1333. doi:10.1186/s12889-019-7651-y

24. Kim MK, Lee SM, Bae SH, et al. Socioeconomic status can affect pregnancy outcomes and complications, even with a universal healthcare system. *Int J Equity Health*. 2018;17(1):2. doi:10.1186/s12939-017-0715-7

Figure S1: State-ranked area deprivation (ADI) by census block in Dane County, Wisconsin

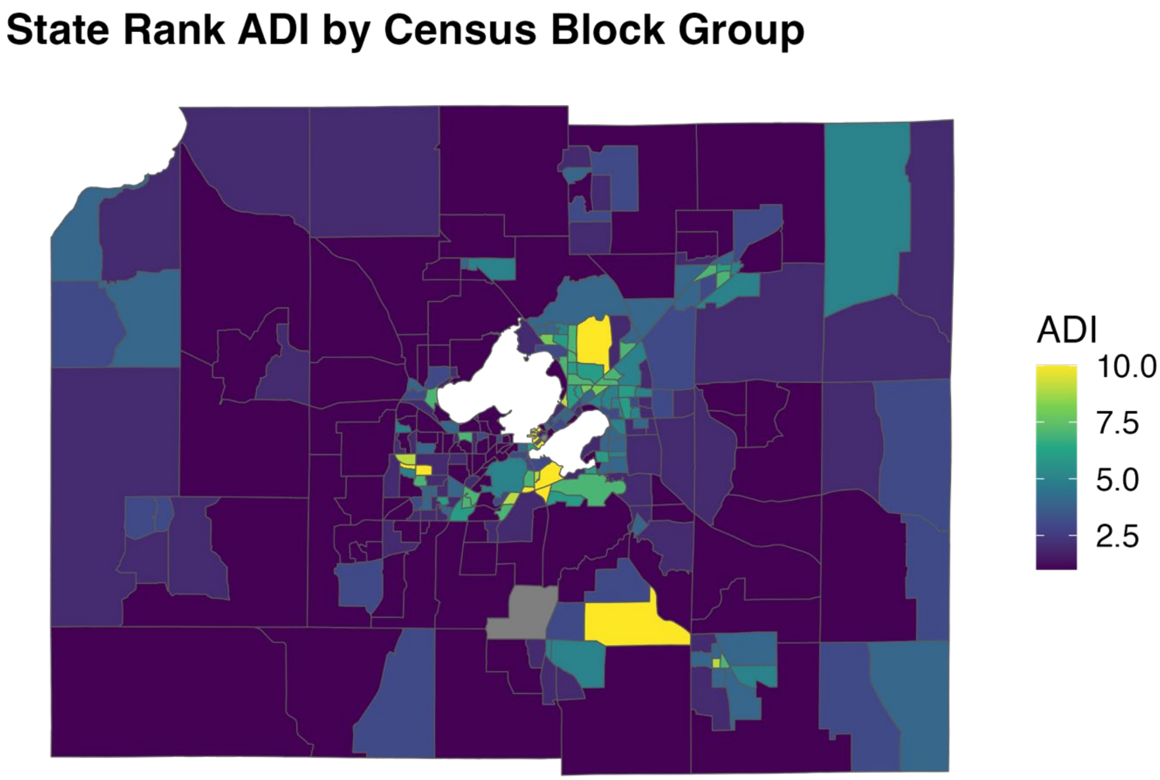
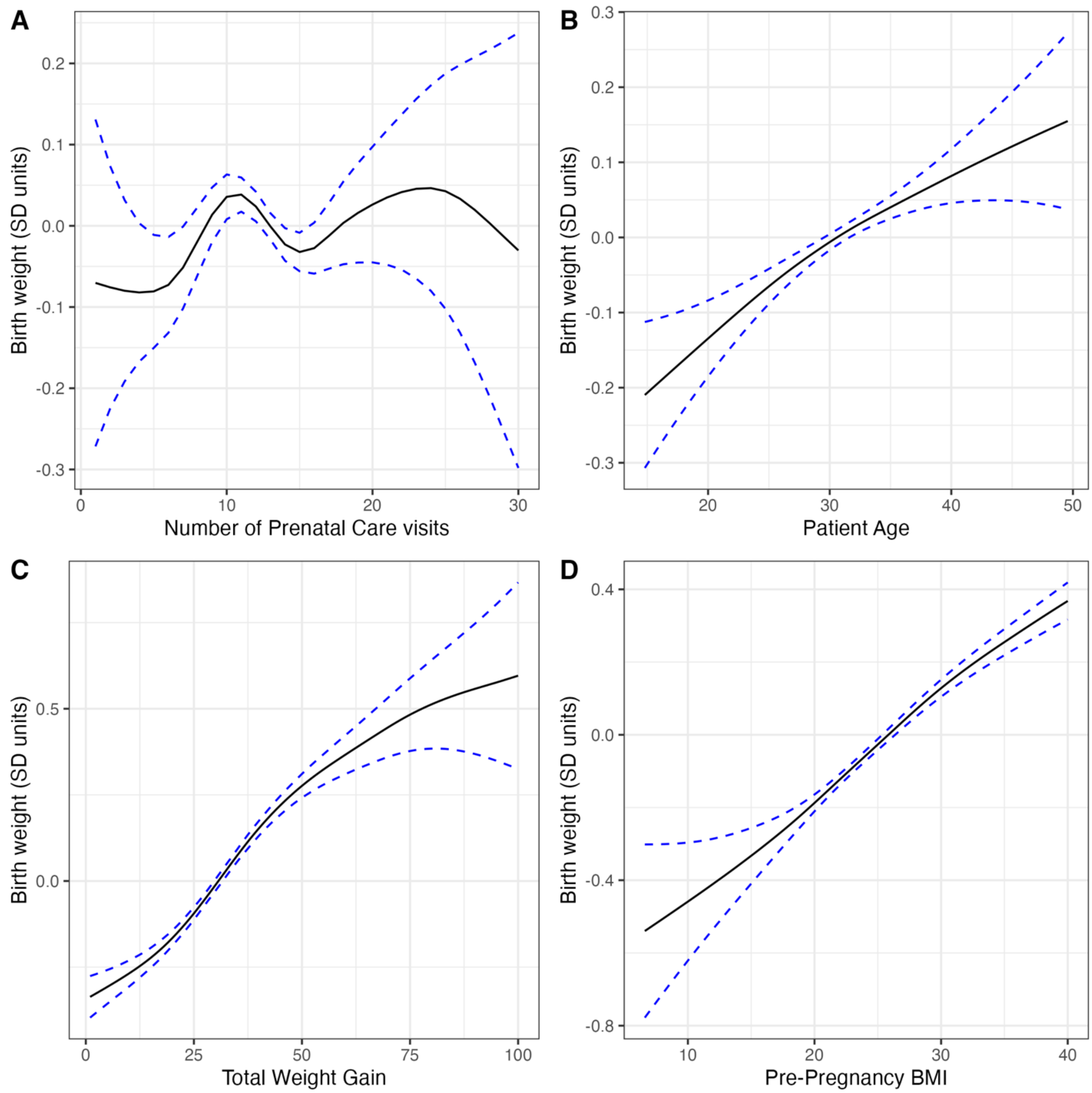


Table S1: Model results

	Birth weight (Standard Units)	
	Estimate (95% CI)	P-Value
ADI-State Rank	-0.01 (-0.01, 0.00)	0.109
White [referent]	--	--
Black	-0.31 (-0.37, -0.25)	< 0.001
Latinx	0.03 (-0.03, 0.09)	0.341
Asian/Pacific Islander	-0.26 (-0.32, -0.21)	<0.001
Multiracial/Other	-0.06 (-0.20, 0.09)	0.465
Unknown	-0.04 (-0.17, 0.09)	0.514
Spatial Trend	--	0.006
Mother's Age	--	<0.001
Number of prenatal care visits	--	0.005
Pre-pregnancy BMI	--	<0.001
Total weight gain	--	<0.001

CI=confidence interval, SD = standard deviation. Model was adjusted for cigarette use, delivery route, insurance type, mother's education, chronic and gestational diabetes, and pregnancy-related hypertension.

Figure S2: Smooth terms in birth weight model. A) non-linear relationship between the number of prenatal care visits and birth weight in standard deviation units; B) non-linear relationship between patient age and birth weight in standard deviation; C) non-linear relationship between total weight gain during pregnancy and birth weight in standard deviation; D) non-linear relationship between pre-pregnancy BMI and birth weight in standard deviation.



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