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DOES SPACE MATTER? AN INVESTIGATION OF THE SPATIAL VARIATION IN GESTATIONAL WEIGHT GAIN ASSOCIATIONS WITH COUNTRY OF BIRTH AMONG HISPANIC WOMEN AND ACCESS TO CARE IN TEXAS

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DEDICATION

To Tara, Liam, and Nora

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DOES SPACE MATTER? AN INVESTIGATION OF THE SPATIAL VARIATION IN GESTATIONAL WEIGHT GAIN ASSOCIATIONS WITH COUNTRY OF BIRTH AMONG HISANIC WOMEN AND ACCESS TO CARE IN TEXAS

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Inadequate and excess gestational weight gain (GWG) are serious, but potentially preventable adverse pregnancy outcomes which affect as many as two-thirds of pregnant women in the United States. While location and space are associated with a variety of pregnancy outcomes, limited research has investigated potential spatial variation in GWG.

The goal of this research is to improve the knowledge of how spatial geography is associated with GWG through secondary analyses of 70,000 to 160,000 birth certificate registry records for Texas mothers with a live birth delivery in 2014. Specifically, this research attempts to assess whether access to obstetrics and gynecologist (OBGYN) providers and country of birth among Hispanic women were associated with gestational weight gain. Overall, this research indicates that space is important in understanding GWG, though the significance of space depends on the studied risk factor. Analyses of women in the Houston-The Woodlands-Sugarland Metropolitan Statistical Area revealed that potential geographic access to OBGYN providers was not associated with inadequate or excess GWG;

although, there was variation in the odds of inadequate or excess GWG in the area. Additionally, analyses of Hispanic women demonstrated statistically significant variation in the association between maternal county of birth and total GWG. Patterns indicated that foreign-born maternal birth compared to maternal birth in the United States is associated with increased total GWG along the Texas-Mexico border and in rural areas in Texas with a shift to less GWG along the Texas I-35 corridor and in northwest Texas. Consistent across the research was the importance of the association between prepregnancy weight and GWG. While space is important to understanding GWG, this research reveals that prepregnancy weight may be the key factor in controlling GWG.

Few studies explore spatial variation in GWG and this was the first to explore variation within Texas which could show variation in studied maternal characteristics across the entire state. Public health researchers may utilize methods from this research as a template for incorporating spatial components into their research as space may improve the modelling process and elucidate the role of studied health characteristics, investigate the possibility of a threshold effect for geographic access to care, and explore the role of spatial variation in the Hispanic Paradox.

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BACKGROUND

Literature Review

Inadequate or excess gestational weight gain (GWG) is a public health concern as excess and inadequate weight gain during pregnancy can have serious adverse pregnancy outcomes for the mother and child. Inadequate GWG is associated with poor pregnancy outcomes including small for gestational age infants (1), infant mortality (2), and preterm labor (3). Excess GWG is associated with macrosomia (1), preeclampsia, hypertensive outcomes, reduced breastfeeding (4), and increased C-section utilization (1,5).

Non-compliance of Institute of Medicine (IOM) recommendations for GWG can occur in two ways: women do not gain enough weight or women gain too much weight. Risk factors for inadequate and excess GWG identified through observational studies include extensively studied individual-level risk factors such as age, alcohol use, race, and income, but also infrequently studied place-based risk factors of rurality and neighborhood conditions. Place-based risk factors present a challenge in conducting epidemiological research as the factors may be associated with both a person's individual socioeconomic risk factors and their health (6). While research is generally consistent on the effects of most GWG risk factors, some research on GWG has produced conflicting results on the associations with access to care, maternal county of birth, and neighborhood effects.

It is important to understand pregnancy related health outcomes such as GWG as pregnancy and deliveries are some of the costliest and most common medical procedures in the United States (US), costing Medicaid in excess of $8 billion dollars in 2013 (7). Wide variation has been shown in the cost of health care delivery in Texas and in national costs of hospital live-birth deliveries, but no research has analyzed how GWG may contribute to the delivery costs.

Prevalence and Trends in Gestational Weight Gain

In the US, an estimated 20.9% of pregnant women had inadequate GWG while 47.2% of women had excess GWG in 2011 and 2012 (8). Approximately 59.2% of women will have one pregnancy with excess GWG (9). Over time, the prevalence of excess and inadequate GWG has increased. Analysis of pregnancies in the US from 2000-2009 using 1990 IOM recommendations found an annual 1.0% reduction in the number of pregnancies with GWG within recommendations and a statistically significant increase in excess weight gain (10). During the same period, from 2003 to 2009, obesity prevalence among pregnant women increased from 17.6% to 20.5% (11); however, the causal relationship between rising obesity prevalence and increasing excess GWG has not been demonstrated (10) and clarification is limited by a lack of large population based studies of GWG trends (10). Table 1 shows the commonly used standards for determining recommended GWG in the US since 2009.

Table 1: 2009 Institute of Medicine Gestational Weight Gain Recommendations (12)

Prepregnancy BMI Classification	**BMI (WHO) ***	**Total Pregnancy Weight Gain (pounds)**	**Average Weight Gain in 2nd and 3rd Trimesters (pounds/week)**
Underweight	<18.5	28-40	1-1.3
Normal	18.5-24.9	25-35	0.8-1
Overweight	25.0-29.9	15-25	0.5-0.7
Obese	>=30.0	11-20	0.4-0.6

* Note: BMI- Body Mass Index (kg/m^2)
WHO- World Health Organization

Individual and Socioeconomic Factors Associated with Gestational Weight Gain

Non-compliance to GWG recommendations is associated with adverse maternal and fetal outcomes including preterm birth, gestational diabetes, and macrosomia (12). More than two-thirds of all pregnancies have GWG that is either inadequate or in excess of recommendations set by the Institute of Medicine (IOM) (8).

GWG is significantly and directly associated with increasing maternal BMI (13–16), negative body image (17), maternal age, race, parity, and maternal education (13). However, some evidence suggests that after controlling for individual maternal characteristics, race may not be an independent risk factor for GWG (18). Some factors are inversely associated with GWG, suggesting a protective effect. These factors include maternal education (14) and maternal depression (19,20). Poor pregnancy outcomes associated with increasing GWG include gestational hypertension, premature rupture of membranes, macrosomia, preeclampsia (14).

Some factors that are weakly, but significantly associated with inadequate GWG (OR: < 2) are sleep deprivation (22,23), parity (3,15), increasing age, alcohol use (15), smoking (3), low per capita income (22), unhealthy diet or lack of exercise (24), initiation month of prenatal care (8,25), obesity, and prepregnancy normal weight in Black women, Hispanic women, and Asian women relative to non-Hispanic white women (8). A moderate association (OR: 2 - 5) has been found between short stature (26) and caloric intake (27) with inadequate GWG. A strong association (OR >5) with inadequate GWG has been found with being a former smoker (26). Some factors are inversely associated with inadequate GWG, suggesting a protective effect. Factors strongly inversely associated (OR < .5) within inadequate GWG include prepregnancy overweight BMI (3,28). A weak protective association (OR 0.8-1.0) with inadequate GWG has been found with maternal support (25).

Poor pregnancy outcomes moderately associated with inadequate GWG include increased risk of inadequate GWG in subsequent pregnancies (29). Pregnancy outcomes weakly associated with inadequate GWG include small for gestational age (1) infant mortality (2), preterm labor (3), weight reduction at 6 months postpartum (30).

Factors moderately and significantly associated with excess GWG are prepregnancy overweight or obesity status (26,28,31), maternal age (27), maternal birth in the US for Hispanic women (25), smoking cessation, and race (23). Factors weakly associated with excess GWG include marriage (31), primiparous pregnancy, negative attitudes towards GWG (19), more than one prior birth (28), lack of exercise (23), and poor vegetable consumption (32). Some factors are inversely associated with excess GWG. Factors moderately inversely associated (OR 0.8 - 0.5) with excess GWG include US residence of fewer than 10 years for Hispanic women, fewer than 8 prenatal visits, maternal BMI less than 19.8, more than one prior birth (27), depression (28) and diet or exercise (24). An underweight prepregnancy BMI is inversely associated with reduced odds of excess GWG (OR < 0.5) (28).

A variety of poor pregnancy outcomes are moderately and significantly associated with excess GWG including macrosomia (1), preeclampsia, hypertensive outcomes (33), and excess GWG in subsequent pregnancies (29). Excess GWG has small associations with reduced breastfeeding (4) and increased C-section utilization (1,5). Although, some research has suggested that BMI, and not GWG, is predictive of breastfeeding utilization (34). Excess GWG is a significant predictor for increased maternal BMI at 1-11 months (35,36), at 3 years

(30,37), 4-12 years (38), and at 18 years postpartum (39). Approximately 11% of all C-sections in the US are attributable to excess GWG (5). Excess GWG has a moderate inverse association with small for gestational age, suggesting a protective effect (1).

Measurement of Gestational Weight Gain

GWG is calculated by subtracting prepregnancy weight from the mother's weight at time of delivery. The Centers for Disease Control (CDC) guidelines suggest that mother's prepregnancy weight be self-reported and recorded in whole pounds (40), mother's height should be self-reported by the mother and recorded in feet and inches (40), and labor and delivery records or admission history are the preferred sources for recording delivery weight (40). Birth certificate delivery weight, prepregnancy height, and prepregnancy weight have been previously validated and are considered acceptable measurements (41). Reporting validity is known to vary by prepregnancy weight and maternal race (42,43), but results in minimal bias in associations between GWG and pregnancy outcomes (43).

Spatial and Place-Based Variation in Health

Public health has a long tradition of studying the geospatial distribution of health and disease, with one of the most prominent examples being John Snow's map of the 1854 cholera outbreak (44). A growing body of spatial epidemiological research has continued that tradition by analyzing georeferenced health data with spatial methods (6,45). Spatial and place-based analysis refers to the analysis of georeferenced data, data with latitude and longitude. Space is commonly thought of as geometric space, but it can also be a social space

(46). Place is a location within space and includes the attributes of that place such as social, economic (46), and environmental features (6). As individuals often live near other individuals with similar demographic and health behaviors, place can confound the relationship between health and studied risk factors, a phenomena known as spatial autocorrelation. Failure to adjust for spatial autocorrelation when analyzing data can overestimate observed effects and underestimate error, increasing the risk of a Type 1 error (47). Methods to analyze spatial place-based data include mapping, aggregating rates, interpolation, and regression (45).

In the US, place has been associated with varying health outcomes. Rural counties tend to have poorer health outcomes than metropolitan counties. Almost 20 percent of individuals residing in rural or remote counties report fair or poor health compared to 14.4% of individuals in metropolitan counties (48); however, some of the geographic differences in health outcomes or access may be explained by adjusting for area-level socioeconomic status (48,49). Variation also can be observed for some pregnancy outcome measures. Teen birth rates across the US cluster such that neighboring counties are more similar than distant counties. Texas appears to have teen birth clusters along the border with Mexico, in West Texas, and parts of East Texas, a possible reflection of the underlying Hispanic population composition and age structure of these areas (50).

Some research has explored the geospatial variation in GWG. Rural or urban residence as defined by Rural Urban Commuting Area Codes, a measure of area population density and commuting patterns (51), is associated with a moderate increase in the odds of inadequate GWG among normal weight women, protective of excess GWG among overweight women, and protective of inadequate and excess GWG in obese women (52). Analysis of Florida GWG found non-complementary patterns in the odds inadequate and excess GWG across the state (53) with the highest odds of excess GWG in north central rural areas. Utilizing a sample size of 1,385,574 deliveries, the research found weak associations for inadequate and excess GWG with nearly every studied risk factor. Moderately associated risk factors of excess GWG were overweight and obese prepregnancy maternal BMI (53).

Place-based factors have been shown to explain some spatially varying health outcomes. Neighborhood incivilities including deteriorated buildings, abandoned buildings, and litter are associated with increased odds of having GWG of less than 15 lbs. and greater than 40 lbs. Increased walkability indicators were associated with an increased odds of having GWG of less than 15 lbs. (54). Inadequate GWG was weakly associated with low-to-medium neighborhood violence quartile (55) and mid-to-high poverty rates (56), and neighborhood socioeconomic status (57). Increasingly walkable neighborhoods reduces the odds of inadequate GWG (58,59). Excess GWG was weakly associated with neighborhood violence quartile (55,59). The role that available social space has on GWG is unclear; some research indicates that it increases the odds of inadequate GWG (59), while other research indicates that social spaces are protective of both inadequate and excess GWG (58). Neighborhood conditions also have been shown to have an impact on maternal anemia (60) and low birth weight (61,62).

Spatial Variation in Health Care Resources

Access to health care is a multifaceted combination of social, geographic, potential, and realized access (63). Social, economic and policy-based aspects of prenatal care access include insurance, personalized care, office wait times, atmosphere (64), finances (64,65), facility expertise (65) and motivation (66). Geographic aspects of access include provider location (65,67), transportation, and provider density (65). Potential access analysis measures the availability of a health care resources; whereas, realized access analysis measures resources obtained and utilized.

Geographic access to care measures are primarily determined by provider to population ratios or potential access, as defined by distance to health care providers (68). The US Department of Health and Human Services has created three classifications for geographic areas with provider shortages: Health Professional Shortage Areas, Medically Underserved Areas and Medically Underserved Populations, and Governor's Designated Secretary Certified Shortage Areas for Rural Health Clinics (69). Areas with provider to population ratios below thresholds may be designated as shortage areas (69). A limitation with shortage area designations is size – when areas are too big, they will obscure small area variation, but too small and their use in analysis is ineffective as individuals may travel across boundaries for health services (70). A more sophisticated method for measuring access is the gravity model. Gravity models are cumulative measurement models that can aggregate the number of health resources within distances like rings around a point (68). Two-step catchment statistics are a modification of gravity models that aggregate provider to population ratios to determine geographic access (70). A review of research on geographic access to health care resources found that 30% of the studies utilized two-step catchment statistics with catchment sizes from 10 to 60 minute drive times or 2 kilometers to 10 kilometers (68).

Research has shown that variation exists in the availability of health care resources across geography. Texas spatial access to primary care providers showed disparities by race, socioeconomic status, rurality, and public health region. By race, non-Hispanic black and Asian had the best potential spatial access followed by Hispanic, Native American, and non-Hispanic white (49). Potential access by race may be reflective of the racial and economic composition of Texas as metropolitan areas had the greatest potential spatial access and isolated rural areas had the worst (49). In 2011, Ninety-five percent of obstetric and 99% of neonatal intensive care units (NICU) were in urban areas. Forty-six percent of US land area was not within 50 miles of an obstetric or NICU (71). However, 87% of the US population has access to both NICUs and obstetric critical care units (71).

In 2016, of the 2,372 licensed and practicing obstetrician and/or gynecologists (OBGYN) in Texas, 94.4% had offices in metropolitan counties (72). Almost 60% of Texas counties did not have a licensed and practicing OBGYN (72). As evident in Table 2, non-metropolitan and border regions had higher population to provider ratios than their regional counterparts. Additionally, as National Center for Health Statistics (NCHS) Urban-Rural Classification Scheme category increases for counties, the population to provider ratio tends to increase. NCHS defined rurality for counties is based upon Office of Management and Budget metropolitan status, population size, and local area economic dependencies (73).

Table 2: 2016 Primary Care Physicians with an Obstetrics and/or Gynecology Specialty by Texas Region

Region	Licensed and Practicing OBGYNs (72)	Resident Population (74)	Population to Provider Ratio
Texas	2,372	27,315,362	11,516
Non-Metro Counties (75)	132	3,143,214	23,812
Metro Counties	2,240	24,172,148	10,791
La Paz Border Area (76)	179	2,877,261	16,074
Non-La Paz Border Area	2,193	24,438,101	11,144
South Texas Border Region (77)	398	5,434,495	13,655
Non-South Texas Border Region (77)	1,974	21,880,867	11,085
NCHS Large Central Metropolitan (73)	1,339	12,805,704	9,564
NCHS Fringe Metropolitan	368	4,969,741	13,505
NCHS Medium Metropolitan	339	4,638,489	13,683
NCHS Small Metropolitan	194	1,758,214	9,063
NCHS Micropolitan	108	1,686,848	15,619
NCHS Noncore	24	1,456,366	60,682

As evident in Table 3, some variation can be observed in OBGYN resources as defined by the ratio of pregnancies to providers. Non-metropolitan counties had higher pregnancy to OBGYN provider ratios than metropolitan counties. Border areas had higher pregnancy to provider ratios than non-border areas. The relationship between NCHS Urban-Rural Classification Scheme rurality and the pregnancy to provider ratio is not consistent. Large central metropolitan counties and small metropolitan counties had the lowest pregnancy to provider ratios. Noncore counties had the highest pregnancy to provider ratios at more than four times the state average.

While spatial variation in health care resources exists, the effect this variation has on health outcomes or utilization is undetermined. Primary care provider utilization is negatively affected by travel times of greater than 20 minutes (78) and positively affected by increasing

PCP population provider ratios (79), but other research has shown that PCP location is not associated the realized access in all studied locations (80). Rurality is associated with higher rates of non-urgent emergency department visits and uninsured ED visits (81).

Table 3: 2015 Primary Care Physicians with an Obstetrics and/or Gynecology Specialty and Total Pregnancies by Texas Region

Region	**Licensed and Practicing OBGYNs (82)**	**Total Pregnancies* (83)**	**Pregnancy to Provider Ratio**
Texas	2,372	458,282	198
Non-Metro Counties (75)	132	42,851	335
Metro Counties	2,240	415,431	190
La Paz Border Area (76)	179	52,019	294
Non-La Paz Border Area	2,193	406,263	190
South Texas Border Region (77)	398	95,891	243
Non-South Texas Border Region (77)	1,974	362,391	188
NCHS Large Central Metro (73)	1,339	233,472	176
NCHS Fringe Metro	368	73,998	217
NCHS Medium Metro	339	80,133	234
NCHS Small Metro	194	27,828	152
NCHS Micropolitan	108	24,257	229
NCHS Noncore	24	18,594	845

* Note: Total pregnancies are the sum of all live births, induced abortions, and fetal deaths

The relationship between geographic access and pregnancy related health outcomes also is undetermined. Spatial proximity to family planning clinics was not associated with teenage pregnancy rates; however, teen pregnancy was weakly associated with increased access to OBGYN per population ratios (84). NICU utilization varies as distance from obstetrics providers increases. Distances of 2 to 4 hours were strongly protective of NICU utilization whereas distances of 1 to 2 hours moderately increased the odds of NICU admissions (85). In Australia, women residing in remote areas were less likely to have constant fetal monitoring, prenatal care in the first 18 weeks, and moderately more likely to see a general practitioner instead of an OBGYN during pregnancy compared to women residing in a major city (86).

Gestational Weight Gain Among Hispanic Women

Hispanic individuals have long been shown to have better than expected health outcomes including reduced mortality rates (87,88), reduced frailty rates (89), adequate gestational age (90,91), and increased birth weight (90,92,93) compared to other populations with similar socioeconomic status, a phenomena referred to as the Hispanic paradox. The effect of Hispanic ethnicity on health outcomes has been shown to be more evident in foreign-born Hispanic populations (88,92) than in US-born Hispanic populations; however, there is debate on whether the phenomena referred to as the Hispanic paradox is a real effect of ethnicity or an artifact of data collection and analysis errors (94–97).

An estimated 30.4% of Hispanic women report inadequate GWG, 34% report adequate GWG, and 35.7% report excess GWG (98). GWG among Hispanic women varies by country of birth and acculturation status. Twenty-five percent of Mexican-born and Spanish speaking Hispanic women had GWG of less than 15 lbs. and 6% had GWG of greater than 40 lbs. Sixteen percent of US-born and English speaking Hispanic women had GWG of less than 15 lbs. and 9% had GWG of greater than 40 lbs (99). Among Hispanic women, residence in a border county with Mexico had a small effect on GWG. Twenty-nine percent of Hispanic women in a border county had inadequate GWG, 29% had adequate, and

42% had excess GWG. Twenty-six percent of Hispanic women residing in a non-border county had inadequate GWG, 32% had adequate GWG, and 42% had excess GWG (100).

At the population-level, risk factors moderately associated with excess GWG among Hispanic populations are US maternal birth, maternal marriage, lack of concern about caloric intake, weight embarrassment (25), maternal age (27), prepregnancy overweight BMI (98). Prepregnancy BMI (25,98), hypertension, and parity (98) have been shown to be weakly associated with excess GWG. Level of maternal support was weakly protective of inadequate GWG (25). Residence of less than ten years, fewer than eight prenatal visits (27), and border county residence (98) were moderately protective of excess GWG. Maternal BMI of less than 19.8 (27,98) and having more than one prior birth (27) were strongly protective of excess GWG.

Factors moderately associated with reducing the odds of inadequate GWG among Hispanic women include no prior live birth and WIC enrollment (98). Risk factors weakly associated with increasing the odds of inadequate GWG include month of prenatal care initiation (25) and diabetes (98). Inadequate prenatal care was moderately associated with increasing the odds for inadequate GWG (98).

Maternal country of birth has been associated with differing pregnancy outcomes and behaviors. Foreign-born Hispanic women have an estimated 19% reduction in the odds of having a low birth weight infant compared to US-born Hispanic women (92). US-born Hispanic women with residence in a high-Mexican immigrant area had a statistically significant increase in infant birth weight of 33-44g (101); however, other research has been inconclusive on any immigrant neighborhood effect on low birthweight (102). A study on breastfeeding found that 91% of Hispanic Mexican-born immigrant women breastfed their infants compared to 53% of US-born Hispanic women (103).

Some geographic pregnancy disparities have been observed among Hispanic women. US-born Hispanic women who reside in a rural area were more likely to have GWG of more than 40 lbs. (13%) and less likely to have GWG of less than 15 lbs (16%) compared to Hispanic women born in Mexico who reside in a rural area (6% and 25% respectively) (99). Twenty-four percent of rural US-born Hispanic women had a C-section compared to 15% of rural Mexican-born Hispanic women (99). Analysis of Florida populations showed that after controlling for spatial proximity, maternal risk factors, and area covariates, maternal US-birth moderately increased the risk of excess GWG and moderately lowered the risk for inadequate GWG (53); although, research of Hispanic women in Texas border counties found no statistical association between nativity and GWG (100). The research also found no association between GWG and metropolitan status or border residency (100).

Pregnancy Associated Costs and Health Care Cost Variation

Pregnancy and live birth account for more than one-quarter of all Medicaid paid hospital stays (7). Nationally, livebirth costs, prior C-sections, and other delivery conditions cost Medicaid an estimated $8,439,000,000 or 13.4% of national health care expenditures (7). The effect of pregnancy costs is especially impactful on Texas as an estimated 46% of resident births were funded by Medicaid in 2014 (104).

Charges for a live birth differ based on the delivery mode and maternal complications. The median national charge for a vaginal delivery was $12,018 compared to

$16,385 for a Cesarean delivery. Charges increased monotonically as the number of comorbidities increases with $2,298 to $2,517 in charges for one comorbidity to $5,905 to $6,302 for three or more comorbidities (105). Prepregnancy diabetes, prenatal hospital admission, emergency department visit, increasing maternal age, and Pacific, East North Central, New England, and Middle Atlantic residence were associated with increased pregnancy charges (105).

There is a substantial variation in average costs between hospitals for live birth deliveries. Nationally, average hospital vaginal deliveries can cost between $1,183 and $11,819, while Cesarean deliveries can cost between $1,249 to $13,688 (106). Delivery costs tends to increase as Cesarean utilization rate increases, Medicaid utilization decreases, rurality increases, delivery risk profile increases, hospital volume decreases, and at not-for-profit and nonfederal public hospitals (106). C-section surgical costs tend to show similar cost variation as costs decrease with increasing hospital volume, Medicaid utilization increases, risk profile decreases, but no cost differences have been shown between rural and urban areas (107).

Little research is available on the association between costs and GWG, but there is some evidence that weight is associated with excess pregnancy costs. A study of British women found that overweight women had 23% higher total pregnancy costs and obese women had costs 37% higher than normal weight women (108). Additionally, as prepregnancy weight classification increases, there is evidence that there is a monotonic increase in the duration of stay and in the number of pregnancy hospital admissions, indicators of increased health resource utilization (109).

Within the field of health economics, health care costs are analyzed by their variation between regions, a field called small area cost variation (110). The variation observed in health care costs and resource utilization is driven by differing financial incentives, resource capacity, ethics, patient access, malpractice risk, and health disparities (111). A variety of measurement areas have been developed or used to study regional variation including "little in from outside" (LIFO) and "little out from inside" (LOFI) areas (112), hospital service areas, hospital referral regions (HRR), distance to service measures, physician hospital networks, or administrative regions such as states and zip codes (111). In the US, studies of local area cost variation almost exclusively utilize Medicare data (111). This can cause an issue in analyzing pregnancy related health conditions as few Medicare enrollees get pregnant. According to the Medicare Inpatient Utilization and Payment Public Use File for 2015, fewer than 20,000 of 9,743,275 Medicare paid inpatient discharges were pregnancy related (113).

Small area cost variation in Texas has been studied regarding the differences between hospital referral region markets. Atul Gawande (114) found that McAllen, TX, a low socioeconomic status area, had the second most expensive Medicare market in the US. Other analysis has shown that Hidalgo County, the home of McAllen, had the highest Medicare spending, but the lowest spending in a private health insurer. The Valley and Hidalgo HHR had the lowest spending per enrolled private health insurance member and was highest in the Wichita Falls and Beaumont HHRs (115). Spending variation across HRRs in Texas was driven by utilization, price differences in service categories and provider leverage, and population health (116). Though this research demonstrates variations in health care costs in Texas, research has yet to confirm these variations with pregnancy related health conditions.

Public Health Significance

This research addresses the association of geographic access to OBGYN providers and county of birth among Hispanic women variation related to GWG outside of IOM recommendations among Texas residents with a live birth in Texas while accounting for the effect of potential spatial dependencies. From John Snow's 1854 map of London to the modern development of the field of spatial epidemiology, the role of geography on health outcomes has long been acknowledged in epidemiology. This research expands upon that long tradition of research by using novel methods and modern computational capabilities to explore GWG.

The studies were able to address these issues by using registry data of Texas resident births. On average, 400,000 Texas women give birth every year. Databases at the Texas Department of State Health Services (DSHS) contained information on maternal demographics, socioeconomic status, residence, complications, and GWG from which researchers can assess the association between maternal characteristics and GWG.

The expected outcome of this research is to provide a greater understanding of the relationship between space and the studied risk factors on GWG. The unique role that place has on GWG has previously been analyzed at large regional levels and never with such granularity. On a macroscale, the ability to identify potential at risk areas affords public health officials the ability to better allocate limited resources across the state. On a microscale, public health interventions to address inadequate or excess GWG may be tailored to the racial, ethnic, and socioeconomic composition of neighborhoods. On an individual-level scale, future studies may advance this research to devise low, medium, or high-risk classifications for pregnancies. Doctors would be able to apply the results to better inform their patient populations of their pregnancy risks.

In the long-term, the research findings will be useful for determining risk factors associated with non-compliance of GWG recommendations. The role that place has on GWG has been sometimes contradictory and the application of spatial analysis methods are rarely applied. This research expands upon the field of spatial epidemiology by advancing our understanding of geographic access and country of birth among Hispanic women in relation to GWG.

Hypothesis, Research Question, Specific Aims or Objectives

The long-term goal of this research is to improve the knowledge of how spatial geography is associated with GWG within the specialty of epidemiology. The overall objective is to elucidate the role in which GWG is associated with geographic access to care and maternal country of birth among Hispanic women. The central hypothesis is that the risk factors associated with GWG were influenced by spatial and place-based factors. The rational for this research is that GWG is a serious, but modifiable pregnancy outcome for which the geospatial and place-based characteristics of the condition were poorly understood.

Aim 1

The first aim that addressed the central hypothesis was:

Aim 1: To assess the relationship between geographic potential access to obstetrician and gynecologist providers and developing inadequate or excess GWG in Houston-The Woodlands-Sugarland Metropolitan Statistical Area resident women with a live birth delivery in 2014.

Hypothesis: Increased access as defined by an increasing floating two-step catchment area statistic within a distance of 15 straight line miles between maternal residence and OBGYN providers will be associated with lower odds of inadequate and excess GWG compared to adequate GWG.

Aim 2

The second aim that addressed the central hypothesis was:

Aim 2: To investigate geospatial variation in the association between maternal country of birth among Hispanic Texas resident women with a live birth delivery and GWG in 2014.

Hypothesis: The relationship between country of birth and total GWG will vary across Texas with a negative direction of association in metropolitan border areas and a positive direction of association in rural areas furthest from the border.

JOURNAL ARTICLE 1

Investigating the Association between Geographic Access to Obstetric and Gynecologic Providers and Gestational Weight Gain in Texas
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ABSTRACT

Introduction Gestational weight gain (GWG) is a modifiable pregnancy outcome. Access to obstetric and gynecological (OBGYN) providers varies by geography and may be associated with pregnancy outcomes. The objective of this study was to assess the relationship between geographic potential access to OBGYN providers and developing inadequate or excess GWG in pregnant women. *Methods* A secondary analysis of Texas birth registry data was conducted of 79,222 mothers with a singleton live birth delivery in the Houston-The Woodlands-Sugarland Metropolitan Statistical Area (MSA) in 2014. A multinomial regression model with tract-level spatial adjacency was used to examine variation in the association between floating two-step catchment areas (F2SCA) of OBGYN access and the odds of inadequate or excess GWG compared to adequate GWG. *Results* Approximately one-third (32.6%) of the mothers had GWG within IOM recommendations, one-fifth (21.1%) had GWG below recommendations, and 45.2% had excess GWG. The F2SCA statistic was highest in Harris County, indicating the highest OBGYN potential geographic access in the metropolitan area; however, geographic potential access to OBGYN providers was not associated with inadequate GWG and excess GWG compared to adequate GWG. *Discussion* Spatial variation was observed in geographic access to OBGYN providers and the odds of inadequate and excess GWG; however, access was not associated with GWG. Researchers

may want utilize spatial regression models when investigating pregnancy outcomes, but may find weak spatial relationships that may not substantially alter study conclusions.

INTRODUCTION

Inadequate and excess gestational weight gain (GWG) are serious and modifiable pregnancy outcomes that affect more than two-thirds of all pregnancies in the US (1) and are growing public health problems as the number of women that gain within Institute of Medicine (IOM) GWG recommendations in the US has declined annually by 1.0% (2). Inadequate or excess GWG can contribute to infants which are small for gestational age (3), infant mortality (4), preterm labor (5), macrosomia (3), preeclampsia, hypertensive outcomes, and increased C-section utilization (3,6). Risk factors for inadequate or excess GWG are varied and include biological risk factors including age (7,8) and prepregnancy BMI (9–11), behavioral risk factors including smoking (11), and social risk factors including race (12). A growing body of literature has recently explored how place-based risk factors may contribute to inadequate or excess GWG. Factors associated with increased odds of inadequate or excess GWG among normal weight women include rurality compared to urbanicity (13,14), and high levels of neighborhood violence (15,16); whereas, the presence of neighborhood social spaces such as parks is inversely associated with inadequate or excess GWG (17).

Geographic disparities are evident in the distribution of prenatal and pregnancy providers in Texas. Of the 2,372 licensed and practicing obstetrician and/or gynecologists (OBGYN) in Texas, 94.4% have their offices in metropolitan counties (18). Almost 60% of Texas counties do not have a licensed and practicing OBGYN and population to provider ratios, a measure of provider access, are better in large central metro counties (19) than in fringe and medium metro counties in Texas (18). Despite the disparity in geographic access, little or no research has analyzed the role that spatial variation in OBGYN access may contribute to differences in GWG across geography; however, other research has demonstrated a relationship between access to health care resources and health outcomes. Pregnancy delivery outcomes were better in high delivery volume (20) or higher level hospitals (21–23) compared to low delivery volume or level hospitals, but some research has found no relation between volume and outcomes (24,25). Research of primary care providers (PCP) has found some relation between access and health outcomes as PCP utilization has been shown to be negatively affected by travel times of greater than 20 minutes (26) and positively affected by increasing PCP population provider ratios (27). Poor pregnancy outcomes were associated with rural OBGYN access in Australia, as women from remote areas were less likely to have constant fetal monitoring, prenatal care in the first 18 weeks, and moderately more likely to see a general practitioner instead of an OBGYN during pregnancy compared to women in a major city (28).

Access to health care is a multifaceted combination of social, geographic, potential, and realized access (29). Prenatal care access is determined in part by factors including health insurance, personalized care, wait times, doctor office atmosphere (30), finances (30,31), facility expertise (31), motivation (32), provider location (31,33), transportation, and provider density (31). Geographic access to care has traditionally been assessed by provider to population ratios within political or geographic areas such as counties or public health regions or by potential access, as defined by distance to health care providers (34). A limitation with provider to population ratios is that when geographic analysis areas too big, they will obscure small area variation, but made too small and their use in analysis is ineffective as individuals may travel across boundaries for health services (35). Additionally, the different geospatial units that can be used to define an area (i.e., counties, Census tracts, etc.) will yield unit-level estimates that are dependent upon the size and shape of the unit (36). A solution to commonly used provider to population ratios are floating two-step catchment areas (F2SCA) which aggregate provider to population ratios to determine geographic access for individuals (35). A review of recent research papers on geographic access to health care found that 30% of the studies utilized F2SCAs (34).

This research seeks to assess the relationship between geographic potential access to OBGYN providers and developing inadequate or excess GWG in pregnant Houston-The Woodlands-Sugarland Metropolitan Statistical Area (MSA) resident women in 2014 using Texas birth certificate records. The hypothesis is that higher OBGYN geographic access compared to lower OBGYN access as measured by F2SCA statistics will be associated with lower odds of inadequate and excess GWG. A hypothesized gradient in the odds of inadequate and excess GWG is expected from the lowest odds in central metropolitan county Census tracts to the highest in fringe metropolitan county tracts, consistent with improved population to provider access in central metropolitan counties (18) and the association between rurality and increased odds of inadequate GWG (13). This research is expected to broaden the growing body of literature on place-based and spatial geographic risk factors for GWG.

METHODS

Study Design and Participants

A secondary data analysis was conducted of live birth registry data collected by the Texas Department of State Health Services (DSHS). Study subjects were Houston-The Woodlands-Sugarland MSA residents in the central county of Harris County and the fringe counties of Austin, Chambers, Fort Bend, Montgomery, Brazoria, Galveston, Liberty, and Waller Counties (19) with a full-term, singleton (37) live birth in the between January 1, 2014 and December 31, 2014.

Data Sources

Birth certificate databases maintained by the Texas DSHS contained information on all Houston-The Woodlands-Sugarland MSA residents with a live birth in 2014 (38). Researchers at the Texas DSHS extracted a subset of the finalized 2014 birth certificate administrative records to create a dataset of 93,843 singleton births by Texas residents in Texas with an exact geocoded addresses. Mothers were included in the study if they had complete information on mother's geocoded address, maternal delivery and maternal prepregnancy weight, and maternal height on the birth certificate. Exact geocoded addresses were necessary to calculate accurate distances between maternal residence and OBGYN providers. A final dataset was created by excluding all mothers with a preterm live birth delivery of less than 37 weeks and records with missing information on any covariates. Restricting the analysis to only mothers with full-term delivery controlled for differences in GWG caused by differences in gestational age. Licensure records maintained by Texas DSHS Health Professions Resource Center (HPRC) contain information on all licensed health care providers in Texas (18). HPRC provided an extract of the licensure data with workplace location information on all 2,318 direct patient care providers with a primary specialty of obstetrics and/or gynecology who were active in Texas in September 2014 (39). A final dataset of 2,214 providers was created after excluding 104 workplace locations without an exact geocoded address.

Measures

Outcome of Interest

The outcome of interest, the three-level categorical variable of inadequate, adequate, and excess GWG was estimated as follows. GWG was calculated as maternal delivery weight minus prepregnancy maternal weight. Following IOM recommendations using the Body Mass Index classification (BMI) (40) underweight BMI (<18.5) pregnant women are recommended to gain 28-40 total lbs., normal BMI (18.5-24.9) women are recommended to gain 25-35 lbs., overweight BMI (25.0-29.9) women are recommended to gain 15-25 lbs., and obese BMI (>=30.0) women are recommended to gain 11-20 lbs (41). GWG less than IOM recommendations was classified as inadequate, GWG within recommendations were classified as adequate, and GWG in excess of IOM recommendations were classified as excess GWG.

Main Exposure Variable

The exposure variable of interest, potential maternal geographic access to OBGYN providers as measured by the F2SCA statistic (x_1) was calculated in R (42) with the distMeeus function in the geosphere package (43) as follows. In the first step, the number of OBGYN providers (*S*) at provider location (*j*) are divided by the number of maternal residences (*P*) at locations (*k*) within a distance (*d*) of 15 linear miles (d_0) from each provider location to calculate the provider-to-delivery statistic (*R*):

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \leq d_0\}} P_k} \tag{1}$$

In the second step, all provider-to-delivery statistics (*R*) at locations (*j*) within a distance (*d*) of 15 linear miles (d_0) of each maternal residence location k (35) are summed to calculate the F2SCA accessibility statistic (A^F):

$$A_k^F = (1000) \sum_{j \in \{d_{kj} \leq d_0\}} R_j \tag{2}$$

The F2SCA statistic was evaluated analyzed as a continuous variable and was scaled by 1,000 to ease interpretation. F2SCA statistics were interpolated with inverse distance weighting and mapped with OBGYN provider locations to show variation in geographic access across the MSA.

Individual-Level Covariates

Maternal socioeconomic status was assessed from self-reported variables from the birth certificate. Maternal race was classified as Non-Hispanic (NH) Anglo, Hispanic (x_2), NH Black (x_3), and NH Other (x_4). Maternal educational attainment was classified as no high school degree (x_5), high school degree or equivalency (x_6), some college (x_7), and bachelor's degree or higher. Maternal country of birth was classified as birth in the United States (US) or not in the US (x_8). Expected payor source was classified as having Medicaid (x_9) or non-Medicaid paid birth. Maternal marital status was classified as married or not married (x_{10}).

Maternal health or health behavior risk factors were assessed from self-reported variables from the birth certificate. Maternal age (x_{11}) was assessed as a continuous variable. Maternal smoking status was classified as any reported cigarette usage during pregnancy (x_{12}) or none. Because the prevalence of type 1 or 2 diabetes was less than 2%, diabetes types were aggregated and any diabetes was classified as yes (x_{13}) or no for any reported gestational or type 1 or 2 diabetes. Pregnancy parity was categorized as no prior deliveries (x_{14}) or one or more prior deliveries. Maternal prepregnancy weight was assessed from birth certificate derived variables of self-reported maternal prepregnancy weight and maternal delivery height and categorized as underweight BMI (<18.5) (x_{15}), normal BMI (18.5-24.9), overweight BMI (25.0-29.9) (x_{16}), and obese BMI (>=30.0) (x_{17}) (40).

Pregnancy health care utilization was assessed from self-reported variables from the birth certificate. The number of prenatal visits (x_{18}) was assessed as a continuous variable. Prenatal care initiation in the first trimester was categorized yes or no (x_{19}) for having the first prenatal visit in pregnancy months one, two, or three. The adequacy of prenatal care utilization index (Kotelchuck index) (44) was calculated from the variables for prenatal care initiation month and the number of prenatal visits. The Kotelchuck index is the ratio of realized prenatal visits compared to the number of expected prenatal visits given the month of prenatal care initiation. The expected number of prenatal visits was provided by the creators of the Kotelchuck index. A ratio value less than 0.5 was categorized as inadequate (x_{20}), a ratio between 0.5 and 0.79 was categorized as intermediate (x_{21}), a ratio value greater than or equal to 0.8 was categorized as adequate or adequate plus. Geocoded maternal residence was assessed from self-reported maternal address from the birth certificate. Texas DSHS provided geocoded maternal residence.

Tract-Level Covariates

Census American Community Survey Five-Year Estimates for 2010-2014 provided tract-level socioeconomic characteristics of maternal residences. The 2010-2014 5-year estimates were collected between January 1, 2010 and December 31, 2014 (45). These estimates represented the average statistics for each area within the time period. Socioeconomic tract characteristics of annual median personal income (t_1), percent of the population at 100% of the federal poverty level (FPL) (t_2), and the percent of the population with any health insurance (t_3) were used as a proxy for possible neighborhood economic effects.

Statistical Analysis

Demographic characteristics of subjects included and excluded from the analytics dataset were compared in order to assess the validity of results since 14.1% of subjects were excluded from the analytics dataset due to missing information or preterm delivery. Chi-square tests for categorical variables and ANOVA tests for continuous variables were used to assess the statistical significance of differences between included and excluded subjects with p-values adjusted using Bonferroni correction.

Summary statistics of mean and standard deviation were calculated for the individual-level continuous variables of F2SCA statistic, maternal age, and the number of prenatal visits. The individual-level categorical variables of GWG, maternal prepregnancy weight, maternal race, parity, maternal country of birth, smoking, any maternal diabetes, marital status, prenatal care utilization index, prenatal care initiated in the first trimester, maternal education, and expected payor source were presented as counts and percent. The tract-level continuous variables of annual median personal income, the percent of individuals less than 100% of FPL, and the percent of individuals with health insurance are presented in maps. Statistical tests were conducted using a type 1 error level of 0.05.

Four Bayesian multinomial additive regression models with random intercepts were used to assess the association between geographic access to OBGYN providers and GWG. The independent variable of F2SCA statistic was included as a continuous variable in the regression models. Known individual level risk factors that are associated with GWG outside of recommendations that were included in the models were maternal race, maternal age, parity, maternal educational attainment (46), maternal prepregnancy weight (1,5,9–11), prenatal care utilization (1,47), maternal country of birth (7), maternal smoking (9), diabetes (48), and marital status (10). Categorical variables were coded using dummy coding as effect coding did not improve convergence in studied models.

Models included tract-level random effects to account for clustering.

$$\pi_{ij} = \frac{e^{n_{ij}}}{\sum_{k=1}^{J} e^{n_{ik}}} \tag{3}$$

Model 1 included individual-level covariates and a random intercept ($f_{unstr}(tract)$). Model 1 is equation (3) where:

$$\eta_{ij} = \beta_{0j} + \sum_{i=1}^{21} \beta_i x_i + f_{unstr}(tract) \tag{4}$$

Model 2 included individual-level and cluster-level covariates measured at the Census tract-level and a random intercept. Model 2 is equation (3) where:

$$\eta_{ij} = \beta_{0j} + \sum_{i=1}^{21} \beta_i x_i + \sum_{i=1}^{3} \beta_i t_i + f_{unstr}(tract) \tag{5}$$

Cluster-level covariates were Census tract annual median personal income, percent of the Census tract with income less than 100% of the federal poverty level, and Census tract median housing value. Models 3 and 4 were similar to Models 1 and 2 respectively, but incorporated spatial effects to account for possible spatial autocorrelation. Model 3 included individual-level covariates, a random intercept, and structured ($f_{str}(tract)$) random spatial effects at the tract-level. Model 3 is equation (3) where:

$$\eta_{ij} = \beta_{0j} + \sum_{i=1}^{21} \beta_i x_i + f_{unstr}(tract) + f_{str}(tract) \tag{6}$$

Model 4 included individual-level covariates, cluster-level covariates, a random intercept, and a structured random spatial effect for all individuals (*i*) within tracts (*j*). Model 4 is equation (3) where:

$$\eta_{ij} = \beta_{0j} + \sum_{i=1}^{21} \beta_i x_i + \sum_{i=1}^{3} \beta_i t_i + f_{unstr}(tract) + f_{str}(tract) \tag{7}$$

Spatial effects were modelled by averaging the effect of neighboring Census tracts defined in an adjacency matrix using rook's case adjacency. The prior for the spatial effect was an intrinsic conditional autoregression (iCAR) model (49). The hyperparameters for the random effect terms were vague default priors of 0.001 (50). A Markov Chain Monte Carlo algorithm implemented by BayesX (50) was used to calculate all model parameters. Convergence of MCMC chains was determined by visualizing the drawn samples for each model parameter. Autocorrelation in samples was determined from autocorrelation plots. The final model was determined by calculating the Deviance Information Criterion (DIC) for each of the four models and selecting the model with the lowest DIC value.

The model with the lowest DIC measure produced point posterior estimates which were exponentiated and presented as mean adjusted odds ratios, standard deviations, and 95% credible intervals Posterior estimates of the adjusted odds of inadequate GWG compared to adequate GWG and excess GWG compared to adequate GWG were categorized using Jenks natural breaks (51) and presented as maps. Plots of posterior estimates of the structured and unstructured spatial effects were not presented as the results were similar to maps of posterior estimate adjusted odds ratios.

RESULTS

There were 93,483 Texas residents with a singleton live birth deliveries between January 1, 2014 and December 31, 2014 in the Houston-The Woodlands-Sugarland MSA. As shown in Figure 1, a total of 1,223 mothers with deliveries were excluded from the analytics dataset due to missing information on recommended GWG and inexact geocoded address information. An additional 13,038 mothers with deliveries were excluded from the analysis due to missing information in any covariate or having a gestational length less than 37 weeks. The final analytics dataset included 79,222 resident deliveries. Comparisons in Table 1 between those included and excluded from the analytics dataset indicated statistically significant differences for most delivery characteristics. Deliveries excluded from the analytics dataset had a lower mean floating two-step catchment area indicating lower average potential geographic access to OBGYN providers compared to those included in the analytics dataset, higher prevalence of smoking, lower prevalence of a bachelor's degree or higher, fewer prenatal visits, lower prevalence of marriage, higher diabetes, higher expected utilization of Medicaid, and more inadequate GWG. The analytics data set also included a higher proportion of deliveries to Non-Hispanic Anglo women and a lower proportion of deliveries to Non-Hispanic Black women in the final analytics data set compared to those excluded. More than one-third of those excluded from the analytics dataset had missing information that prevented the determination of prenatal care utilization index values.

Approximately one-third (32.6%) of the mothers had GWG within IOM recommendations, one-fifth (21.1%) had GWG below recommendations, and 45.2% had excess GWG. Less than half (46.0%) of the mothers had a normal BMI while more than half were either overweight (26.9%) or obese (23.2%). The study population had few (3.9%) underweight mothers. Mothers was predominantly Hispanic (43.9%) followed by Non-Hispanic Anglo (30.8%), Non-Hispanic Black (15.5%), and Non-Hispanic Other (9.8%). The mean age of the mothers was 28.15 years (SD 5.9). Almost two-thirds (60.9%) of the mothers had a prior birth. Mothers were predominantly (63.6%) born in the US. Most

(97.9%) mothers reported no smoking during their pregnancy. Nearly three out of five women (59.8%) in the study reported prenatal care in the first trimester. Mothers reported an average of 10.17 prenatal visits (SD 3.9). More than half of the mothers had some college (27.0%) or higher (29.2%) with the remainder split between no high school diploma (21.8%) and a high school diploma (22.0%). More than one-half (54.5%) of the mothers did not expect Medicaid to pay the birth delivery costs.

Distribution of the F2SCA Statistic

Mean F2SCA statistic for the MSA was 7.26 (SD 2.92), which indicates that on average, there were 7.26 providers within 15 miles for every 1,000 mothers with a delivery. As shown in Table 2, OBGYN potential geographic access was generally higher for women of low socioeconomic status as the mean F2SCA statistic was highest for mothers with no high school degree, mothers not born in the US, not married mothers, mothers less than 20 years of age, mothers with diabetes, and in Census tracts with low median personal income, higher levels of poverty, and with lower rates of health insurance.

As shown in Figure 2, OBGYN providers were primary located in central county Harris County. The F2SCA statistic was highest in Harris County, indicating the highest OBGYN potential geographic access in the metropolitan area. Moderate geographic access was noted in fringe metropolitan counties along the Gulf of Mexico, and north of Harris County. Lowest access, as indicated by dark blue and black colors, was located in the northwest, far north, and northeast portions of the metropolitan area.

Distribution of Tract-Level Covariates

Socioeconomic tract-level covariates exhibited some similar spatial patterns as evident in Figures 3a, 3b, and 3c. The percent of the population with health insurance by tract varied from 35.6 to 100%. Utilization of health insurance was lowest in north, east and southwest Harris County with highest utilization seen in the western portion of the county center and the periphery inside Harris County. The percent of the population less than the federal poverty level at the tract level varied from zero to 67 percent and was highest in north, east, and southwest portions of Harris County. Tract annual median personal annual income varied from $2,760 to $97,380. The highest annual median personal annual income was observed in the western portion of Harris County and along the periphery of Harris County. Lowest annual median personal annual income was observed in the central, southwest, and northeast portions of Harris County.

Association of F2SCA Statistic and GWG

Model 4 had the lowest DIC value of 159,535.16. Models 1, 2, and 3 had DIC values of 159,644.68, 159,626.86, and 159,538.85, respectively. Results are presented for model 4 in Table 3. Regression estimates for all models are available in Appendix B. After controlling for all mother's characteristics of prepregnancy weight, race, age, parity, maternal country of birth, smoking, diabetes, prenatal care utilization index, initiation of prenatal care in the first trimester, number of prenatal visits, educational attainment, expected payor source and tract-level characteristics of median personal income, income less than 100% of FPL, and percent of the tract with health insurance, the odds of inadequate GWG compared to adequate GWG given a one unit increase in the F2SCA statistic was 1.01 with a 95% credible interval of 0.997 to 1.02 indicating that OBGYN geographic access was not associated with any increase in the odds of inadequate GWG compared to adequate GWG. The adjusted odds of excess GWG compared to adequate GWG for a one unit increase in the F2SCA statistic was 0.99 with a credible interval of 0.85 to 1.16 indicating that OBGYN geographic access was not associated with any increase in the odds of excess GWG compared to adequate GWG. There was a 95% probability that increased geographic potential access to OBGYN providers had no reduction in the odds of inadequate or excess GWG compared to adequate GWG.

Covariates

Model 4 results indicate that a variety of medical and socioeconomic factors were associated with inadequate GWG compared to adequate GWG. No tract-level covariates were associated with any meaningful association with inadequate or excess GWG compared to adequate GWG. Factors inversely associated with the odds of inadequate GWG, an indication of a protective association, included prepregnancy overweight BMI (OR 0.65), obesity (OR 0.93), no prior births (OR 0.89), and an increasing number of prenatal visits (OR 0.96). Factors associated with increasing the odds of inadequate GWG included Hispanic maternal ethnicity (OR 1.08), Non-Hispanic Black ethnicity (OR 1.20), Non-Hispanic Other ethnicity (OR 1.1), any diabetes (1.31), mother not married (OR 1.07), no prenatal care in the first trimester (OR 1.07), no high school degree (OR 1.14), a high school degree (OR 1.12), and an expected Medicaid paid birth (OR 1.09).

Factors that were inversely associated with excess GWG compared to adequate GWG and had a credible interval that did not include 1 were underweight prepregnancy weight (OR

0.54), Hispanic ethnicity (OR 0.79), Non-Hispanic Other ethnicity (OR 0.76), a one year increase in maternal age (OR 0.99), maternal birth not in the US (OR 0.80), any diabetes (OR 0.84), no prenatal care in the first trimester (OR 0.95), and no high school degree (OR 0.94). Factors associated with increasing the odds of excess GWG included overweight BMI (OR 2.35), obesity (OR 2.41), no prior births (OR 1.32), smoking during pregnancy (OR 1.22), mother not married (OR 1.12), an increasing number of prenatal visits (OR 1.01), and some college (OR 1.13).

Spatial Effects of GWG

The posterior probabilities of inadequate and excess GWG compared to adequate GWG by tract are shown in Figures 4a and 4b. The odds of excess GWG compared to adequate GWG varied from 0.67 to 0.74 in the central core tracts of Harris County and along the Gulf of Mexico to 0.98 to 1.10 along the northern Harris County border and north of the central county. The odds of inadequate GWG compared to adequate GWG varied from 0.56 to 0.60 in the north and west of Harris County to 0.72 to 0.76 in tracts in central Harris County.

DISCUSSION

This is one of the first studies to examine the association between potential geographic access to OBGYN providers and pregnancy outcomes. This research was based on a population from what is known to be “the most diverse city in America” (52). The more than 75,000 births used in the analysis represent 2.0% of the births in the United States (53) and 19.8% of the births in Texas in 2014 (38).

While it is plausible that increased geographic potential access to OBGYN providers may lead to improved pregnancy outcomes, relative to those with lower access as evident by prior research on PCP utilization (26,27) and OBGYN utilization among Australian women (54), this research demonstrated that higher potential geographic access to OBGYN providers was not associated with inadequate or excess GWG compared to lower potential access. Moreover, the odds ratios were virtually equal to one. Accordingly, any increase in the size of the analytics dataset is unlikely to render the relationship clinically meaningful. Some prior research has shown that geographic access is associated with pregnancy outcomes like NICU utilization (28) and fetal monitoring (54); however, these studies compared individuals that drove an hour or longer to obtain pregnancy care. It is possible that OBGYN potential access is associated with GWG, but that the 15 mile access standard in this study was too small or that access within the Houston-The Woodlands-Sugarland MSA is not sufficiently inadequate to detect any GWG differences.

Consistent with prior research, most covariates were weakly associated with GWG (14). The largest associations among studied covariates and inadequate GWG were overweight maternal BMI, inadequate prenatal care, parity, and diabetes. The largest associations with excess GWG were maternal birth not in the US and underweight, overweight, and obese BMI. Prior studies have found similar protective associations between excess GWG, maternal birth not in the US (55), and prenatal care (7). This research demonstrates that there are few “smoking gun” solutions to the problem of GWG. Parity is not a modifiable behavior that can be addressed with public health interventions and advantages of maternal country of birth may come from selective immigration among healthy mothers (53). Aside from reducing inadequate prenatal care, the most substantive improvement to reducing the odds of inadequate or excess GWG may come from promoting healthy weight behaviors prior to pregnancy.

DIC values indicated preference for the spatial adjacency model with tract level covariates over all other studied models; however, tract level covariates did not demonstrate any association with inadequate or excess GWG. The largest association among tract-level covariates was the percent of the population in poverty, indicating that increasing poverty may be associated with increasing in the odds of inadequate GWG and reducing in the odds of excess GWG, consistent with prior research (56). This research indicated that incorporating spatial adjacency may improve the modelling of pregnancy health outcomes, but is unable to demonstrate any meaningful spatial associations with GWG.

Maps of the posterior probabilities of inadequate and excess GWG showed that tract-level probabilities of inadequate or excess GWG were contradictory such that a more protective tract for excess GWG was generally less protective of inadequate GWG. Figure 4a shows that the most protective tracts for excess GWG were central Harris County tracts. A ring of less protective tracts surrounded the central tracts and extended to the north of Harris County. Tracts become more protective of excess GWG along the periphery of the MSA. Tract-level associations with inadequate GWG display a similar, but opposite pattern. A comparison of Figures 3b and 4b show that it is plausible that tract-level socioeconomic status may be inversely associated with odds of excess GWG as annual median personal income was highest in central core tracts and declined along the periphery of Harris County; however, model results show that annual median personal income was not associated with inadequate or excess GWG.

Like all studies, the current study has both strengths and limitations. While the analytics data set included a diverse maternal population, the research only utilizes Texas residents from the Houston-The Woodlands-Sugarland MSA and may not be generalizable outside of the area. Exclusion criteria and variable missingness resulted in the removal of more than 14% of the possible study population from the analytics dataset, an indication that the analytics dataset may not be representative of the MSA population. Mothers in the analytics dataset had higher socioeconomic status and fewer riskier pregnancy conditions as evidenced by their lower prevalence of diabetes, smoking, and obesity compared to mothers excluded from the analysis, conditions that may have reduced the possibility of poor pregnancy outcomes including GWG outside recommendations. Tests indicated statistically significant variation in maternal characteristics, but the tests may have been overpowered and detected clinically meaningless differences. Additionally, the study population did not include pregnancies with a preterm or multiparous birth, pregnancies that may exacerbate the need for OBGYN provider access.

Birth certificate and OBGYN licensure data utilized in this research could not identify mothers with high-risk pregnancies or OBGYN providers for high-risk pregnancies. The distribution of high-risk OBGYN providers is not expected to be uniformly distributed throughout the study area. Consequently, mothers with a high-risk pregnancy may have been unable to utilize their nearby OBGYN providers and the measured F2SCA may have overestimated their true potential geographic access. Additionally, mothers with high-risk pregnancies may have complications that could alter their risk profile for adverse pregnancy outcomes and potentially increase their risk for inadequate or excess GWG. It is unknown how this population may have influenced model results.

Distance was calculated using straight line distance due to computation limitations. The relationship between time traveled and distance is not likely to be consistent throughout a day or between urban and rural environments. Future research may utilize road network measurements to improve F2SCA measures, but the results presented in this research utilized a large study population and improvements are unlikely to change the overall research findings unless changes are substantial.

This research indicates that geographic access to OBGYN providers did not have any meaningful association with improving GWG outcomes, but maps displayed varying associations between access and GWG across the Houston-The Woodlands-Sugarland MSA. BMI had the strongest associations with GWG and indicated that improving prepregnancy weight may be the best opportunity for public health interventions to reduce inadequate or excess GWG. Future researchers may want to consider the use of spatial regression models when investigating pregnancy outcomes as they were preferable at modelling GWG compared to non-spatial models, but researchers may find weak spatial relationships that may not substantially alter study conclusions.

OTHER INFORMATION

This work was produced with data from the Texas Department of State Health Services, but does not necessarily indicate endorsement of the results. Conflict of interest: none declared.

Human Subjects

Study consent was not obtained as individuals were not personally contacted, but the Texas Department of State Health Services Institutional Review Board and the UTHSC Committee for Protection of Human Subjects reviewed the proposed analysis plan to ensure subject protection and adherence to HIPAA regulations.

TABLES

Table 1: Social and Demographic Characteristics of Texas Women with a Live Birth by Gestational Weight Gain Category, 2014

Variable	Mothers Used in Analysis (n=79,222)		Mothers Excluded from Analysis (n=13,038)		
	n	**Mean (SD); (%)**	**n**	**Mean (SD); (%)**	
Gestational weight gain					
Inadequate	17,535	21.1%	3,776	29.0%	*
Adequate	25,852	32.6%	4,122	31.6%	
Excess	35,835	45.2%	5,140	39.4%	
Missing			0		
F2SCA OBGYN statistic	79,222	7.26 (2.92)	13,038	6.71 (2.42)	*
Missing			0		
Maternal race					
NH Anglo	24,410	30.8%	3,192	24.5%	*
Hispanic	34,813	43.9%	5,768	44.2%	
NH Black	12,270	15.5%	3,014	23.1%	
NH Other	7,729	9.8%	1,064	8.2%	
Missing			0		
Maternal educational attainment					
No high school degree	17,302	21.8%	3,362	26.1%	*
High school degree	17,396	22.0%	3,142	24.3%	
Some college	21,423	27.0%	3,427	26.6%	
Bachelor’s degree or higher	23,101	29.2%	2,973	23.0%	
Missing			134		
Maternal country of birth					
Birth in the US	50,372	63.6%	8,598	66.1%	*
Birth not in the US	28,850	36.4%	4,410	33.9%	
Missing			30		
Expected payor source					
Medicaid	36,065	45.5%	6,557	51.2%	*
Non-Medicaid	43,157	54.5%	6,240	48.8%	
Missing			241		
Marital status					
Married	47,394	59.8%	6,836	52.5%	*
Not married	31,828	40.2%	6,188	47.5%	
Misssing			14		
Maternal age	79,222	28.15 (5.94)	13,034	28.14 (6.29)	
Missing			4		
Maternal smoking status					
Any smoking during pregnancy	1,634	2.1%	338	2.6%	*

None	77,588	97.9%	12,698	97.4%	
Missing			2		
Any diabetes					
Yes	4,473	5.6%	1,099	8.4%	*
No	74,749	94.4%	11,939	91.6%	
Missing			0		
Parity					
0 Prior births	30,974	39.1%	4,899	37.8%	
1+ Prior births	48,248	60.9%	8,071	62.2%	
Missing			68		
Maternal prepregnancy weight					
Underweight BMI	3,121	3.9%	489	3.8%	*
Normal BMI	36,413	46.0%	5,636	43.2%	
Overweight BMI	21,301	26.9%	3,468	26.6%	
Obese BMI	18,387	23.2%	3,445	26.4%	
Missing			0		
Number of prenatal visits	79,222	10.17 (3.90)	11,619	9.3 (4.5)	*
Missing			1,419		
Prenatal care initiated in the first trimester					
Yes	47,347	59.8%	4,435	52.9%	*
No	31,875	40.2%	3,949	47.1%	
Missing			4,654		
Prenatal care utilization index					
Inadequate	13,991	17.7%	1,465	19.5%	*
Intermediate	39,459	49.8%	2,280	30.3%	
Adequate or adequate plus	25,772	32.5%	3,787	50.3%	
Missing			5,506		

Abbreviations: SD, standard deviation

* Indicates a statistically significant difference between included and excluded observations used in the analysis.

Table 2: Floating Two-Step Catchment Area Statistic by Maternal Characteristics of Texas Women with a Live Birth by Gestational Weight Gain Category, 2014

Variable	**Floating Two Step Catchment Area** (n=79,222)	
	Mean	**Standard Deviation**
Gestational weight gain		
Inadequate	7.58	2.87
Adequate	7.33	2.89
Excess	7.04	2.94
Maternal race		
NH Anglo	6.14	2.94
Hispanic	7.74	2.83
NH Black	7.86	2.66
NH Other	7.62	2.65
Maternal educational attainment		
No high school degree	8.06	2.78
High school degree	7.2	3.02
Some college	6.83	2.93
Bachelor's degree or higher	7.09	2.81
Maternal country of birth		
Birth in the US	6.87	2.95
Birth not in the US	7.93	2.72
Expected payor source		
Medicaid	7.45	2.96
Non-Medicaid	7.1	2.87
Marital status		
Married	7.04	2.91
Not married	7.58	2.9
Maternal age		
<20 Years	7.47	2.99
20-29 Years	7.23	2.96
30-39 Years	7.24	2.85
40+ Years	7.44	2.82
Maternal smoking status		
Any smoking during pregnancy	5.56	2.99
None	7.29	2.9
Any diabetes		
Yes	7.65	2.79
No	7.23	2.92
Parity		
0 Prior births	7.26	2.89
1+ Prior births	7.26	2.93

Maternal prepregnancy weight		
Underweight BMI	7.27	2.93
Normal BMI	7.23	2.91
Overweight BMI	7.34	2.9
Obese BMI	7.22	2.94
Number of prenatal visits		
<10 Visits	7.48	2.95
10-19 Visits	7.13	2.89
20+ Visits	7.35	2.79
Prenatal care initiated in the first trimester		
Yes	7.15	2.89
No	7.42	2.94
Prenatal care utilization index		
Inadequate	7.5	2.93
Intermediate	7.28	2.94
Adequate or adequate plus	7.08	2.86
Tract-level annual median personal income		
<$20,000	8.88	2.11
$20,000-$39,000	6.87	3.06
$40,000+	6.7	2.68
Tract-level income less than 100% of FPL (%)		
<5%	6.26	2.52
5-14%	6.59	2.81
15-24%	7.04	3.23
25%+	8.9	2.2
Tract-level with health insurance (%)		
<60%	9.43	1.68
60-79%	7.45	3.01
80-89%	6.44	2.7
90%+	6.27	2.68

Table 3: Adjusted Odds Ratios and 95% Credible Intervals of Inadequate or Excess GWG by Social and Demographic Characteristics for Texas Women with a Live Birth, 2014

Variable	**Inadequate**		**Excess**	
	OR	**95% CI**	**OR**	**95% CI**
Intercept	0.65	0.47, 0.88	1.17	1.12, 1.23
F2SCA OBGYN statistic	1.01	0.99, 1.02	0.99	0.85, 1.16
Maternal race				
NH Anglo (ref)				
Hispanic	1.08	1.01, 1.15	0.79	0.75, 0.83
NH Black	1.2	1.12, 1.29	1.01	0.96, 1.07
NH Other	1.1	1.02, 1.19	0.76	0.71, 0.82
Maternal educational attainment				
No high school degree	1.14	1.06, 1.22	0.94	0.88, 0.99
High school degree	1.14	1.06, 1.23	1.05	0.99, 1.12
Some college	1.04	0.97, 1.10	1.13	1.07, 1.19
Bachelor's degree or higher (ref)				
Maternal country of birth				
Birth in the US (ref)				
Birth not in the US	0.88	0.68, 1.15	0.80	0.76, 0.83
Expected payor source				
Medicaid	1.09	1.05, 1.15	1.0	0.96, 1.04
Non-Medicaid (ref)				
Marital status				
Married (ref)				
Not married	1.07	1.02, 1.12	1.12	1.08, 1.16
Maternal age	0.99	0.99, 1.0	0.99	0.99, 0.99
Maternal smoking status				
Any smoking during pregnancy	0.99	0.98, 1.0	1.22	1.08, 1.38
None (ref)				
Any diabetes				
Yes	1.31	1.20, 1.41	0.84	0.78, 0.91
No (ref)				
Parity				
0 Prior births	0.89	0.85, 0.93	1.32	1.27, 1.37
1+ Prior births (ref)				
Maternal prepregnancy weight				
Underweight BMI	1.02	0.93, 1.11	0.55	0.5, 0.61
Normal BMI (ref)				
Overweight BMI	0.65	0.61, 0.68	2.35	2.25, 2.45
Obese BMI	0.93	0.88, 0.98	2.41	2.3, 2.52
Number of prenatal visits	0.99	0.98, 0.99	1.01	1.01, 1.02

Prenatal care initiated in the first trimester				
Yes (ref)				
No	1.07	1.02, 1.13	0.95	0.91, 0.99
Prenatal care utilization index				
Inadequate	1.25	1.13, 1.39	1.06	0.96, 1.16
Intermediate	0.96	0.90, 1.02	1.02	0.98, 1.07
Adequate or adequate plus (ref)				
Tract-level covariates:				
Annual median personal income	1.0	0.99,1.0	0.99	0.99,1.0
Income less than 100% of FPL (%)	1.3	0.99, 1.71	0.93	0.74, 1.27
With health insurance (%)	0.94	0.68, 1.27	1.29	0.97, 1.71

Abbreviations: OR, Odds Ratio; CI, credible interval

Figure 1: Flow chart for the final analytics dataset selection process

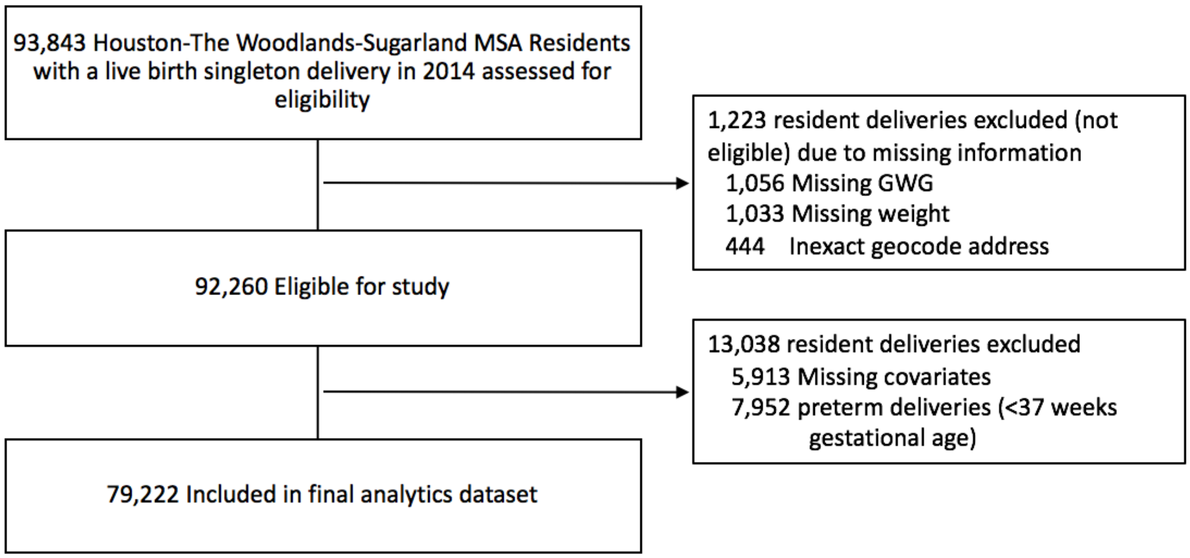


Figure 2: Distribution of F2SCA and OBGYN Providers in the Houston-The Woodlands-Sugarland MSA, 2014

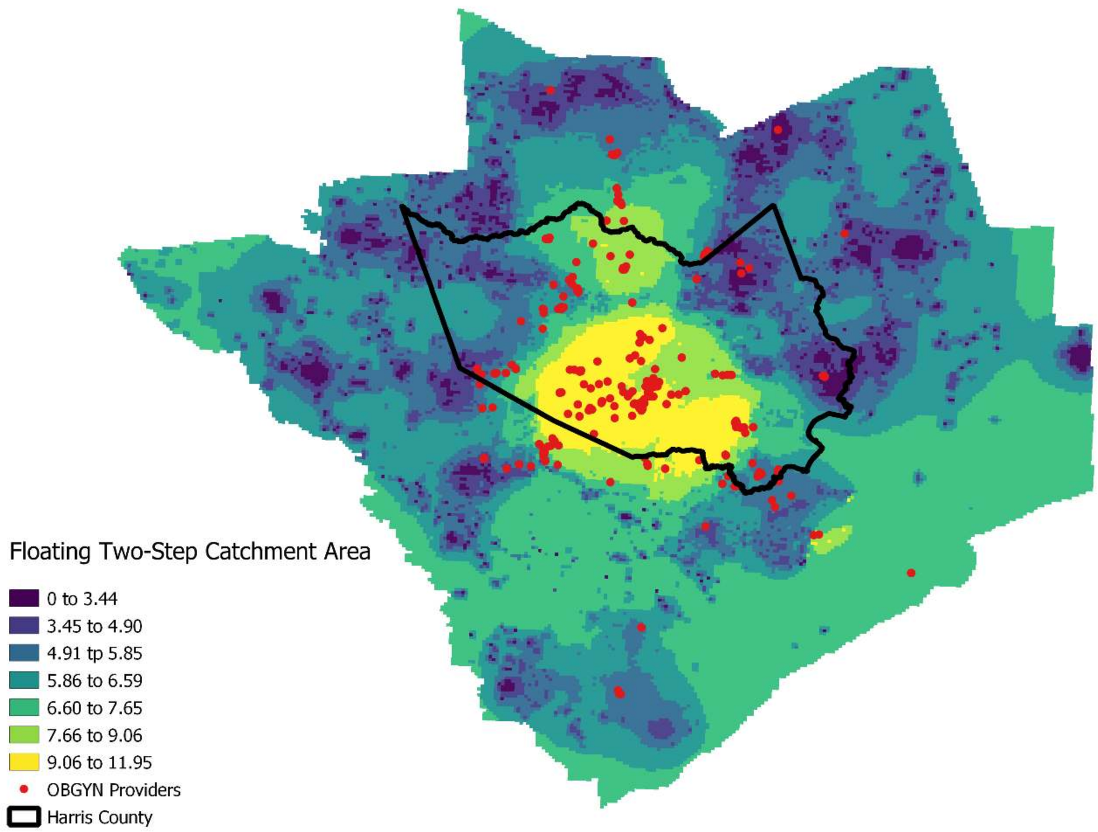


Figure 3a: Distribution of the Percent of Residents with Healthcare Insurance in the Houston-The Woodlands-Sugarland MSA by Census Tract, 2014

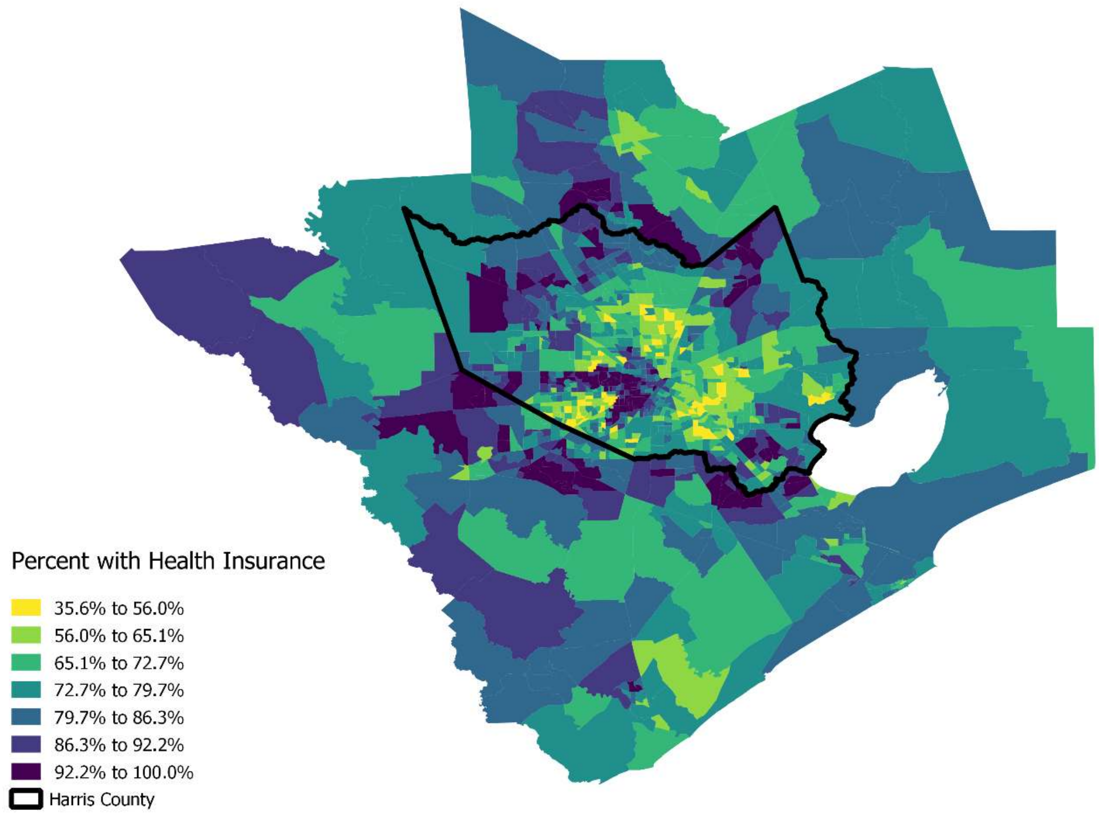


Figure 3b: Distribution of Resident Annual Median Personal Income in the Houston-The Woodlands-Sugarland MSA by Census Tract, 2014

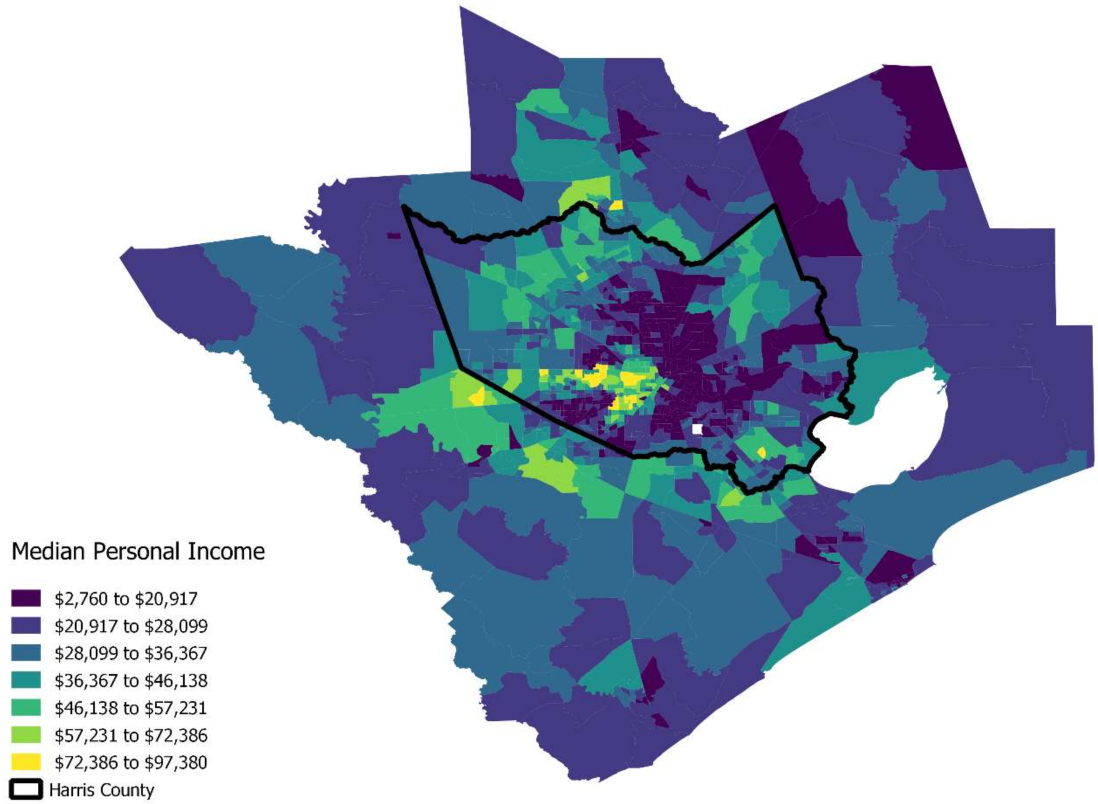


Figure 3c: Distribution of the Percent of Residents with Income Less than 100% of the Federal Poverty Level in the Houston-The Woodlands-Sugarland MSA by Census Tract, 2014

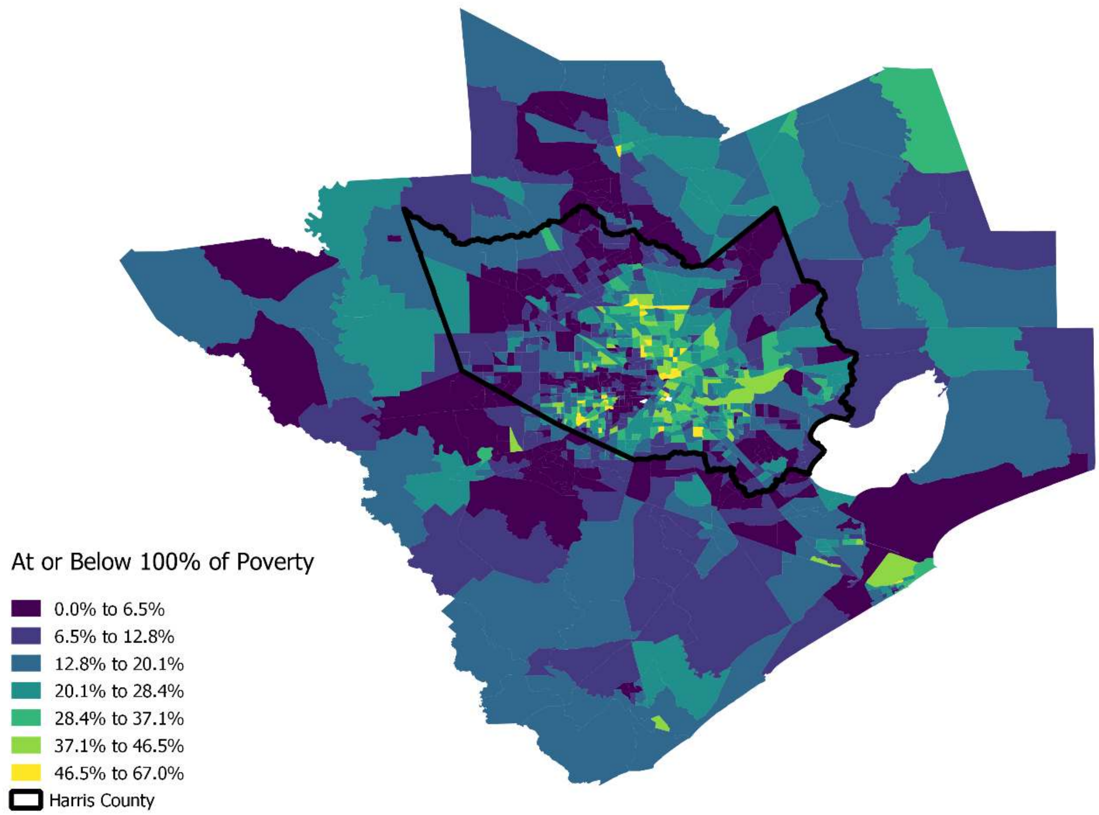


Figure 4a: Posterior Probability of the Odds of the Association Between Increased Potential Geographic Access to OBGYN Providers and Inadequate GWG Compared to Adequate GWG, 2014

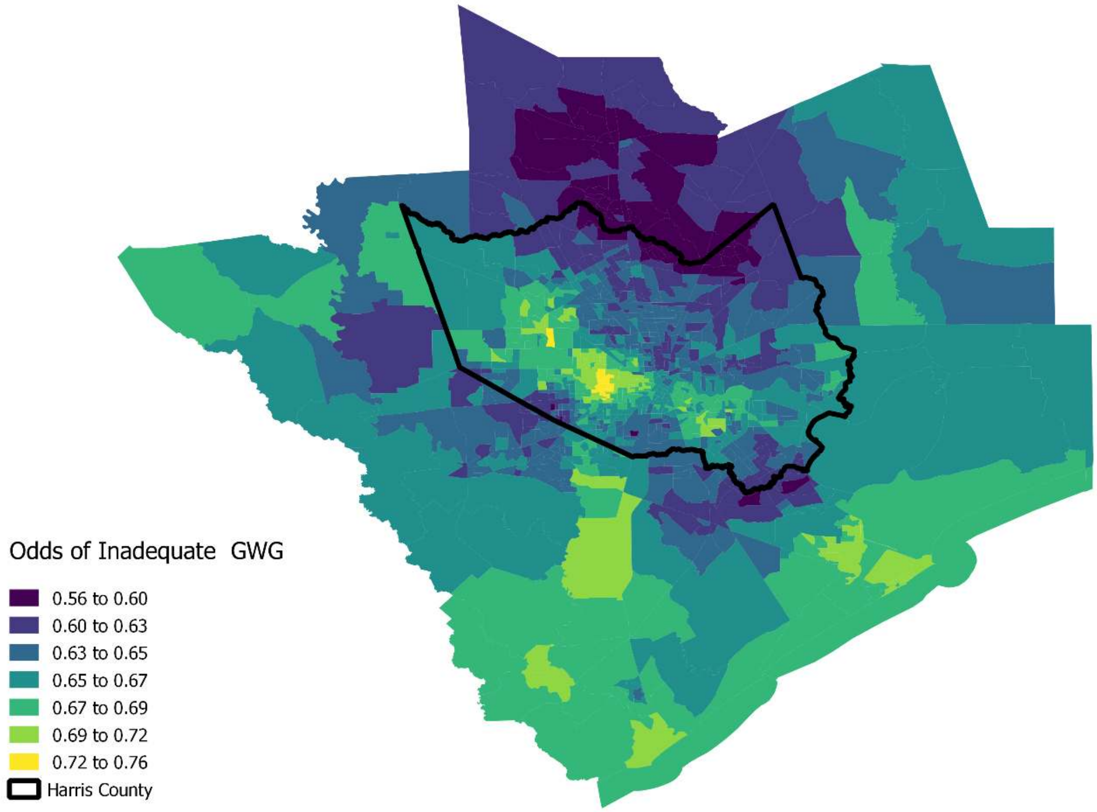
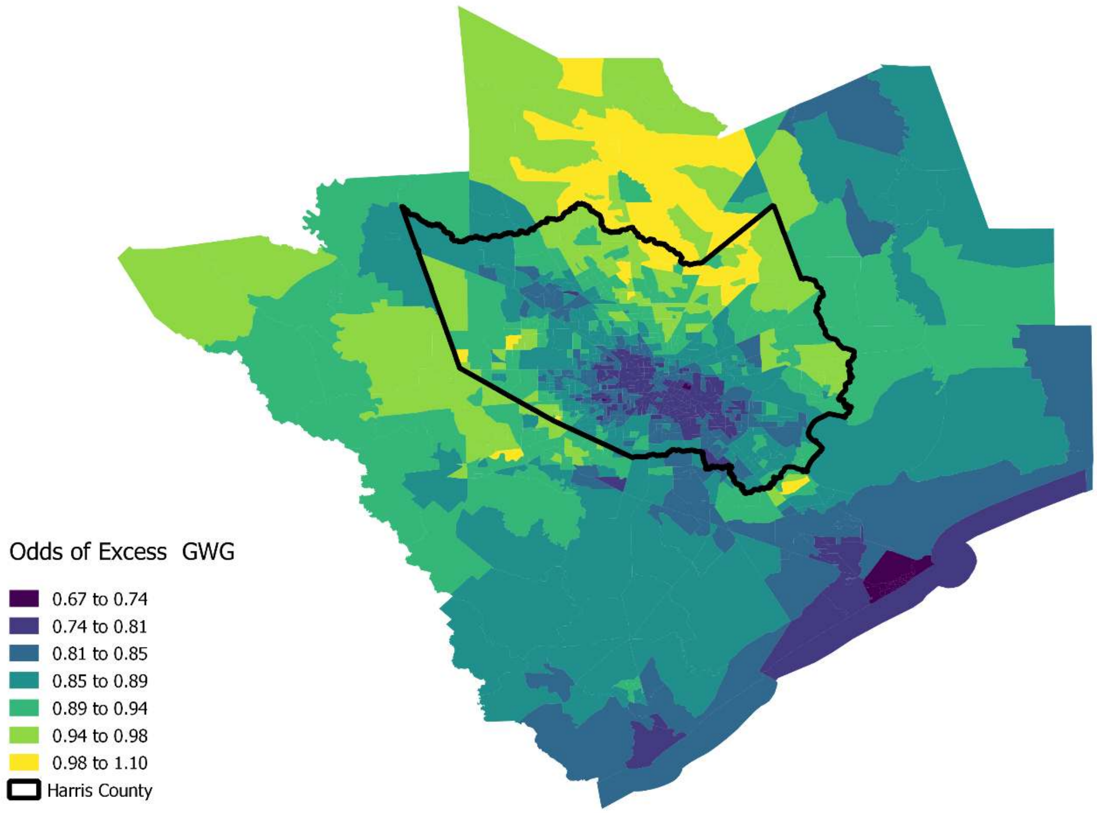


Figure 4b: Posterior Probability of the Odds of the Association Between Increased Potential Geographic Access to OBGYN Providers and Excess GWG Compared to Adequate GWG, 2014



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JOURNAL ARTICLE 2

Gestational Weight Gain and the Hispanic Paradox: Does Location Matter?
American Journal of Public Health

ABSTRACT

Objectives. To investigate geospatial variation in the association between mother's country of birth and total gestational weight gain (GWG) among pregnant Hispanic women in Texas.

Methods. A secondary analysis of Texas birth registry data was performed for 146,809 Hispanic mothers with a singleton live birth delivery in 2014. Big Geographically Weighted Regression (GWR) models calculated small-area associations between maternal country of birth and total GWG across Texas. Results were mapped and compared with state-level linear regression model estimates.

Results. Spatial variation in the relationship between country of birth and total GWG indicated that foreign birth was associated with GWG between -7.34 to 2.14 pounds across Texas. At the state-level maternal birth not in the US was associate with 2.73 fewer pounds of total GWG compared to Hispanic mothers born in the US.

Conclusions. Geographic location is important to understanding the role of maternal country of birth on pregnancy GWG. Variation across the state indicates that future researchers should be cautious when analyzing risk factors for GWG among Hispanic women as observed relationships may not be present in other locations. Small-area patterns may not

support research on the epidemiological advantages from foreign-born birth and suggests that Hispanic Paradox research should incorporate location.

INTRODUCTION

Gestational weight gain (GWG) outside of Institute of Medicine (IOM) recommendations affects two-thirds of Hispanic women in the United States (1) and is associated with a number of poor pregnancy outcomes including infant mortality (2), preterm labor (3), macrosomia (4), and increased C-section utilization (4,5). Hispanic women have long been shown to have better pregnancy outcomes than expected including adequate gestational age (6,7) and increased birth weight (6,8,9) compared to other populations with similar socioeconomic status. The epidemiological advantage among Hispanic women, a phenomena referred to as the Hispanic paradox, has been observed to reduce the odds of inadequate or excess GWG (10); although, there is debate on whether the Hispanic paradox is a real effect of ethnicity or an artifact of data collection and analysis errors (11–14). The effect of Hispanic ethnicity on health outcomes has been shown to be more evident in foreign-born Hispanic populations (8,15) than in United States (US)-born Hispanic populations and has an attenuated effect in second and third-generation immigrants (16,17). This research seeks to answer an infrequently addressed question: is location within the Texas important for understanding the Hispanic Paradox? To address this question, this study examined the association between maternal foreign-birth status and GWG.

Foreign-born Hispanic women have less GWG compared to US-born counterparts with moderate to strong associations between US-birth and excess GWG (10,18). Twenty-five percent of Mexican-born and Spanish speaking Hispanic women had GWG of less than 15 lbs and 6% had GWG of greater than 40 lbs In contrast, a study of deliveries in California showed that 16% of US-born and English speaking Hispanic women had GWG of less than 15 lbs and 9% had GWG of greater than 40 lbs (8). Hispanic women born in the US who resided in a rural area were more likely to have GWG of more than 40 lbs (13%) and less likely to have GWG of less than 15 lbs (16%) compared to Hispanic women born in Mexico who resided in a rural area (6% and 25% respectively) (19).

Various biological and social risk factors associated with GWG have been identified among Hispanic women. Risk factors weakly or moderately associated with excess GWG among Hispanic women include weight embarrassment (10), age (20), parity (1), and hypertension (1). Among Hispanic women, overweight BMI has been moderately associated with (1) excess GWG while BMI of less than 19.8 (1,20) was strongly protective of excess GWG. Factors moderately associated with reducing the odds of inadequate GWG among Hispanic women include no prior live birth and WIC enrollment (1). Some risk factors weakly or moderately associated with increasing the odds of inadequate GWG include month of prenatal care initiation (10), diabetes (1), and inadequate prenatal care (1).

Location may be important in explaining the observed differences in health outcomes among Hispanic women through a process of segmented assimilation (21) in which divergent acculturation paths result in residence in neighborhoods with varied socioeconomic and ethnic composition. However, research analyzing the way that location may be associated with GWG among Hispanic women has been limited (22) and conflicting. Border county residence has been shown to be moderately protective of excess GWG compared to adequate GWG and Texas Hispanic women in border counties had slightly higher prevalence of inadequate GWG (29%) and lower prevalence of adequate GWG (29%) compared to Hispanic women residing in non-border counties (26% and 32% respectively) (1); however, other research found no association between GWG and border residency (23). Other research has explored the geospatial variation in GWG in Florida and found non-complementary patterns in the odds inadequate and excess GWG across the state (18) with the highest odds of excess GWG in rural areas. High population density has been moderately associated with increased odds of inadequate GWG and lower odds of excess GWG in normal weight women (24).

The objective of this research is to investigate geospatial variation in the association between mother's country of birth and total GWG among pregnant Hispanic women in Texas in 2014, a state with the second largest Hispanic population in the US (25) and the second largest foreign-born population after California (26). The hypothesis of this research is that the association between country birth and total GWG would vary across Texas with a negative direction of association in metropolitan border areas and a positive direction of association in rural areas furthest from the border as prior research indicated that GWG may be associated with border residency (1) and rurality (19). This research utilizes birth records and geographically weighted regression (GWR) (27) methods to calculate small area estimates of the association between maternal country of birth and total GWG that are measured across Texas and mapped to show any geographic variation.

METHODS

Study Design and Participants

A secondary cross-sectional data analysis of live birth delivery data collected by the Texas Department of State Health Services (DSHS) (28) was conducted. Study subjects were Texas Hispanic women residents with a full-term, singleton (29) live birth in Texas between January 1, 2014 and December 31, 2014.

Data Source

Researchers at the Texas DSHS extracted a subset of all finalized 2014 birth certificate administrative records for women (28) to create a dataset of 184,837 geocoded Texas resident Hispanic singleton births. Mothers with multiparous delivery were not included in this research to control for differences in expected GWG compared to mothers with singleton deliveries (30). Deliveries were included in the study if they had complete information on mother's geocoded address and maternal prepregnancy and maternal delivery weight on the birth certificate. Exact geocoded addresses were necessary to calculate accurate distances between maternal residences. A final dataset was created by excluding all women with a preterm live birth deliveries of less than 37 weeks and women with birth records with missing information on any covariates. Restricting the analysis to only full-term deliveries controlled for differences in GWG caused by differences in gestational age.

Measures

Outcome of Interest

The outcome of interest, total GWG, was determined from self-reported maternal prepregnancy and maternal delivery weight from birth certificate variables. Total GWG was calculated as delivery weight minus prepregnancy weight. Total GWG was measured in pounds and analyzed as a continuous variable.

Main Exposure Variable

The main exposure variable of interest is maternal country of birth and assessed from self-reported variables from the birth certificate. Mother's country of birth is classified as birth in the US or not in the US.

Covariates

Known factors that were associated with total GWG including maternal age, parity, maternal educational attainment (31), maternal prepregnancy weight (3,32–35)(3,34–37), maternal maternal smoking status (9), diabetes (1), prenatal care utilization (10,35), Medicaid utilization, marital status (33), and infant birth weight (2) were obtained from self-reported variables from the birth certificate. Maternal age (x_1) was assessed as a continuous variable. Pregnancy parity was categorized as no prior deliveries (x_2) or one or more prior deliveries. Maternal educational attainment was classified as no high school degree (x_3), high school degree or equivalency (x_4), some college (x_5), and bachelor's degree or higher. Maternal prepregnancy weight was assessed from birth certificate derived variables of self-reported maternal prepregnancy weight and maternal delivery height and categorized as underweight BMI (<18.5) (x_6), normal BMI (18.5-24.9), overweight BMI (25.0-29.9) (x_7), and obese BMI (>=30.0) (x_8) (36). Maternal smoking status was classified as yes (x_9) or no for any reported cigarette usage during pregnancy. Gestational diabetes was classified as yes (x_{10}) or no for reporting any gestational diabetes. Type 1 or 2 diabetes was classified as yes (x_{11}) or no for any reported maternal prepregnancy related diabetes. Prenatal care initiation in the first trimester was categorized as yes (x_{12}) or no for the first prenatal visit in pregnancy months one, two, or three. The adequacy of prenatal care utilization index (Kotelchuck index) (37) was calculated from the variables for prenatal care initiation month and the number of prenatal visits. The Kotelchuck index is the ratio of realized prenatal visits compared to the number of expected prenatal visits given the month of prenatal care initiation. The expected number of prenatal visits was provided by the creators of the Kotelchuck index. A ratio value less than 0.5 was categorized as inadequate (x_{13}), a ratio between 0.5 and 0.79 was categorized as intermediate (x_{14}), a ratio value greater than or equal to 0.8 was categorized as adequate or adequate plus. The number of prenatal visits (x_{15}) was assessed as a continuous variable. Expected payor source was classified as Medicaid (x_{16}) or non-Medicaid paid birth. Maternal marital status was classified as married not married (x_{17}). Infant birth weight (x_{18}) was reported as continuous in pounds.

Statistical Analysis

Demographic characteristics of mothers included and excluded from the analytics dataset were compared in order to assess the validity of results since 16.9% of mothers were excluded from the analytics dataset due to missing information or preterm delivery. Chi-square tests for categorical variables and ANOVA tests for continuous variables were used to assess the statistical significance of differences between included and excluded subjects with p-values adjusted using Bonferroni correction.

Summary statistics of mean and standard deviation were calculated for the continuous variables of total GWG, maternal age, number of prenatal visits, and infant birth weight. The categorical variables of maternal country of birth, maternal prepregnancy weight, parity, any smoking during pregnancy, gestational diabetes, type 1 or 2 diabetes, marital status, prenatal care utilization index, prenatal care initiated in the first trimester, maternal educational attainment, and expected payor source were presented as counts and percent. Statistical tests were conducted using a type 1 error level of 0.05.

Two regression models were utilized to evaluate the association between maternal country of birth and total GWG. Model 1 was a linear regression model to assess state-level associations between maternal country of birth and total GWG. Model 2 was a geographically weighted regression (GWR) model (27) to assess small area variation in the association between maternal country of birth and total GWG. In order to analyze parsimonious regression models, covariates x_1 to x_{18} were evaluated for inclusion in Models 1 and 2 in two steps. Step one was the first part of the purposeful selection process (38) by which each covariate was included in a univariate linear regression model with the outcome of total GWG. Covariates with a p-value less than or equal to 0.2 for the statistical association with total GWG were retained and evaluated in step two. Step two covariate selection was determined by calculating Akaike information criterion (AIC) values for OLS regression models. A model with the exposure variable of interest, x_0, and all covariates retained from step one was compared to models with one covariate variable removed. The reduced model that minimized the AIC value was selected and the process repeated until no reduced model had a lower AIC value than the current model. Models 1 and 2 included x_o and all covariates from the model with the lowest AIC value in step two.

Model 1 produced state-level regression coefficients that were presented as estimates with 95% confidence intervals. Results were interpreted by identifying risk factors with a statistical association with total GWG.

Big GWR (39) functions calculated small area Model 2 regression estimates across Texas equal to the number of deliveries. Each regression utilized observations for the *n* nearest neighbors to each maternal residence location (40). In some small areas in Texas, every individual had the same value for a regression covariate and the default Big GWR software (39) was unable to calculate regression coefficients, so the software was modified to utilize a variable number of nearest neighbors. The minimum *n* was set at 400 and iteratively increased by increments of 100 if regression values were the same for any covariate until dissimilar values were obtained. Model 2 regression coefficients, standard errors, and the number of *n* nearest neighbors were associated with the latitude and longitude of the maternal residence (27).

Model 2 produced coefficient estimates that were presented as the mean and 95% interval of observed small area estimates. Ninety-nine Monte Carlo (27) simulations were used to calculate geographic stationarity test statistics to assess if Model 2 small area estimates varied across Texas. Stationarity test results were presented as p-values for the main exposure variable and Model 2 covariates. Estimates of Model 2 maternal country of birth regression coefficients and standard errors were presented as maps and categorized using modified Jenks natural breaks (41) to show potential spatial variation across Texas. Computational limitations prevented using kriging to interpolate values between maternal residence locations, so inverse distance weighting was used. Model 2 results were interpreted by identifying areas in Texas in which maternal country of birth had the most pronounced magnitude of association with total GWG and identifying GWR estimates with spatially varying relationships with total GWG.

Models 1 and 2 were compared by evaluating differences in the direction and magnitude of their regression coefficients.

RESULTS

There were 184,837 singleton live birth deliveries among Hispanic Texas women between January 1, 2014 and December 31, 2014. As shown in Figure 1, a total of 8,060 deliveries were excluded from the analytics dataset due to missing information on GWG and inexact geocoded maternal residence information. Another 29,968 deliveries were excluded due to missing information in any covariate or having a gestational length less than 37 weeks. The final analytics dataset included 146,809 deliveries.

Comparisons in Table 1 between women included and excluded from the analytics datasets indicated small but statistically significant differences for most maternal characteristics. More than half of the women excluded from the analysis dataset had missing information that prevented the determination of prenatal care utilization index values and more than one-third of women excluded from the analysis dataset had missing information that prevented determining the trimester of prenatal care initiation; however, the number of prenatal care visits is similar between those included and excluded. Overall, mothers were similar between those included and excluded from the dataset, but mothers included were more likely be foreign-born, so their pregnancy outcomes may be expected to be better than those excluded from the study (8,15).

On average, mothers were 26.6 years of age, gained 28.4 lbs during their pregnancies, and had 10.1 prenatal care visits. More than half (58.2%) of mothers were born in the US. Mother's prepregnancy BMI was predominantly normal (42.3%), but more than half of the mothers had either an overweight BMI (28.3%) or an obese BMI (26.5%) with the remainder classified having an underweight BMI (3.1%). Few mothers smoked during their pregnancy (1.1%), had gestational diabetes (5.1%), or type 1 or 2 diabetes (0.8%). Forty nine percent (49.3%) of mothers were married (49.3%). About a third (32.8%) of mothers had adequate or adequate plus prenatal care, 48.5% had intermediate, and 18.6% had inadequate care. More than half (57.8%) of mothers had prenatal care in the first trimester. Almost two-thirds of mothers did not have any college attainment of any kind with 33.0% not attaining a high school degree, 31.7% having high school degree, and the remainder having some college (24.9%) or a bachelor's degree or higher (10.5%). More than half (56.8%) of the women in this study expected Medicaid to pay for the delivery. As shown in Table 2, GWG was higher among Hispanic women born in the US and similar for most maternal characteristics. GWG was highest for mothers with a bachelor's degree, a non-Medicaid paid birth, mothers who were not married, women less than 20 years of age, women with any smoking during their pregnancy, mothers with prior births, mothers with an underweight BMI, mothers with intermediate, adequate or adequate plus prenatal care, and mothers with an infant with whose infant birth weight was 2,500g or more.

Step one of the model selection process removed expected Medicaid payor (x_{12}) and prenatal care in the first trimester (x_{16}) from further evaluation in regression models. No covariates were removed from the process in step two. The final analysis models for Model 1 and Model included x_0 and the covariates x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{13}, x_{14},x_{15}, x_{17}, and x_{18}.

Model 1 State-Level Results

Model 1 state-level regression estimates for the association between foreign-born country of birth and total GWG in Table 3 was a statistically significant -2.73 lbs. This indicates that at the state-level, maternal birth not in the US compared to maternal birth in the US for Hispanic women was associated with 2.73 lbs less total GWG. At the state-level, all but one covariate demonstrated a statistically significant association with total GWG in Model 1. Only maternal attainment of some college compared to a bachelor's degree did not have a statistically significant association with total GWG. The largest Model 1 state-level associations with increased total GWG were having no prior births (3.35 lbs) and a one-pound increase in infant birth weight (3.04 lbs). The largest state-level Model 1 associations with decreased total GWG were prepregnancy obese BMI (-8.61 lbs) and prepregnancy overweight BMI (-2.93 lbs) compared to prepregnancy normal weight BMI.

Model 2 GWR Results

The mean of all Model 2 small area regression estimates in for the association between foreign-born country of birth and total GWG was -2.50 lbs with a 95% interval of observed Model 2 regression estimates between -7.34 and 2.14 lbs. Figure 2a shows Model 2 spatial variation in the association between foreign-born birth and total GWG. The magnitude of regression estimates were highest along the Texas-Mexico border, west, and in the Texas panhandle. The largest negative regression estimate magnitude was present in northwest Texas and along the I-35 corridor from Laredo through San Antonio, and Austin. As shown in Figure 2b, the distribution of the standard error for the Model 2 coefficient of foreign-born birth was smallest in south Texas along the Texas-Mexico border. The largest standard error was present in northwest Texas and southwest Texas near the Gulf of Mexico coastline. The Monte Carlo geographic stationarity test in Table 3 indicated a statistically significant amount of spatial variation across Texas in Model 2 estimates for the association between maternal country of birth and total GWG.

Thirteen of the eighteen Model 2 GWR covariates demonstrated statistically significant non-stationarity, an indication that there was statistically significant variation across Texas in their associations with total GWG. The direction of associations in Model 2 covariates changed across Texas for all coefficients except obesity and infant birth weight. According to Model 2 GWR coefficient estimates, prepregnancy obese BMI was associated with a reduction in total GWG with variability across Texas between -13.69 and -2.77 lbs. The 95% interval of Model 2 estimates indicated that infant birth weight was associated with an increase in total GWG across Texas with GWR coefficients between 0.82 to 5.25 lbs.

Medical covariates with a varying association with total GWG across Texas include underweight and overweight BMI compared to normal BMI, a one year increase in maternal age, no prior maternal births, type 1 or 2 diabetes, and gestational diabetes. Socioeconomic covariates with a varying association with total GWG across Texas include smoking while pregnant, marital status, prenatal care utilization for inadequate or intermediate care, the number of prenatal visits, and maternal educational attainment of no high school degree, a high school degree or some college compared to a bachelor's degree or higher.

Model 2 utilized a modified Big GWR algorithm with a variable number of *n* nearest neighbors. Figure 2c shows that *n* varied between 400 and 4,200 neighbors with the largest *n* in south Texas along the Texas-Mexico border in two locations near Laredo and Brownsville, TX.

Comparison of Model 1 and Model 2 Results

Comparisons of state-level Model 1 regression estimates and Model 2 small area regression estimates demonstrated a few differences. Any smoking during pregnancy was associated with an increase of 3.88 lbs in total GWG at the state-level; however, the mean association of all GWR estimates was 1.98, a 49% reduction. The magnitude of the Model 1 association between type 1 or 2 diabetes and total GWG (-0.92 lbs) was twice as large as Model 2 mean GWR estimates (-0.46 lbs). Model 2 GWR coefficients for maternal educational attainment for no high school degree (-.2 lbs) and high school degree (-0.3) are 64% and 32% lower than corresponding state-level Model 1 coefficients (-0.55 and -0.41).

The Model 1 estimate for the association between some college education and total GWG was 0.06 lbs, but the Model 2 mean of GWR estimates was a 0.12 lbs, a 200% increase.

DISCUSSION

This research utilized a modified version of new big GWR software that permitted analysis of a study population of more than 140,000 deliveries, one of the largest GWR models reported to date (42). On average, foreign-born Hispanic women gained a statistically significant 2.73 fewer pounds during their pregnancy compared to their US-born counterparts. While a number of studies have analyzed the relationship between country of origin among Hispanic women and total GWG, localized estimates that show variation across space have never been previously attempted at this scale or with this degree of granularity. The study population was large and represents almost one-sixth (16.5%) of all singleton Hispanic pregnancies with a live-birth nationwide (43). By utilizing Texas birth records, the study represented a state with the longest border with Mexico (44), the second largest foreign-born population of any US state (26), and the state with the second highest proportion of foreign-born Hispanic individuals with Mexican origin (86.8%) (45).

This research demonstrates that geographic location is important to understanding the role of maternal country of birth on pregnancy total GWG. As evident by Model 2 estimates, there was a more than 9-pound difference in the 95% interval between the lowest and highest parts of Texas in the association of between country of birth and total GWG. Statistical tests of stationarity indicated that the associations between country of birth and most of the studied risk factors with total GWG varied across Texas and their relationships should not be treated as constant. Future researchers should be cautious when interpreting associations between these maternal characteristics and total GWG among Hispanic women as the associations may not be observed in other locations. Moreover, the standard method to control for rurality or border status by including indicator covariates in regression models may not be adequate as this research observed variations within these areas ranging from positive to negative associations with total GWG.

Model 2 GWR results shown in Figure 2a indicate that the largest negative association between foreign-born birth and total GWG was observed along the I-35 corridor and the largest positive association was along the Texas-Mexico border and in rural west and northwest Texas. The two areas differ in both population composition, infrastructure, and health outcomes. The I-35 corridor contains the Texas economic driver of the most trafficked inland port in the United States in Laredo (46), seven of the fifteen fastest growing cities in the United States (47), and is 41% Non-Hispanic Anglo (48). The southernmost Texas-Mexico border counties of Cameron, Hidalgo, Starr, Willacy, and Zapata are 91% Hispanic (48) and have the highest poverty rates of any counties in Texas (49). Western Texas counties are among the slowest growing counties in the states and many have experienced population decline between 2000 and 2017 (47). Additionally, the rural areas of west and northwest Texas are likely to fewer healthy food resources as rural residents have lower geographic supermarket access compared to metropolitan residents, which is associated with increased obesity (47). These areas also differ in expected GWG as residents of rural areas have higher odds of inadequate GWG and metropolitan residents have higher odds of excess GWG (24).

Prior research has examined maternal country of birth among Hispanic women in an attempt to explain better than expected health outcomes (8,10,15). This research presents a new method for investigating the Hispanic paradox and posits that observed differences between Hispanic women born in the US and their foreign-born counterparts may be partially explained by location of residence within the US. Model 2 GWR estimates shown in Figure 2a would suggest that country of birth would be associated with total GWG of 3.7 to 5.6 lbs for a US born Hispanic woman residing in Laredo; whereas, a foreign-born Hispanic woman residing a few miles away near McAllen may be expected to gain a similar amount. Studies comparing individuals in these locations may find little or no differences in total GWG that could be explained by country of birth. It is hypothesized that differences may be a consequence of diverging socioeconomic status between US-born and foreign-born Hispanic women in different economic environments and resulting associations with GWG (4,31,51). The educational and social network advantages that US-born Hispanic women (52) have compared to foreign-born Hispanic women may result in different socioeconomic outcomes, an effect exaggerated in the economically advantaged area along I-35. In economically poor rural and ethnically homogenous areas (53) along the Texas-Mexico border, economic advantages that acculturation may provide US-born Hispanic women may be less impactful resulting in socioeconomic status that more similar to foreign-born Hispanic women. Local-level patterns may not support research on the epidemiological advantages from foreign-born birth; however, at the state-level, Model 1 results corroborated prior Hispanic paradox research (1,19) by demonstrating that total GWG was lower among foreign-born Hispanic women than among Hispanic women born in the US.

An alternative hypothesis for differences in GWG observed in this research between Hispanic mothers born in the US and not in the US is the possibility of social network influence along the Texas-Mexico border. Social network influence has been associated with a variety of pregnancy behaviors and outcomes including breastfeeding (54), low birth weight (55), and contraceptive use (56). Additionally, social networks have been associated with modifying body size norms (57) and higher obesity levels (58). Social network size has been shown to larger in Hispanic enclaves compared to areas with fewer Hispanic residents (59). The predominantly Hispanic Texas-Mexico border may result in larger social networks among foreign-born Hispanic women, resulting in greater influence on body image and GWG compared to Hispanic women in the less Hispanic I-35 corridor.

Results from this study are consistent with prior research that demonstrates marriage (10), maternal age (20), parity (60) are associated with excess GWG. At the state-level in Model 1, these maternal characteristics were associated with increasing total GWG. This research showed that inadequate prenatal care and diabetes were associated with decreasing total GWG, a result consistent with prior research that demonstrates these characteristics are associated with an increased odds of inadequate GWG (10,61). Contrary to prior research that overweight prepregnancy BMI is associated with increasing the odds of excess GWG among Hispanic women (1), this research revealed that overweight and obese prepregnancy BMI were associated with a reduction in total GWG.

This research allowed for the analysis of Hispanic women in a new and innovative way, but has a number of limitations. The research used self-reported data for assessing maternal prepregnancy weight in calculating total GWG as weight was unable to be verified by medical records. GWG validity is known to vary by maternal prepregnancy weight and maternal race (62,63), but prior research has shown minimal bias in associations between GWG and pregnancy outcomes (63). While the analytics data set included a large number of US Hispanic deliveries, the research only utilized Texas residents and may not be generalizable outside of the state. Exclusion criteria and missing information resulted in the removal of more than 16.9% of the possible mothers from the analytics dataset. Mothers in the analytics dataset had a higher socioeconomic status compared to women excluded from the analytics dataset as signified by higher marital rates, a lower prevalence of expected Medicaid paid deliveries and a higher proportion with a bachelor's degree or higher. Lower socioeconomic status is associated with inadequate GWG (51) and increasing education is associated with increased GWG (31). Consequently, mothers utilized in this study may have more total GWG than expected for a Texas Hispanic woman which may exaggerate some relationships by increasing their magnitude away from zero.

Care must be taken when comparing Model 2 GWR small area estimates across Texas. GWR bias is known to increase with an increasing number of nearest *n* neighbors in calculations (27). GWR calculation issues along the Texas-Mexico border required increasing *n* to more than ten times the predetermined minimum. This modification smoothed small area estimates towards state-level estimates and reduced the ability to infer local geographic differences. Additionally, care should be exercised when interpreting smoking and type 1 or 2 diabetes Model 2 estimates as low state-level prevalence may have resulted in unstable small area GWR estimates and large 95% intervals.

This study was unable to differentiate between Hispanic ethnicities. More than 86% of the Texas Hispanic population is of Mexican origin (45), and it is probable that research that analyzes Cuban, Puerto Rican, South American, or other subpopulations may reveal different GWG relationships. Future research may attempt to analyze GWG patterns among women of different ethnicities to determine if spatial patterns similar to those in Model 2 are observed.

This research indicates that location is important to understanding how foreign-born status is associated with total GWG and presents a new possibility for explaining some of the Hispanic Paradox. Small area patterns in the association between maternal country of birth and total GWG show a pattern across Texas which may be representative of economic differences between metropolitan, rural, and border areas. Future research should exercise caution when modelling GWG at the state-level and address observed geographic variation in GWG by utilizing spatial models and identify potential causal mechanisms for the observed differences by geographic location and provide methods for predicting the role of the surrounding environment in modifying GWG.

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Human Subjects, Animal Subjects, or Safety Considerations

Study consent was not obtained as individuals were not able to be personally contacted, but the Texas Department of State Health Services Institutional Review Board and the UTHSC Committee for Protection of Human Subjects reviewed the proposed analysis plan and ensured subject privacy protections.

TABLES

Table 1: Social and Demographic Characteristics of Texas Hispanic Women with a Live Birth by Gestational Weight Gain Category, 2014

Characteristic	**Mothers Used in Analysis** (n=146,809)		**Mothers Excluded from Analysis** (n=29,968)		
	n	**Mean (SD); (%)**	**n**	**Mean (SD); (%)**	
Gestational Weight Gain (lbs)	146,809	28.4 (14.5)	29,968	26.2 (14.9)	*
Maternal Country of Birth					
Birth in the US	85,446	58.2%	18,985	63.6%	*
Birth not in the US	61,363	41.8%	10,924	36.5%	
Missing			59	0.2%	
Maternal educational attainment					
No high school degree	48,380	33.0%	10,029	33.6%	*
High school degree	46,488	31.7%	9,851	33.0%	
Some college	36,499	24.9%	7,250	24.3%	
Bachelor’s degree or higher	15,442	10.5%	2,713	9.1%	
Missing			125		
Expected payor source					
Medicaid	83,359	56.8%	17,856	60.1%	*
Non-Medicaid	63,450	43.2%	11,846	39.9%	
Missing			266		
Marital Status					
Married	72,314	49.3%	14,336	47.9%	*
Not Married	74,495	50.7%	15,619	52.1%	
Missing			13		
Maternal age	146,809	26.6 (6.1)	29,965	26.7 (6.3)	
Missing			3		
Maternal smoking status					
Any smoking during pregnancy	1,628	1.1%	336	1.1%	
None	145,181	98.9%	29,625	98.9%	
Missing			7		
Gestational diabetes					
Yes	7,472	5.1%	2,062	6.9%	*
No	139,337	94.9%	27,906	93.1%	
Missing			0		
Type 1 or 2 diabetes					
Yes	1,143	0.8%	403	1.3%	*
No	145,666	99.2%	29,565	98.7%	
Missing			0		
Parity					
0 Prior births	51,312	35.0%	10,035	33.5%	*
1+ Prior births	95,497	65.0%	19,892	66.5%	

Missing			41		
Maternal Prepregnancy Weight					
Underweight	4,487	3.1%	978	3.3%	*
Normal	61,909	42.3%	11,512	38.5%	
Overweight	41,499	28.3%	8,393	28.1%	
Obese	38,914	26.5%	8,990	30.1%	
Missing			95		
Number of prenatal visits	146,809	10.1 (4.0)	28,444	9.5 (4.3)	*
Missing			1,524		
Prenatal care initiated in the first trimester					
Yes	84,797	57.8%	8,234	27.4%	*
No	62,012	42.2%	21,784	72.6%	
Missing			11,950		
Prenatal care utilization index					
Inadequate	27,379	18.6%	2,861	20.2%	*
Intermediate	71,261	48.5%	4,344	30.7%	
Adequate or Adequate Plus	48,169	32.8%	6,927	49.0%	
Missing			15,836		
Infant birth weight (lbs)	146,809	7.4 (1.0)	29,836	6.3 (1.7)	*
Missing			105		

Abbreviations: SD, standard deviation

* Indicates a statistically significant difference between included and excluded subjects used in the analysis.

Table 2: Social and Demographic Characteristics of Texas Hispanic Women with a Live Birth by Gestational Weight Gain Category, 2014

Characteristic	**Gestational Weight Gain (lbs)** (n=146,809)	
	Mean	**Standard Deviation**
Maternal Country of Birth		
Birth in the US	29.4	15.2
Birth not in the US	27.0	13.3
Maternal educational attainment		
No high school degree	27.4	14.6
High school degree	28.4	14.4
Some college	29.2	14.8
Bachelor's degree or higher	30.0	13.2
Expected payor source		
Medicaid	28.4	14.8
Non-Medicaid	28.5	14.0
Marital Status		
Married	27.9	14.1
Not Married	28.9	14.8
Maternal age		
<20 Years	30.9	14.8
20-29 Years	28.4	14.5
30-39 Years	27.6	14.2
40+ Years	25.9	13.7
Maternal smoking status		
Any smoking during pregnancy	31.6	18.2
None	28.4	14.4
Gestational diabetes		
Yes	25.1	15.6
No	28.6	14.4
Type 1 or 2 diabetes		
Yes	26.0	16.3
No	28.4	14.5
Parity		
0 Prior births	31.2	14.6
1+ Prior births	26.9	14.2
Maternal Prepregnancy Weight		
Underweight	32.7	13.3
Normal	31.3	12.7
Overweight	28.5	14.4
Obese	23.4	15.9
Number of prenatal visits		
<10 Visits	27.5	14.6
10-19 Visits	29.0	14.4

20+ Visits	27.5	16.0
Prenatal care initiated in the first trimester		
Yes	28.9	14.3
No	27.8	14.6
Prenatal care utilization index		
Inadequate	26.9	15.0
Intermediate	28.8	14.1
Adequate or Adequate Plus	28.8	14.6
Infant birth weight		
Extremely Low Birth Weight (<1,000g)	4	nc
Very Low Birth Weight (1,000-1,499g)	26.1	16.8
Low Birth Weight (1,500-2,499g)	24.4	13.8
Birth Weight (2,500g+)	28.5	14.5

Abbreviations: nc, not calculable

Table 3: Associations between Social and Demographic Characteristics and Gestational Weight Gain among Texas Hispanic Women with a Live Birth, 2014

Independent Variable	**Model 1**		**Model 2**		
	β	**95% CI**	***β***	**95% Interval**	**P-value[a]**
Intercept	8.84	8.01, 9.67	9.0	-16.65, 33.01	0.0
Maternal Country of Birth					
Birth in the US (ref)					
Birth not in the US	-2.73	-2.89, -2.57	-2.5	-7.34, 2.14	0.0
Maternal educational attainment					
No high school degree	-0.55	-0.82, -0.27	-0.2	-9.34, 8.65	0.0
High school degree	-0.41	-0.67, -0.14	-0.28	-9.61, 7.54	0.01
Some college	0.06	-0.20, 0.33	0.12	-8.82, 8.2	0.0
Bachelor's degree or higher (ref)					
Marital Status					
Married (ref)					
Not Married	0.44	0.29, 0.59	0.51	-4.76,3.54	0.74
Maternal age	0.01	0.0, 0.03	0.02	-0.38, 0.41	0.23
Any smoking during pregnancy					
Yes	3.88	3.21, 4.55	1.98	-28.15, 34.80	0.0
No (ref)					
Gestational diabetes					
Yes	-1.94	-2.26, -1.62	-1.61	-10.67, 8.86	0.01
No (ref)					
Type 1 or 2 diabetes					
Yes	-0.92	-1.72, -0.13	-0.46	-23.34, 26.69	0.73
No (ref)					
Parity					
0 Prior births	3.35	3.19, 3.51	3.45	-1.39, 8.17	0.0
1+ Prior births (ref)					
Maternal Prepregnancy Weight					
Underweight	1.79	1.37, 2.20	2.06	-6.94, 13.37	0.89
Normal (ref)					
Overweight	-2.93	-3.10, -2.76	-2.87	-7.37, 1.67	0.43
Obese	-8.61	-8.79, -8.43	-8.43	-13.69, -2.77	0.02
Number of Prenatal Visits	0.03	0.0, 0.06	0.03	-0.82, 0.97	0.03

Prenatal care utilization index					
Inadequate	-1.52	-1.88 -1.16	-1.61	-11.47, 9.07	0.02
Intermediate	-0.27	-0.47, -0.08	-0.34	-5.74, 5.25	0.03
Adequate and Adequate Plus (ref)					
Infant birth weight	3.04	2.97, 3.11	3.04	0.82, 5.25	0.0

Abbreviations: CI, confidence interval

[a] p-values were determined from 99 Monte Carlo stationarity simulations

Figure 1: Flow chart for the final analytics dataset selection process

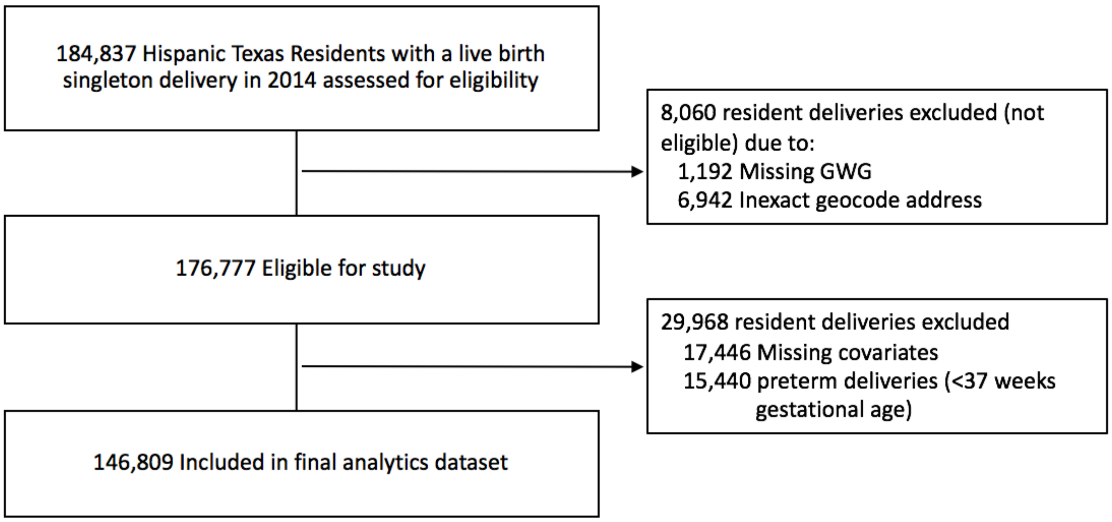


Figure 2a: Model 2 GWR Estimates for the Association Between Maternal Foreign-Born Birth and GWG Among Hispanic Women, 2014

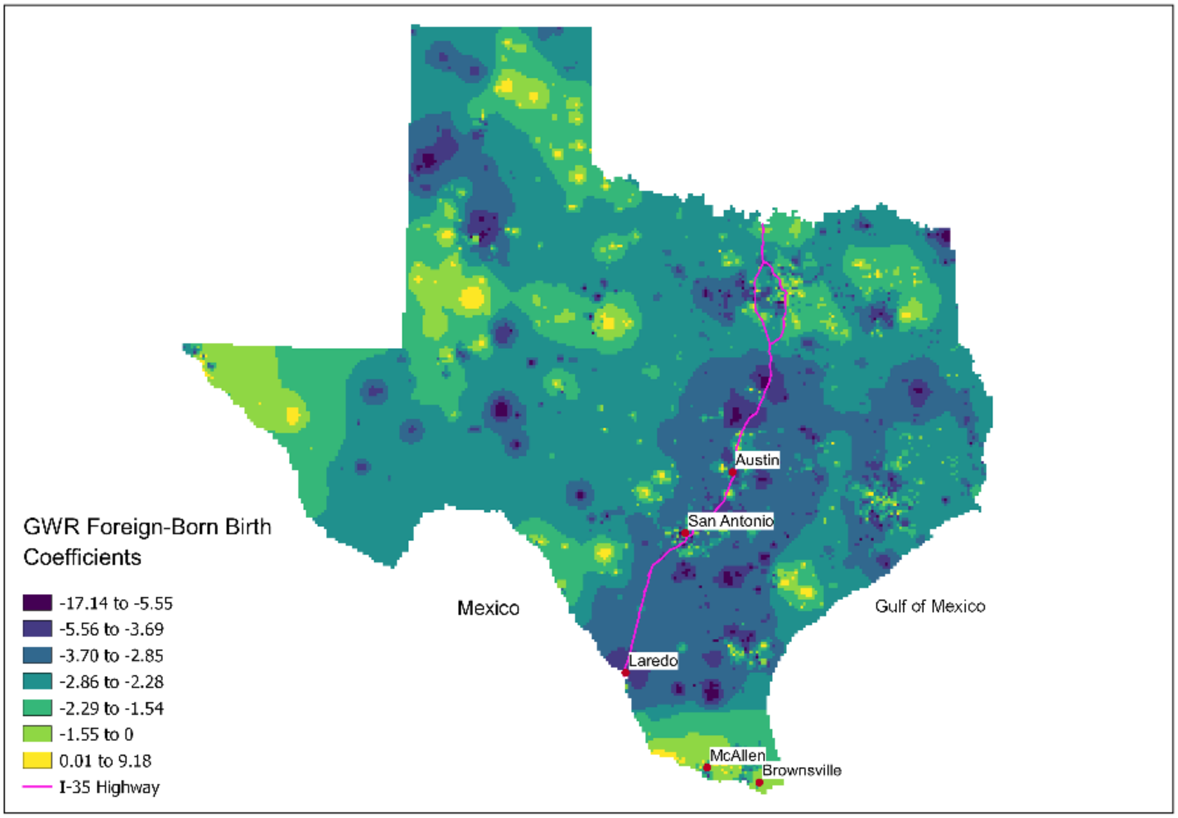


Figure 2b: Model 2 GWR Standard Errors for the Association Between Maternal Foreign-Born Birth and GWG Among Hispanic Women, 2014

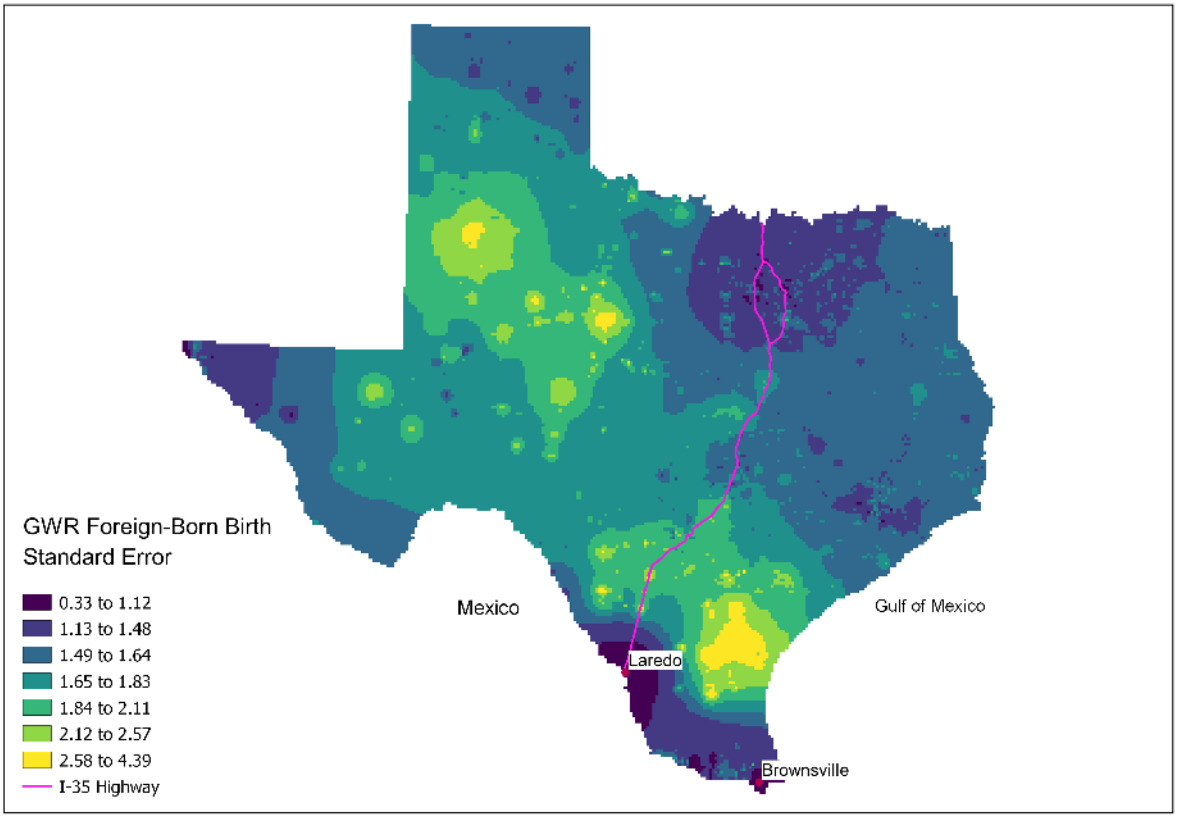
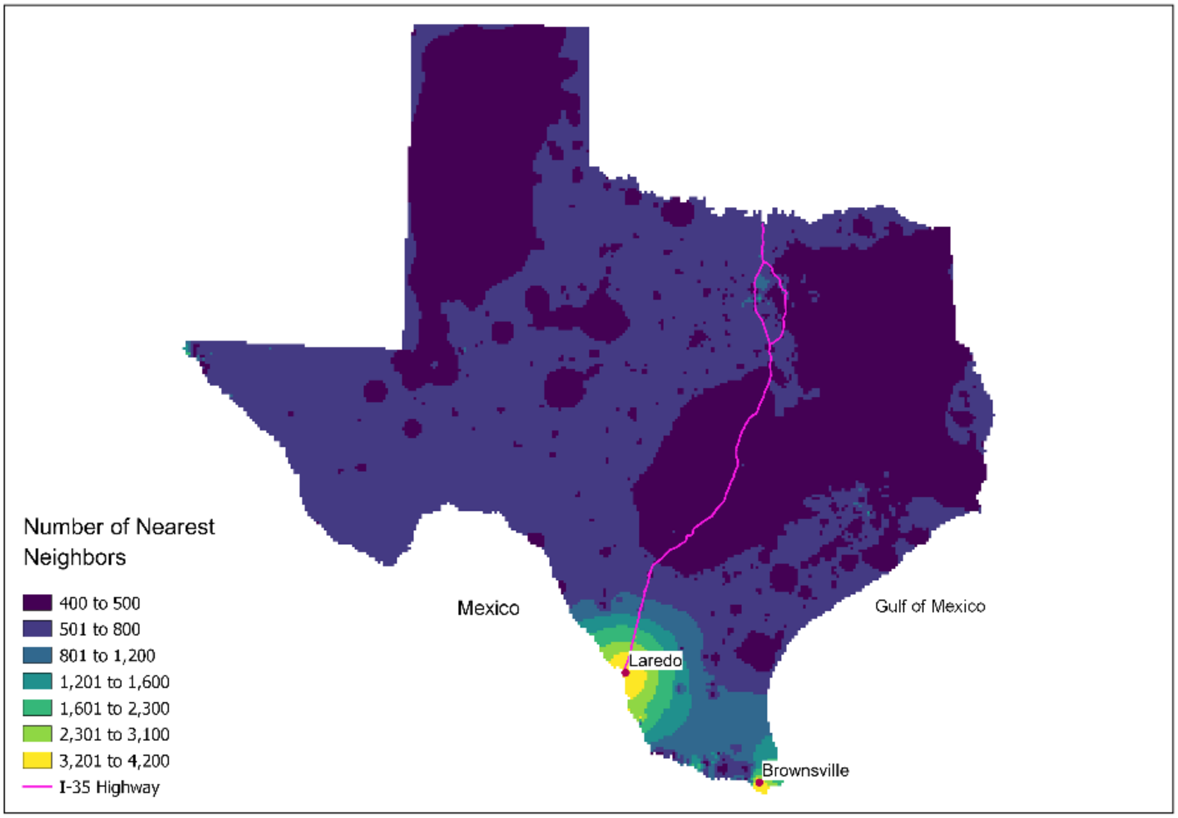


Figure 2c: Number of n Nearest Neighbors Used in the Estimation of GWR Model 2 Parameters



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DISCUSSION

Summary

Nearly two-thirds of pregnant women in the United States (US) had inadequate or excess GWG in 2011 and 2012 (8). This research is one of the first studies to examine associations between OBGYN access and maternal country of birth with GWG while accounting for the potential influence of space. The central hypothesis of this research is that the risk factors associated with GWG, and costs for treating pregnancies with inadequate or excess GWG compared to adequate GWG, are influenced by spatial and place-based factors. Using a newly developed spatial statistical tools and Texas birth registry data for 2014, we conducted one of the largest studies of GWG to date and showed that these associations and outcomes vary across space in Texas. The 79,000 to 146,000 Texas resident births used to evaluate the research hypothesis represent between 20% and 37% of all Texas births, 2% of all national births, and 16.5% of national Hispanic singleton births (119). The studied geography is diverse, including “the most diverse city in America” in Houston, Texas, (120) and the second largest foreign-born population of any US state (121) with the second highest proportion of foreign-born Hispanic individuals of Mexican origin (86.8%) (122).

Overall, this research indicates that space is important in understanding GWG, though the significance of space depends on the studied risk factor. This research demonstrates spatial variation in the odds of inadequate and excess GWG compared to adequate GWG across the Houston-The Woodlands-Sugarland MSA. The most protective tracts for excess GWG were in central Harris County and a ring of less protective tracts surrounded the central tracts extending to the north of Harris County. Tract-level associations with inadequate GWG display a similar, but opposite pattern. While variation in the odds of inadequate and excess GWG was observed, the main place-based exposure of interest, OBGYN access, is not associated with GWG. This research also demonstrates that GWG has statistically significant variation in associations with maternal country of birth and most studied risk factors among Hispanic women across Texas. This indicates that the association between country of birth and total GWG cannot be modelled as continuous across the state. Spatial patterns indicated that foreign-born maternal birth compared to maternal birth in the United States is associated with increased total GWG along the Texas-Mexico border and in rural areas in Texas with a shift to less GWG along the Texas I-35 corridor and in northwest Texas. It is hypothesized that differences between US and foreign-born Hispanic may be partially explained by place-based factors of regional economic disparities across Texas and related to economic differences in assimilation patterns.

Significant Results

Geographic Access to OBGYN Providers

The research identified that some, but not all studied risk factors have statistically significant associations with inadequate or excess GWG compared to adequate GWG. The research demonstrates that higher potential geographic access compared to lower potential access to OBGYN providers is not associated with inadequate or excess GWG compared to adequate GWG. The 15 mile distance standard utilized in this research may have been too small to detect access differences, alternatively OBGYN access within the Houston-The

Woodlands-Sugarland MSA may not be sufficiently high and does not exhibit enough variation to detect any GWG differences.

When comparing spatial and non-spatial models, the model selection process using DIC values indicated that a model incorporating tract-level covariates and tract spatial adjacency information was preferable to all other studied models. However, the research was unable to demonstrate any meaningful tract-level associations with GWG. The model selection process may have favored the most complex model as this study had more than 80,000 mothers and could accommodate many model parameters before overfitting the data. DIC values were similar between Model 3 and Model 4 which indicates that model improvements from adding the tract-level adjacency matrix resulted in a model fit only slightly better than the overfitting from adding additional model estimates. Moreover, the studied associations in this research were largely consistent between the four studied models as evident in Appendix B indicating that space is not a strong confounder between the association of OBGYN access and GWG. Future research utilizing fewer observations may find DIC preference for less complex models that do not incorporate spatial adjacency, but this research indicates that simpler models may produce model results similar to more complex models.

Consistent with prior research (53), most of the studied associations with inadequate or excess GWG compared to adequate GWG were weak. Prepregnancy weight had a moderate association with inadequate and excess GWG (OR >2 or OR 0.5-0.8) compared to adequate GWG, a relationship observed in other studies (26,28,31,53). Hispanic ethnicity and non-Hispanic Black maternal race had a moderate association with excess GWG compared to adequate GWG, consistent with prior research (123). However, prior research (123) found that Hispanic ethnicity was associated with excess GWG; whereas, this research found Hispanic ethnicity protective. All other covariates were weakly or not associated with GWG. Increasing the population size may improve statistical significance for some covariates, but the magnitude of the observed associations were small and unlikely to change enough to make them clinically significant.

Maternal Country of Birth and GWG

GWR models demonstrated that geographic location is important to understanding the role of maternal country of birth on pregnancy GWG. Maps of the variation in the association between country of birth and GWG showed the largest negative association between foreign-born maternal status and GWG was along the I-35 corridor and the largest positive association was along the Texas-Mexico border and in rural northwest Texas. This indicates that in the I-35 corridor cities of Laredo, San Antonio, and Austin foreign-born women, compared to birth in US-born, experienced reduced GWG. Conversely, along the border and in northwest Texas foreign-born status is associated with GWG gain. Overall, there was a difference of more than 9 pounds in the 95% interval between the lowest and highest parts of Texas. Statistical tests for geographic variation showed that this variation was statistically significant and not constant across Texas. This indicates that future researchers should be cautious when interpreting small area associations between maternal country of birth and GWG among Hispanic women who reside in Texas, as the association may not be observed in other locations.

This research presents a new and unaddressed aspect in understanding the Hispanic Paradox, an epidemiological phenomena in which Hispanic individuals have better than expected health outcomes compared to non-Hispanic individuals. This research demonstrated that some variation in health outcomes among Hispanic women may be due to differences in geographic residence, a spatial effect that has never been previously observed as prior research was limited to analyzing aggregate-level data or used regional-level interaction terms that prevented analysis with much geographic granularity. It is hypothesized that the differences in the association between maternal country of birth and total GWG may be a reflection of advantages for acculturated US-born Hispanic women in economically advantaged urban areas.

Prepregnancy Weight

Consistent across the research was the importance of the association between prepregnancy weight and GWG. Overweight and obese maternal prepregnancy weight were associated with a two-fold greater odds of excess GWG compared to adequate GWG and inversely associated with the odds of inadequate GWG compared to adequate GWG in the Houston-The Woodlands-Sugarland MSA. An increased odds of excess GWG has been associated with maternal prepregnancy overweight or obese BMI in prior research (26,28,31,53). Prepregnancy obesity was associated with an increased odds of inadequate GWG (8,53) in prior research; whereas, this research observed a protective association. Almost paradoxically, obesity had the largest magnitude of association with total GWG reduction among all studied maternal characteristics in Hispanic women. The associations between prepregnancy overweight or obese BMI and reductions in total GWG have been observed in prior studies (13–16). The increased odds of excess GWG in overweight and obese mothers despite less total GWG compared to normal weight mothers may be attributed to the lower limit of acceptable GWG in obese women (8).

While space is important to understanding GWG this research reveals that prepregnancy weight may be the key factor in controlling GWG. Prior research demonstrated an association between prepregnancy weight and GWG (26,28,31); however, no prior research has shown that this relationship is non-constant across Texas. If a Hispanic woman were to lose weight sufficient to transition from an obese to normal BMI, she would be expected to gain 8 fewer pounds of gestational weight, but the amount could vary between 13.69 to 2.77 pounds depending on her residence. Understanding the relationship between prepregnancy weight and GWG is important because obesity is one of the few modifiable maternal characteristics identified in this study that can be addressed by public health interventions.

Big GWR

This research was enabled by the development of software that improved the computation of categorical variables in GWR models. GWR models determine the nearest neighbors to an observation and calculate small area regression estimates (124). Big GWR models can accommodate larger datasets than typical GWR models by using a k-d-tree search algorithm to calculate distances to nearest neighbors, thereby reducing computational workload and improving speed (118). The Big GWR software used a fixed number of nearest neighbors and was originally designed to only analyze continuous variables, but categorical variables could be included in GWR models with dummy variable coding. The default Big GWR software failed when attempting to calculate small area estimates across Texas because in some small areas a homogenous population was observed whereby each individual shared the same maternal characteristic. When every individual has the same value for a regression covariate the X matrix becomes non-singular and regression coefficients cannot be calculated.

Modifications to the Big GWR software included the development of an algorithm that permitted the use of a non-fixed number of nearest neighbors. The software set a number of nearest neighbors, referred to as the bandwidth, which would iteratively increase by increments of 100 when a homogenous population was encountered until the bandwidth was large enough to capture a heterogeneous subpopulation from which regression coefficients were calculable. The software captured all regression coefficients, standard errors for all estimates, and the required bandwidths. Additionally, Monte Carlo simulation methods were modified from functions in GWmodel (124) to utilize Big GWR methods to calculate geographic stationarity test statistics.

The software does have limitations and care should be taken when analyzing some GWR local area estimates. GWR model bias is a function of bandwidth size (125), as bandwidth increases the estimates become less local and more global. The large bandwidths necessary to calculate regression coefficients along the Texas-Mexico border indicate a large amount of potential bias. Standard GWR software optimizes the bandwidth to minimize bias and regression coefficient variance (125). The modifications to the Big GWR software prevented the ability to use default optimization methods and RAM limitations prevented the application of a fixed bandwidth to utilize across the state. Consequently, the modified Big GWR functions will never be optimal regarding bandwidth and will always have some bias.

The large intervals for some GWR covariates may indicate that the software should not be used to analyze sparsely observed covariates. Smoking and type 1 or 2 diabetes were observed in approximately 1% of all pregnant Hispanic women in Texas. Mean GWR estimates for these covariates were 50% the magnitude of state-level estimates and 95% intervals were twelve to fifty times greater than point estimates. As no variable selection process has been implemented for Big GWR methods, variables were assessed for inclusion in state-level models, but this process may be inadequate for determining variables suitable for GWR analyses.

The proliferation of geocoding tools and GPS enabled devices have enabled the collection of geographic data, but software and computational time requirements prevent the utilization of many spatial models (126). This software utilized in this study has potential application in a variety of public health applications due to its minimal computer needs (118). While this research was conducted at the state level, no software or hardware limitation prevents utilizing the Big GWR functionality for modelling at larger scales. This research required about 8 hours to analyze 140,000 observations. Given enough time it is possible to calculate local GWR estimates across regions or nations, especially if the models were run in parallel.

Public Health Implications

This is one of the first studies to examine the spatial variation in the associations between various risk factors and GWG. The research identified a number of risk factors that are associated with non-compliance of IOM GWG recommendations and presented potential future research opportunities and tools for public health practitioners. The study expanded upon Hispanic Paradox research by detecting previously unidentified geographic patterns in the association between maternal country of birth and total GWG among Hispanic which may explain some of the disparities between US-born and foreign-born women observed in prior research. Future researchers studying Hispanic GWG should accounting for geographic location as space may confound relationships and overestimate effects between studied risk factors and GWG. The research did not show any association between potential geographic access and GWG, but it is plausible given prior research on OBGYN utilization among remote Australian women (86) that there may be a geographic distance threshold for access whereby individuals inside and outside the threshold have divergent GWG outcomes. The research may have been unable to detect any associations between access and GWG as the level of OBGYN access in Houston-The Woodlands-Sugarland MSA may have not been insufficient. Future researchers should investigate the possibility of a threshold distance for access by assessing various distances between OBGYN providers and mother's residence.

The analyses in this research can be used to identify potentially at risk groups that have associations between risk factors and outcomes that are divergent compared to other populations in an area. Commonly used geographic analysis would hide these subpopulations behind region or county-level interaction terms. Identifying these unique groups affords the opportunity for public health practitioners to identify causal mechanisms for differences and create possible health interventions for their geographic areas. The ability to identify potential at risk populations affords public health officials the ability to better allocate limited resources.

This research may serve as a template for public health practitioners to implement complex spatial models. Space is important to understanding health outcomes, but software and hardware limitations may inhibit he use of spatial models (126). Modifications to Big GWR developed in this study can accommodate categorical data that are commonly used in public health research. The software is easily scalable to calculate small area estimates for entire regions or nations. However, results from this research may demonstrate to public health practitioners that the effort to calculate the more complex models is not worth the minor improvements in some results. The influence of space on GWG may be minimal for some outcomes and measured risk factors as evident by model results for geographic access to OBGYN models that weren't substantially different in Appendix B. Reframing the research question about access to OBGYN providers and analyzing without accounting for possible spatial influence would have resulted in similar results which would have taken minutes to compute instead of days.

Limitations and Strengths

This research had more than 10% missing deliveries and results may not be representative of Texas mothers. Mothers included in these studies had higher socioeconomic status as indicated by lower Medicaid utilization, higher educational attainment, and higher prevalence of marriage compared to women excluded from final datasets. As higher socioeconomic status is associated with better health outcomes compared to individuals with lower socioeconomic status (13,22), the populations in this study may have had lower than expected prevalence of excess or inadequate GWG. Consequently, mothers utilized in this study may have experienced more GWG within IOM recommendations than expected, which may attenuate the association between some risk factors and GWG. Additionally, the research used self-reported data for assessing prepregnancy weight in calculating total GWG, which may result in measurement bias. GWG validity is known to vary by prepregnancy weight and maternal race (42,43), but prior research has shown minimal overall bias and had little impact on associations between GWG and pregnancy outcomes (43).

The research only utilized Texas resident women with a full-term delivery and may not be generalizable to other geographic areas or all pregnant women. Restricting the analysis to only full-term deliveries reduced the number of potential maternal complications that can confound GWG, but it is possible that full-term deliveries are in lesser need of OBGYN providers compared to higher-risk preterm deliveries. Overall, Texas is fast growing and largely young with a non-Hispanic white population less than 50% of the total population (127) which may not reflect demographic characteristics in other states?. Future research may want to incorporate preterm deliveries and alternate populations.

The research was largely exploratory and was not designed to identify causal mechanisms for any observed associations. The secondary birth certificate data used to analyze Hispanic women only included some socioeconomic and biological maternal characteristics. Additionally, information on location was geocoded to provide an exact address, but local area information was only available at the tract level, so neighborhood characteristics were unavailable. Future research should try to incorporate more personal maternal information through the use of alternate data sources to address this shortcoming.

Access to care is more than just a consideration of distance requirements. This research was limited by data in the birth certificate and OBGYN licensure files and was not able to incorporate other components of access including office hours or whether the office was accepting patients. These, and other factors, are known to affect whether someone utilizes provider services (64,65). Future research may improve upon this research by incorporating other components of access.

This research has a number of strengths including the analyses of small areas not previously examined, geocoded residence addresses, and a large data size. Maternal residence on the birth certificate was geocoded by the Texas DSHS to provide the exact latitude and longitude for all mothers with a live-birth delivery in Texas. This allowed for the analysis of non-aggregate data and identification of neighborhood-level small area variation in GWG outcomes among Hispanic mothers. The use of geocoded data permitted exact distances to be calculated between each mother and all OBGYN providers, which improved measurements over many studies that did not analyze birth deliveries with geocoded addresses (100). This research was conducted in Texas, the state with the second biggest land area and population in the US (128). The large population allowed for one of the largest studies of GWG ever conducted and was generalizable to Texas or the Houston-The Woodlands-Sugarland MSA. Prior research on GWG in the Houston area sampled individuals from a single hospital and was not able to generalize to the metropolitan area (25). Through the utilization of birth certificate registry records for all mothers with a singleton live births in Texas, this research represents between 2% and 4% of all births in the US in 2014 (129).

Conclusion

This research is part of a long history of epidemiological research that seeks to understand how space may be associated with health outcomes. This research showed that space was important to understanding GWG as models and results showed variation in risk factors across Texas. What began with John Snow's famous cholera map of London (44) continues today with the mapping and analysis of pregnancy outcomes in Texas. New methods utilized and developed in this research may improve public health by assessing the role of studied maternal characteristics in GWG, providing a template for future research, and by identifying new avenues of research to explain variation in the Hispanic Paradox.

APPENDICES

Appendix A: UTHSC Committee for Protection of Human Subjects Approval Letter

UTHealth
The University of Texas
Health Science Center at Houston

Committee for the Protection of Human Subjects
6410 Fannin Street, Suite 1100
Houston, Texas 77030

Dr. Christopher Webb
UT-H - GEN - Default Department Code

NOTICE OF APPROVAL TO BEGIN RESEARCH **January 23, 2018**

HSC-SPH-17-0987 - Investigating the Spatial Relationship Between Gestational Weight Gain and Access to Care, Nativity Among Hispanic Women, and Pregnancy Care Costs in Texas

Number of Subjects Approved: Target: 399482 **/Screen:** 399482

PROVISIONS: This approval relates to the research to be conducted under the above referenced title and/or to any associated materials considered by the Committee for the Protection of Human Subjects, e.g. study documents, informed consent, etc.

APPROVED: By Expedited Review and Approval

REVIEW DATE: 01/23/2018

APPROVAL DATE: 01/23/2018

EXPIRATION DATE: 12/31/2018

CHAIRPERSON: L. Maximilian Buja, MD *L. Maximilian Buja*

Subject to any provisions noted above, you may now begin this research.

CHANGES: The principal investigator (PI) must receive approval from the CPHS before initiating any changes, including those required by the sponsor, which would affect human subjects, e.g. changes in methods or procedures, numbers or kinds of human subjects, or revisions to the informed consent document or procedures. The addition of co-investigators must also receive approval from the CPHS. **ALL PROTOCOL REVISIONS MUST BE SUBMITTED TO THE SPONSOR OF THE RESEARCH.**

INFORMED CONSENT DETERMINATION:
Waiver of Consent Granted

HEALTH INSURANCE PORTABILITY and ACCOUNTABILITY ACT (HIPAA):
Waiver for Retrospective Chart Review granted:
Information to be accessed: Date of Birth, Treatment Dates
Information to be retained: Date of Birth, Treatment Dates

UNANTICIPATED RISK OR HARM, OR ADVERSE DRUG REACTIONS: The PI will immediately inform the CPHS of any unanticipated problems involving risks to subjects or others, of any serious harm to subjects, and of any adverse drug reactions.

RECORDS: The PI will maintain adequate records, including signed consent and HIPAA documents if required, in a manner that ensures subject confidentiality.

Appendix B: Multinomial Regression Model Results for Journal Article "Investigating the Association between Geographic Access to OBGYN Providers and Gestational Weight Gain"

Table 1: Adjusted Odds Ratios of Inadequate or Excess GWG by Social and Demographic Characteristics for Texas Women with a Live Birth for Models 1 and 2, 2014

	Model 1				Model 2			
DIC	159,644.68				159,626.86			
Variable	**Inadequate**		**Excess**		**Inadequate**		**Excess**	
	OR	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Intercept	0.60	0.50, 0.73	1.19	1.13, 1.25	0.65	0.50, 0.90	1.18	1.13, 1.23
Two-step catchment statistic (/100)	1.01	1.01, 1.02	0.99	0.84, 1.14	1.01	1.003, 1.02	0.997	0.85, 1.15
Maternal Prepregnancy Weight								
Underweight	1.02	0.94, 1.10	0.56	0.51, 0.61	1.02	0.94, 1.10	0.55	0.50, 0.62
Normal (ref)								
Overweight	0.65	0.61, 0.69	2.34	2.24, 2.44	0.65	0.61, 0.69	2.34	2.25, 2.45
Obese	0.93	0.88, .98	2.39	2.28, 2.49	0.93	0.88, 0.98	2.40	2.29, 2.52
Maternal race								
NH White (ref)								
Hispanic	1.09	1.03, 1.15	0.78	0.74, 0.83	1.08	1.02, 1.14	0.79	0.75, 0.83
NH Black	1.22	1.13, 1.31	1.02	0.96, 1.09	1.21	1.12, 1.31	1.02	0.96, 1.09
NH Other	1.10	1.03, 1.20	0.76	0.71, 0.82	1.10	1.02, 1.18	0.76	0.71, 0.83
Maternal age	1.00	0.99, 1.00	0.99	0.99, 0.999	0.997	0.99, 1.002	0.994	0.991, 0.998
Parity								
0 Prior births	0.89	0.85, 0.93	1.32	1.27, 1.36	0.88	0.85, 0.92	1.31	1.26, 1.37
1+ Prior births (ref)								
Maternal Nativity								
Birth in the US (ref)								
Birth not in the US	1.12	0.95, 1.32	0.80	0.77, 0.84	1.002	0.75, 1.33	0.80	0.76, 0.84

Any smoking during pregnancy	0.98	0.97, 0.99	1.22	1.07, 1.37	0.98	0.98, 0.99	1.22	1.09, 1.40
Yes								
No (ref)								
Any Diabetes								
Yes	1.33	1.23, 1.43	0.84	0.78, 0.90	1.31	1.20, 1.42	0.85	0.79, 0.92
No (ref)								
Marital Status								
Married (ref)								
Not Married	1.08	1.04, 1.13	1.11	1.07, 1.15	1.08	1.03, 1.13	1.11	1.07, 1.16
Prenatal care utilization index								
Inadequate	1.26	1.13, 1.39	1.05	0.96, 1.15	1.26	1.13, 1.40	1.06	0.96, 1.16
Intermediate	0.96	0.91, 1.02	1.03	0.98, 1.07	0.96	0.91, 1.01	1.03	0.98, 1.08
Adequate or Adequate Plus (ref)								
Prenatal care initiated in the first trimester								
Yes (ref)								
No	1.07	1.02, 1.12	0.95	0.91, 0.99	1.07	1.02, 1.12	0.95	0.90, 0.99
Number of prenatal visits	0.99	0.98, 0.99	1.01	1.004, 1.02	0.99	0.98, 0.995	1.01	1.005, 1.02
Maternal educational attainment								
No high school degree	1.17	1.09, 1.26	0.93	0.87, 0.99	1.14	1.05, 1.23	0.94	0.89, 0.999
High school degree	1.15	1.07, 1.23	1.05	0.997, 1.11	1.14	1.07, 1.21	1.06	1.0002, 1.12
Some college	1.04	0.98, 1.10	1.14	1.08, 1.19	1.03	0.97, 1.09	1.14	1.09, 1.20
Bachelor's degree or higher (ref)								

Expected payor source								
Medicaid	1.11	1.05, 1.16	0.99	0.96, 1.03	1.10	1.04, 1.15	0.99	0.95, 1.03
Non-Medicaid (ref)								
Tract Level Covariates:								
Median personal income					1.00	0.99, 1.00	0.999	0.999, 0.999
Income less than 100% of FPL (%)					1.34	1.02, 1.74	0.82	0.65, 1.10
With Health Insurance (%)					0.87	0.61, 1.15	1.30	0.97, 1.77

Abbreviations: OR, Odds Ratio; CI, credible interval

Table 2: Adjusted Odds Ratios of Inadequate or Excess GWG by Social and Demographic Characteristics for Texas Women with a Live Birth for Models 3 and 4, 2014

	Model 3				Model 4			
DIC	159,538.85				159,535.16			
Variable	**Inadequate**		**Excess**		**Inadequate**		**Excess**	
	OR	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Intercept	0.63	0.52, 0.77	1.18	1.12, 1.24	0.65	0.47, 0.88	1.17	1.12, 1.23
Two-step catchment statistic (/100)	1.01	0.999, 1.02	0.99	0.84, 1.15	1.01	0.996, 1.02	0.99	0.85, 1.16
Maternal Prepregnancy Weight								
Underweight	1.02	0.93, 1.11	0.55	0.51, 0.61	1.02	0.93, 1.11	0.55	0.50, 0.61
Normal (ref)								
Overweight	0.65	0.61, 0.68	2.34	2.25, 2.44	0.65	0.61, 0.68	2.35	2.25, 2.45
Obese	0.93	0.88, 0.98	2.40	2.30, 2.51	0.93	0.88, 0.98	2.41	2.30, 2.52
Maternal race								
NH White (ref)								
Hispanic	1.09	1.03, 1.16	0.79	0.75, 0.83	1.08	1.01, 1.15	0.79	0.75, 0.83
NH Black	1.21	1.13, 1.30	1.01	0.96, 1.08	1.20	1.12, 1.29	1.01	0.96, 1.07
NH Other	1.10	1.02, 1.19	0.76	0.71, 0.82	1.10	1.02, 1.19	0.76	0.71, 0.82
Maternal age	0.997	0.99, 1.001	0.995	0.991, .998	0.998	0.99, 1.002	0.99	0.99, 0.998
Parity								
0 Prior births	0.88	0.85, 0.92	1.32	1.28, 1.37	0.89	0.85, 0.93	1.32	1.27, 1.37
1+ Prior births (ref)								
Maternal Nativity								
Birth in the US (ref)								
Birth not in the US	1.003	0.83, 1.20	0.79	0.76, 0.83	0.88	0.68, 1.15	0.80	0.76, 0.83
Any smoking during pregnancy	0.99	0.98, 1.0002	1.21	1.08, 1.37	0.99	0.98, 1.001	1.22	1.08, 1.38
Yes								

No (ref)								
Any Diabetes								
Yes	1.31	1.20, 1.42	0.84	0.78, 0.90	1.31	1.20, 1.41	0.84	0.78, 0.91
No (ref)								
Marital Status								
Married (ref)								
Not Married	1.08	1.03, 1.13	1.12	1.07, 1.17	1.07	1.02, 1.12	1.12	1.08, 1.16
Prenatal care utilization index								
Inadequate	1.25	1.12, 1.39	1.05	0.96, 1.16	1.25	1.13 1.39	1.06	0.96, 1.16
Intermediate	0.96	0.90, 1.01	1.02	0.97, 1.07	0.96	0.90, 1.02	1.02	0.98, 1.07
Adequate or Adequate Plus (ref)								
Prenatal care initiated in the first trimester								
Yes (ref)								
No	1.08	1.03, 1.13	0.95	0.91, 0.99	1.07	1.02, 1.13	0.95	0.91, 0.99
Number of prenatal visits	0.99	0.98, 0.995	1.01	1.004, 1.02	0.99	0.98, 0.995	1.01	1.004, 1.02
Maternal educational attainment								
No high school degree	1.17	1.09, 1.25	0.94	0.88, 0.99	1.14	1.06, 1.22	0.94	0.88, 0.998
High school degree	1.16	1.08, 1.24	1.05	0.99, 1.12	1.14	1.06, 1.23	1.05	0.99, 1.12
Some college	1.05	0.99, 1.11	1.13	1.08, 1.19	1.04	0.97, 1.10	1.13	1.07, 1.19
Bachelor's degree or higher (ref)								
Expected payor source								
Medicaid	1.10	1.05, 1.15	0.999	0.96, 1.04	1.09	1.05, 1.15	1.001	0.96, 1.04
Non-Medicaid (ref)								

Tract Level Covariates:				
Median personal income	1.0	0.999,1.0001	0.999	0.999,1.0001
Income less than 100% of FPL (%)	1.30	0.99, 1.71	0.93	0.74, 1.27
With Health Insurance (%)	0.94	0.68, 1.27	1.29	0.97, 1.71

Abbreviations: OR, Odds Ratio; CI, credible interval

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