MATERNAL MORTALITY: SPATIAL AND RACIAL DISPARITIES IN UNITED STATES

by

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Dedicated to My Parents

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ABSTRACT

Over the last century, developed countries have been successful in enhancing maternal health and reducing Maternal Mortality Ratio (MMR). By 2018, MMR across OECD countries and World Bank Group Regions have converged towards very low levels, averaging more than 5 deaths per 100,000 live births. The United States has become an outlier among the developed countries in maternal deaths and compares unfavorably to a number of poorer countries where the ratio has declined. In 2017, the US ranked worst in MMR among the 39 industrialized nations. United States has experienced almost a 142 percent increase in MMR from 1987-2018. According to the Centers for Disease Control and Prevention (CDC), every year in the US, more than 700 women die due to the pregnancy or childbirth-related complications, with 60 percent of these deaths being preventable. Within the US, MMR varies considerably, leaving large disparities across states as well as between all racial groups. This research study aims to understand the interplay of spatial and racial impacts on the variation of maternal mortality ratios within the US. The paper estimates Ordinary Least Squares (OLS) and Spatial Lag Models for MMR using cross-sectional US state data for 2012-2017, taken from CDC. The results show that the dominant root causes of high maternal mortality differ between black and white women.

CHAPTER 1. INTRODUCTION

The health of a mother and baby is a fundamental measure for a society's advancement. Maternal health is therefore alternatives used for estimating health status in developing countries. Therefore, the death of a woman during pregnancy, or after the termination of pregnancy, is a significant tragedy for the family as well as for the society. All over the world, an outsized number of women die or suffer severe injuries due to pregnancy and childbirth. Although a definite measurement of maternal mortality levels remains challenging, it is evident that many thousands of women are still dying from pregnancy-related complications and plenty of these deaths remain uncounted.

By 2030, the Sustainable Development Goal (3.1) is to cut back Maternal Mortality Ratio (MMR) to less than 70 deaths per 100,000 live births (SDG 3, 2019). Previously, the Millennium Development Goal 5 (MDG 5A) was to reduce the 1990 MMR by 75 percent by 2015 and WHO's 2015 report mentions that although there was substantial progress, no MDG region could achieve this target (WHO, UNICEF, UNFPA, World Bank, & UNDP, 2015). Moreover, this report revealed that worldwide over the past 25 years, MMR dropped by almost 44 percent and the lifetime risk of maternal mortality also dropped from 1 in 73 to 1 in 180. Still in 2017, daily close to 810 women died from pregnancy or childbirth related complications that were mostly preventable. In this same period, the lifetime risk of maternal mortality was computed 1 in 190 women (WHO, 2020a).

Maternal death is considerably higher in the least developed countries with Southern Asia and sub-Saharan Africa accounting for about 86 percent of the universal maternal deaths in 2017. The countries with extremely high MMR are South Sudan, Chad, and Sierra Leone (more than 1,100 deaths per 100,000 live births). Globally, with a 38 percent reduction in maternal mortality (from 342 deaths to 211 deaths per 100,000 live births) between 2000 and 2017, the US is one of the 13 countries that has gone against the flow, showing increasing ratios (WHO, UNICEF, UNFPA, Bank, & UNDP, 2019). Maternal mortality ratios have been falling in every other wealthy country as well as in many less affluent countries. For example, OECD countries have converged to very low levels of MMR, averaging about 5.5 deaths in 100,000 live births by 2018 (OECD, 2020). As such, the US has become an outlier among the rich nations in maternal deaths and compares unfavorably to a number of poorer countries where the ratio has declined, including Vietnam, Iran, Romania, and Russia (IHME, 2018b).

In 2017, the US ranked worst in maternal mortality among the 39 industrialized nations (Allison Winter, 2019). During the period from 2000 to 2017, the annualized rate of change in MMR was +2.5 percent for North America, where it is +2.6 percent for the US and +0.6 percent for Canada. This annualized rate of change was negative in every other region of the world. South Asia had the highest annual reduction in MMR (Figure 1) during that time.

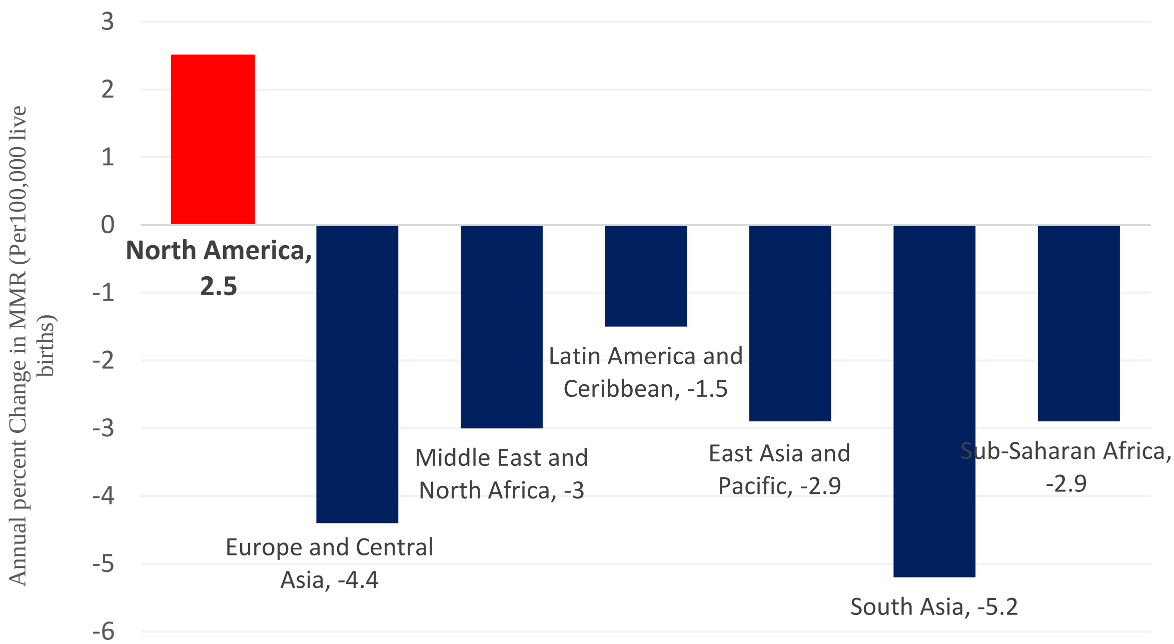


Figure 1**.** Average Annual Percent Change in Maternal Mortality Ratio, 2000-2017
Source: WHO MMR Data (WHO et al., 2019)

In comparison to selected developed countries during 2017, MMR of the US was 19 deaths where it was 7 deaths in the United Kingdom and 10 deaths in Canada (WHO et al., 2019). Figure 2 shows that, by 2017, the national MMRs had converged towards very low levels in some developed countries,[1] but the ratio of the United States went in the opposite direction. The ratio increased about 58 percent from 1990 to 2017 in the US. New Zealand, Republic of Korea, Sweden made remarkable progress in reducing MMR. Recent data also shows that women in the US are

[1] Countries in every World Bank Group region are listed at: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups%20

six times as prone to die as women in Scandinavian countries and more than three times as prone to die as Canadian women during their maternal period (IHME, 2018b). This uptick happened yet as maternal death dropped in the less-developed countries around the world. Currently women giving birth in Saudi Arabia or China are at lower risk of dying than women giving birth in the United States.

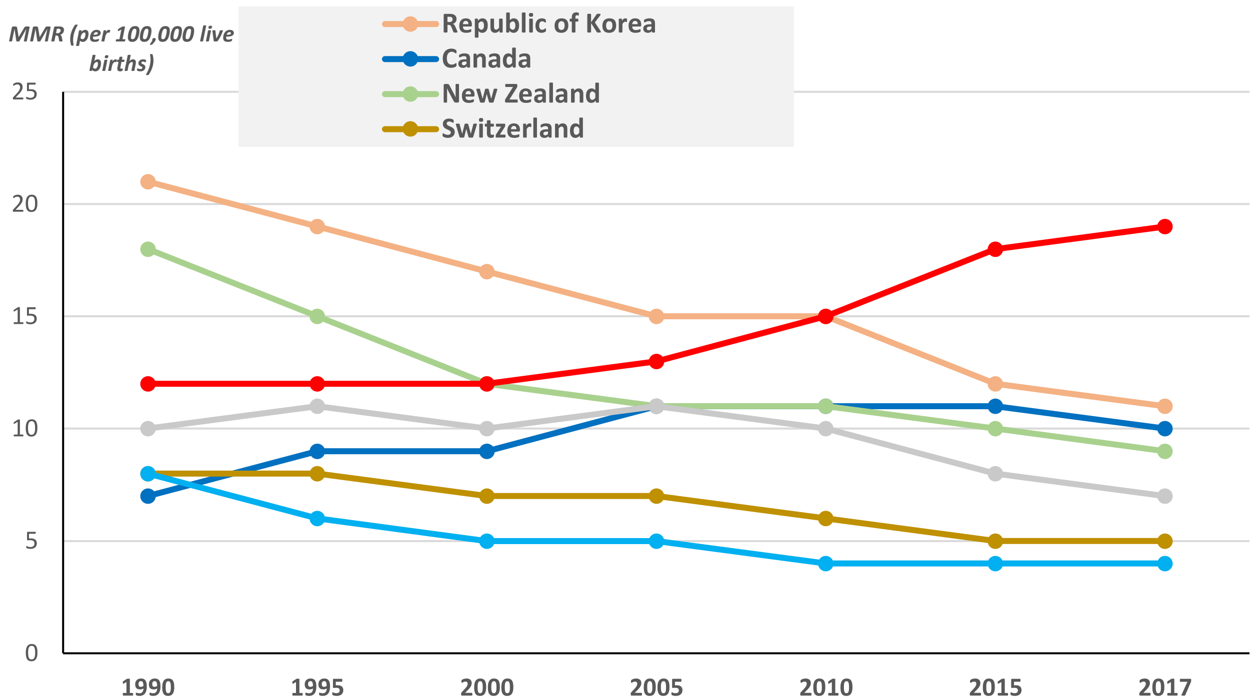


Figure 2. Maternal Mortality Ratio in Selected Developed Countries 1990 – 2017
Data Source: WHO MMR Data (WHO et al., 2019)

Over the past decades, the US experienced an increasing ratio of maternal deaths in every year. The Centers for Disease Control and Prevention (CDC) in their recent report mentioned that, every year in the US, about 700 to 900 women die because of pregnancy or delivery related complications (CDC, 2020a), In the developed world a significant decline in maternal deaths happened during the mid-20th century but in the US, the decline stalled in the late 20th century. In 1915, the US MMR was about 608 deaths and reduced to 12.1 deaths per 100,000 live births in 2003, rose again to 17.4 in 2018 (Hoyert, 2007; Hoyert & Miniño, 2020; Hoyert, Uddin, & Miniño, 2020). Furthermore, around 2000, the ratio began to rise and became almost double. Figure 3 shows the uprising trend of maternal deaths ratio where the US experienced an almost 142 percent increase of MMR from 1987-2018.

The reason for this disturbing trend is not evident. It is not clear whether the degree to which this increase in maternal deaths in the US can be attributed to enhanced identification of deaths or an actual increase in risk (Creanga et al., 2015a). At the same time, there is a persistent disparity in maternal mortality between African-American women compared to White women in the US (Creanga et al., 2012). Importantly, the impact of advanced maternal age on pregnancy-related maternal deaths might be an important contributing factor (Davis, Hoyert, Goodman, Hirai, & Callaghan, 2017).

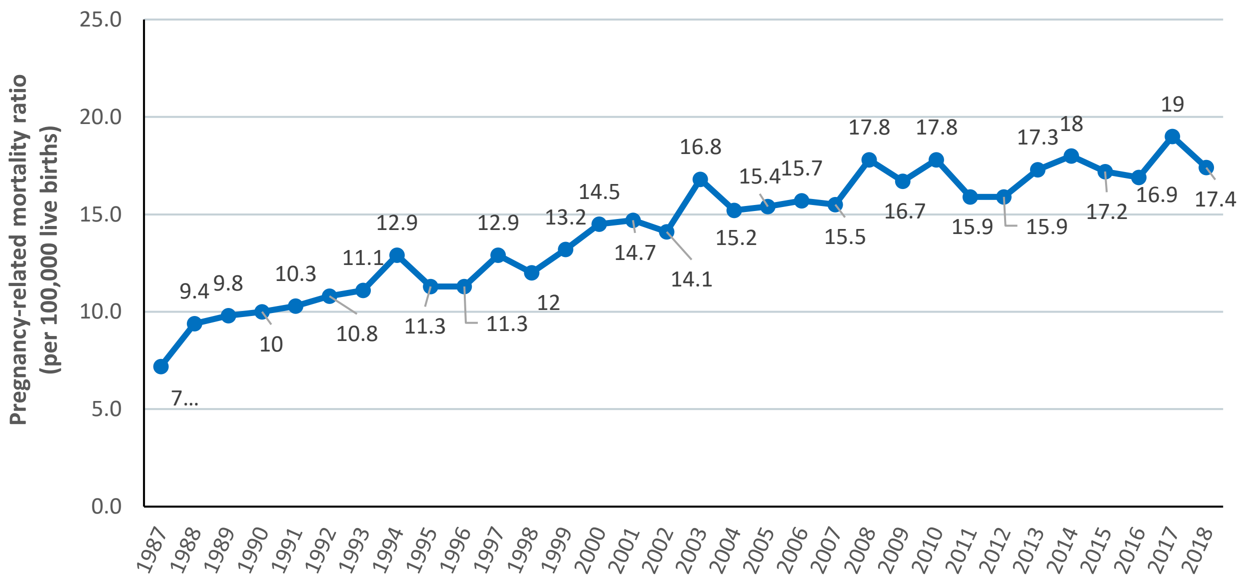


Figure 3. Trends in Pregnancy-Related Mortality in the United States: 1987-2018
Source: Pregnancy Mortality Surveillance System, CDC (CDC, 2020b)

In the US, spending on healthcare is among the highest in the world but still, the maternal mortality ratio is increasing significantly. According to a recent study, about 60 percent of maternal deaths are preventable (CDC, 2020c). But due to medical errors, unequal access to care, and pre-existing conditions, the life-threatening complications for new mothers in the US have been doubled in the last two decades. Additionally, in recent years, severe maternal morbidity has been increasing. For instance, in 2014, more than 50,000 women in the US were affected by maternal morbidity. The consequences of this increasing trend include longer hospital stays and increased medical treatment costs (CDC, 2020c).

The upsurge of maternal deaths in the US is worrisome and historic. Within the US, MMR varies substantially, manifested by large disparities across states as well as among racial groups. In 2018, state MMRs averaged about 17.4 deaths, ranging between 9.7 (Illinois) and 45.9 (Arkansas) deaths per 100,000 live births (NCHS, 2020). Moreover, the MMR gap between non-Hispanic black and white was almost 23 deaths per 100,000 live births. In 2017, disaggregating by race shows stark contrasts by race and across states. For whites, the MMR varied between 11.5 (North Dakota) and 57.74 (Louisiana), for blacks between 18.5 (Arizona) and 151.2 (New Mexico). Figure 3 shows that over time, the US maternal mortality ratios have not experienced substantial reductions and for blacks, the MMR increased in many states. These developments are worrisome considering the goal of US Department of Disease Prevention and Health Promotion's (Healthy People 2020):

1) reaching an MMR of 11.4 by the year 2020 (Healthy People, 2020b); and
2) eradicating racial disparities in accessing health care.

The 2020 strategic initiatives of the "Healthy People 2020" explicitly address maternal mortality issues by comparing its target with a baseline year's (2007) ratio of 12.7 (12.1 in Non-Metropolitan areas and 12.8 in Metropolitan area) (Healthy People, 2020b). A series of articles published in the *New York Times* and *ProPublica* in the last few years also have emphasized the poor national standing of the US in world rankings, spatial and racial disparities, as well as potential causes such as the inefficiency of health care centers during emergencies, excessive bleeding during childbirth and disparities in access to health care.

Many studies already have discussed the role of social determinants of health in explaining unfavorable birth outcomes, neonatal disparity, low birth weight (Lorch & Enlow, 2016). However, comparatively little attention has been given to exploring the linkage between social factors and MMR. In this thesis, we are contributing to this area. The focus of this research is on the interplay of spatial and racial impacts on the variation of maternal mortality ratios within the US. Two questions are addressed here:

1) The first question asks whether racial disparities persist once variations in the typical predictors of maternal mortality—mother's education, age, teenage birth rate, prenatal care, health insurance coverage, and tobacco use during pregnancy—are considered.

2) The second question asks whether spatial disparities persist even after the racial disparities are considered along with the traditional predictors. Towards that end, spatial econometric models are estimated for maternal mortality ratios in US states.

We hypothesize that racial and spatial disparities persist even after controlling for social factors, behavioral factors, healthcare availability and accessibility. The research paper is divided into five parts. Following this introduction section, the next section provides the background of the study, when dealing with the literature on the determinants of maternal deaths as well as the spatiotemporal variation of black and white MMR in the US. The third section presents data and variables. The fourth section reports the empirical analysis, starting with model specifications and is followed by the modeling results in the fifth chapter. The paper concludes with a summary of the findings, limitations of the study, and few suggestions for the possible future research.

CHAPTER 2. BACKGROUND

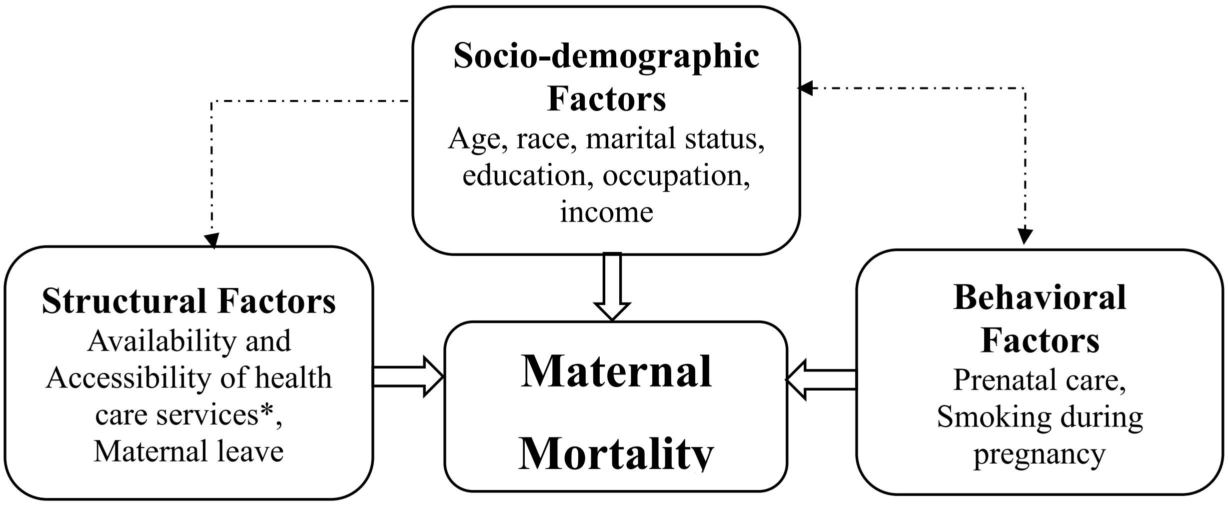
2.1 Determinants of Maternal Mortality

A woman's body experiences considerable hormonal transformations during pregnancy, most of which are normal. But the situation gets worse if there is any disbalance or abnormal transition happens. A women's death during pregnancy or postpartum is a tragic occurrence which has instantaneous as well as long term influences on her family. Her valuable years of community contribution are gone, and surviving children are left motherless. From individual health determinants to universal issues, maternal deaths act as an early warning system for a society's whole health system.

According to the WHO, if a woman dies during pregnancy or anytime within 42 days of the termination of pregnancy, not from any accidental cause but any event related to or aggravated by the pregnancy, it will be considered as a maternal death (WHO, 2020b). After the 10th revision of the International Classification of Disease (ICD-10), the new term late maternal deaths were added. If a woman dies from obstetric causes anytime from 42 days to within one year after the termination of pregnancy, then it will be considered as a late maternal death (Hoyert, 2007). Maternal death is commonly measured as the maternal mortality ratio (MMR). For each 100,000 live births in a certain area, MMR represents the number of women who die from pregnancy-related causes. This ratio is often considered an indicator of a nation's health.

Maternal death is a tragedy because most of the deaths due to pregnancy are considered preventable through timely effective intervention. In the US, according to a recent report from the CDC, about three in five maternal deaths were preventable during 2013-2017 period (Petersen, Davis, Goodman, Cox, Mayes, et al., 2019). The root causes of maternal mortality are multiple and complex as maternal health is a complicated issue that is influenced by many interconnected factors. And to prevent any future death, a better understanding of the circumstances of pregnancy-related deaths is essential. According to Solar and Irwin, individuals with differential exposure and vulnerability to social determinants may experience differential rates of pregnancy complications and disability (Solar & Irwin, 2010). Hence, social determinants of health influence the susceptibility to maternal mortality and morbidity.

We can group the contextual factors into three broad categories: socio-demographic, structural, and behavioral factors. Following Waldorf and Chen (2010), Figure 4 shows the interconnection between factors that influence maternal death.



**Health care services refer to hospitals, acute care facilities, physician offices and clinics that comprise the healthcare system of a region*

Figure 4. Factors Influencing Maternal Mortality

2.1.1 Socio-economic Factors

In general, there is insufficient socio-economic data in the death certificate. But understanding the connection between socio-demographic factors or maternal attributes like age, race, marital status as well as economic status is very important to combat the high risk of maternal death. Some of the maternal attributes have a direct impact on maternal deaths. In countries with high income, women sometimes have—due to their lifestyle—health conditions that worsen during pregnancy. These conditions may include, for example, obesity, gestational diabetes, and anemia. In affluent countries, MMR decreases with an increase in years of education. The Institute for Health Matrix and Evaluation finds that on average with 8.13 years of education, MMR is 66.29; with 13.5 years of education, MMR is 4.99 in high-income countries (IHME, 2018b).

The mother's age influences the incidence of multiple births as well as of high-risk pregnancies. According to the CDC, women aged 40 years and older experience an almost eight times higher death rate (81.9 versus 10.6 per 100,000 live births) than women under age 25 years (NCHS, 2020). And the overall risk gets higher with maternal age (Petersen, Davis, Goodman, Cox, Syverson, et al., 2019). The maternal health crisis in the US reflects the rising levels of poverty and significant economic inequalities as well. For all women, higher rates of deaths are associated with higher poverty rates. A study done by Gupta Singh found that women with middle and high poverty groups in the US had a 90 to 220 percent risk of higher maternal death compared to a low poverty group. He found that higher poverty rates, percentage of immigration population, and cesarean rates are uniquely associated with higher maternal mortality rates (Singh, 2010).

2.1.2 Structural Factors

The salient structural factors include the availability and accessibility of health care services and maternal leave options from the workplace. For many women, difficulties in accessing proper health care start before pregnancy. They face difficulties in access to family planning services and regular primary health care. Despite the execution of the Affordable Care Act (ACA), which contained the abolition of racial disparities as the main goal, racial disparities in access to care in the US still exists (Buchmueller, Levinson, Levy, & Wolfe, 2016). And similarly, there are disparities in access to health insurance which is critically important for a healthy pregnancy.

Moreover, safe childbirth depends crucially on the health care facility settings where a pregnant woman delivers her child. There is still a shortage of healthcare personnel in the US. According to the latest survey of the American Congress of Obstetricians and Gynecologists (ACOG), around fifteen percent of the US population lives in a rural area but only six percent of obs-gynae physicians work in rural areas. Less than half of rural women reside within a 30-minute driving distance to a nearby hospital that offers obstetric services (Dina Fine Maron, 2017). Some rural counties do not even have obstetrical services, and primary care physicians are not filling that gap in sufficient numbers. In 2010, about 10 percent of family physicians offered obstetrics services, compared to 23 percent in 2000 (Tong et al., 2013). With the high number of hospital closure and shortage of physicians in rural areas, access to quality healthcare in rural areas has been in decline. Since 2010, almost eighty rural hospitals have been closed in the US and a third of the remaining rural hospitals are about to be closed due to a shortage of funds (SHEPS, 2014).

Best practices for handling obstetric emergencies exist but the inconsistency in terms of clinical performances still contributes to disparities and it inevitably results in poor outcomes for pregnant women (Agrawal, 2014). And without proper approaches to incorporate such obstetric emergencies during childbirth, some women receive high quality of health care while others do not get that. According to a report of USA Today, women suffer life-changing physical injuries or sometimes even die during their childbirth because of ignoring basic practices by the hospitals, doctors, and nurses. By employing simple actions like measuring blood loss during and after child delivery and providing proper treatment for controlling high blood pressure at the birth center, can save the lives of many mothers (Ungar, 2019).

Thus, access to proper health care is the key to minimize the risk of pregnancy-related death. Limited availability of maternity leave is also one of the challenges mothers usually face. Paid and unpaid leave during or after pregnancy should have distinct consequences. Choosing between a paycheck and leave without payment might increase adverse short and long-term health outcomes during postpartum recovery for a mother.

2.1.3 Behavioral Factors

Behavioral factors such as consuming tobacco products during pregnancy, maintaining a sedentary lifestyle, and not having prenatal care also play a crucial role in maternal death. Smoking cigarettes and using different tobacco products during pregnancy is detrimental to the health of both baby and mother. It is sometimes linked to miscarriage, ectopic pregnancy, low birth weight, excessive bleeding, etc. According to a recent analysis by America's Health Rankings' for 2013-2017, about 6.9 percent of women used tobacco during their pregnancy and West Virginia has the highest prevalence with 24.7 percent of women (AHR, 2019). The study also found that during pregnancy, women residing in rural counties are almost twice as likely to smoke than those residing in urban counties (Creanga et al., 2015b). The initiation of prenatal care provides health practitioners an opportunity to identify the risk factors early. It increases the possibility to address chronic health issues like diabetics, hypertension, and obesity. Another study found that inadequate prenatal care is associated with an increased risk of premature delivery (Krueger & Scholl, 2000). Hence, maintaining a healthier lifestyle, having regular check-ups and consistent health care is key to having a healthy pregnancy.

2.2 Causes of Maternal Death

Maternal deaths are categorized by the International Classification of Diseases, 10th Revision's (ICD-10) into some underlying death cause codes: A34 (obstetrical tetanus), O00-O95, and O98-O99 (Pregnancy, childbirth, and the puerperium). Late maternal deaths (those occurring more than 42 days following pregnancy) are identified using codes O96-O97. The definition of maternal death does not consider accidental and incidental deaths (WHO, 2009). According to the WHO, there are two types of maternal death causes: direct causes and indirect causes of obstetric deaths. Direct obstetric death results from obstetric complications during pregnancy, labor, and puerperium from intervention, inaccurate or absence of the treatment. It refers to conditions that women would only experience if she is pregnant, while indirect maternal deaths are from a co-morbid condition.

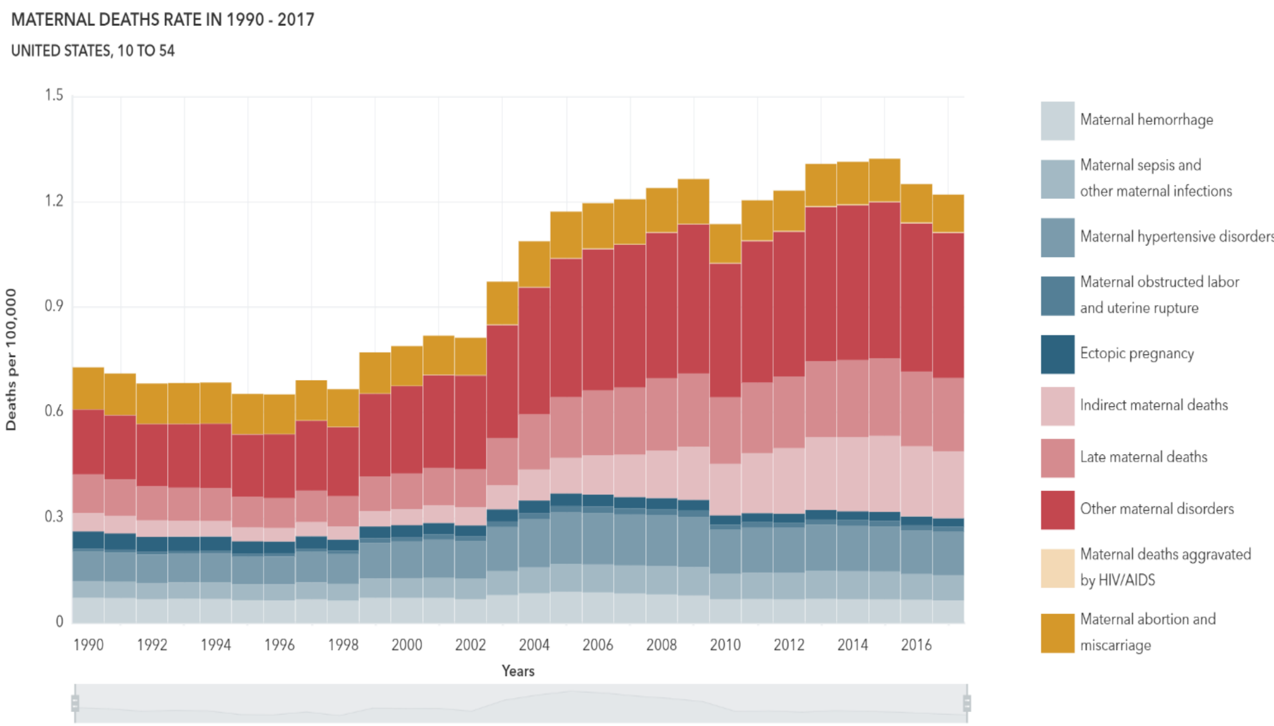


Figure 5. Causes of Maternal Death in the United States, 1990-2017
Source: Adapted from Maternal Health Atlas of Institute for Health Metrics and Evaluation (IHME) https://maternalhealthatlas.org/breakdown

Indirect obstetric deaths are the consequences of a previous existing disease or any sort of disease which develops during pregnancy. It also considers diseases exacerbated by physiologic impacts of pregnancy but not due to the direct obstetric causes. Late maternal deaths consider any death from indirect or direct causes within 43 days to one year after the termination of pregnancy (Hoyert et al., 2020; WHO, 2009). Among the direct causes, excessive bleeding after childbirth or postpartum hemorrhage, are considered the main causes of maternal death around the world (UNICEF, 2019).

In the US, other maternal disorders including anemia, gestational diabetes, and embolism capture the largest portion of maternal deaths (IHME, 2018a). As half of the pregnancies in the United States are not in planned way, many women do not focus on chronic health issues in advance (Nina Martin & Renne Montagne, 2017). As a result, most of them end up with risky pregnancies. Besides, a larger number of C-sections commences to life-threatening complications to mothers. Figure 5 shows the different causes of maternal deaths in the United States.

A study to explore the causes of maternal death in California shows that there was a strong possibility to alter the outcomes of about 41 percent of deaths. The notable preventable deaths are from preeclampsia (60 percent) and hemorrhage (70 percent) (Main, McCain, Morton, Holtby, & Lawton, 2015). To explore the maternal deaths, a recent report from the maternal mortality review committee of Colorado, Delaware, Ohio, and Georgia mentions that hemorrhage and cardiovascular conditions are the primary causes of maternal deaths, followed by cardiomyopathy, infection, embolism, mental health disorder, and preeclampsia between 2008 to 2012 in US (CDC Foundation, 2017).

2.3 Identification of Maternal Deaths in the United States

In the US, there are two national sources of maternal deaths data from CDC. The first one is the National Vital Statistics System (NVSS) of the National Center for Health Statistics (NCHS), and second one is the Pregnancy Mortality Surveillance System (PMSS). NCHS provides MMR(per 100,000 live births) from the death certificates using the WHO's definition (deaths during or 42 days after the termination of pregnancy) (CDC, 2020a) and has provided MMR information since 1915. These rates are used for US official data for maternal mortality as well as for international comparison by the WHO. As NVSS depends only on death certificates, there is a lack of detail information such as what happened to cause a woman's death. Then in 1986, to better understand the maternal deaths beyond the coded death certificate data, the PMSS was developed by the CDC and the ACOG (Amy et al., 2018).

PMSS introduced two terms to identify potential maternal deaths, causes of death, and finding a link between fetal death and birth certificates. Those are pregnancy-associated death (death during or within one year after the end of pregnancy, and from any cause that not related to pregnancy. Deaths having temporal relationship to pregnancy also are included), pregnancy-related deaths (death of a woman caused by pregnancy related complications or its management but not due to accidental causes during or within one year after termination of pregnancy. In addition to having a temporal relationship to pregnancy, these are related to pregnancy management) (Davis, Smoots, & Goodman, 2019).

In the US, New York City and all the 50 states and Washington District of Columbia send their copies of death certificates, linked birth or fetal death certificates to CDC. After reviewing the information, medically trained epidemiologists then determine the underlying causes of death and decide whether it is pregnancy-related or pregnancy-associated but not related. Studies show that before 2000, the examination of maternal deaths indicated substantial underreporting of maternal deaths in NVSS (Horon, 2005; MacKay et al. 2005).

To improve the identification of maternal deaths, a pregnancy question with a series of checkboxes (to determine whether the woman was currently or recently pregnant) has been added to the 2003 revision of the US death certificate. Physicians are instructed to check the specific box for a known pregnancy within the time frames before the death. By mid-2017, all states had adopted the revised version of the death certificates.

After including only a checkbox on the revised death certificate, it might possible that some deaths are assigned as a maternal code when the medical conditions are incidental to the pregnancy. It means those are neither caused nor complicated by pregnancy. Consequently, without having enough information on the certificate, coders assign a maternal code by assuming that there is a relationship between pregnancy and the medical conditions (Hoyert et al., 2020).

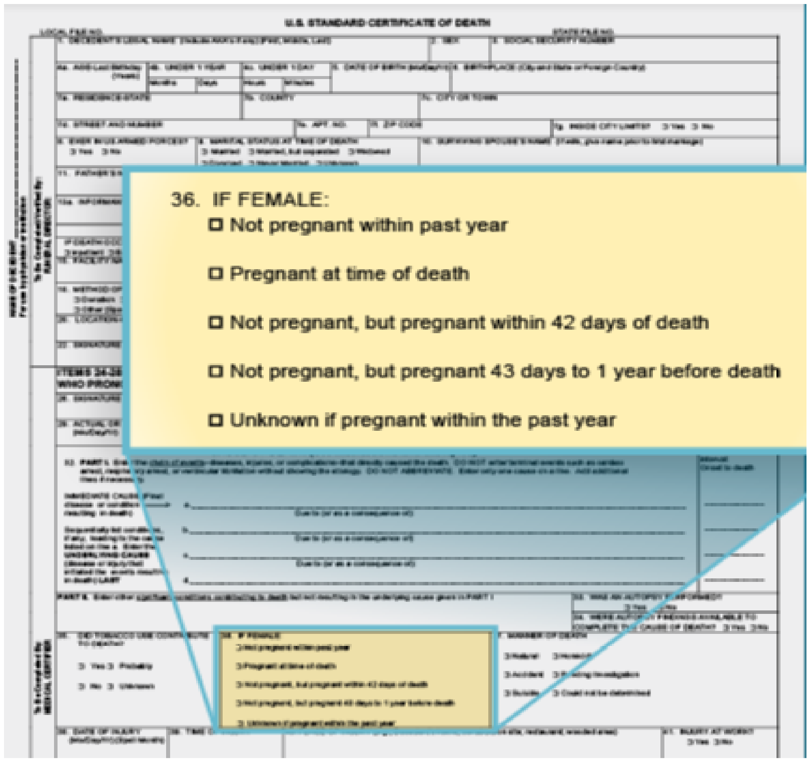


Figure 6. Pregnancy Checkbox from the United States standard certificate of death
Source: Adapted from (Branum, 2020).

It has been already evident that there was a certain percentage of death certificates where a pregnancy checkbox may have been selected in error (Rossen, Womanck, Hoyert, Anderson, & Uddin, 2020) especially for the group of women who are 40 years or older (Davis et al., 2017). Finding error rates in this group, NCHS has released 2018 maternal mortality data with a new coding system applicable to women aged 45 and older (NCHS, 2019). Despite the outcomes that the pregnancy checkbox contributed to the increase of true and false maternal deaths, the absolute risk of maternal death still remains very high with persistent racial and geographic disparities (Amy et al., 2018).

2.4 Racial Variations of Maternal Mortality across the US

Not every woman experiences the same difficulty or risk during pregnancy and childbirth. In the US, racial or ethnic disparities in pregnancy-related mortality are substantial. Unlike white mothers, the deaths of black mothers are the main contributors to the highest rate of maternal mortality in the US (Moaddab et al., 2018). During the past six decades, maternal death has remained around three to four times higher amongst black women than the white women (Singh, 2010). Compared to white women, American/Alaska Natives and Black women were two to three times more likely to die from pregnancy-related complications from 2007 to 2016 in the US. Black women who are older than 30 years, mostly experience MMRs that are 4 to 5 times higher than those of their white counterparts (Petersen, Davis, Goodman, Cox, Syverson, et al., 2019).

According to a recent report from the CDC, there are still broad gaps between MMR of non-Hispanic white women (14.7), non-Hispanic black women (37.1), and Hispanic women (11.8) (NCHS, 2020). Black woman's voices and concerns are also absent from the public discussion about the maternal health crisis and tackling the problems. This unequal risk, which black women experience during and after their pregnancy, leads to more maternal mortality, morbidity crisis in the US and these gaps are not changing over time as well as across the age groups. Figure 7 shows that Black women have the highest pregnancy-related deaths (40.8 deaths) which is about three times higher than the white women (12.7). The disparity ratios have not changed over time.

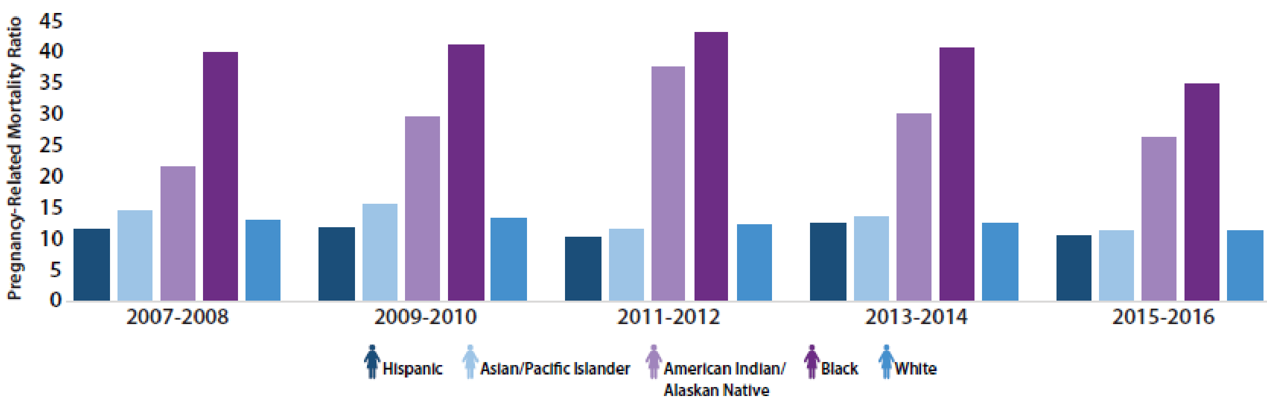


Figure 7. Pregnancy-Related Maternal Deaths in 2007-2016: Racial/Ethnic Disparities in the US
Source: Adapted from the maternal mortality section of CDC (CDC, 2020d).

Pregnancy outcomes for black women are intensifying many efforts taken by medical experts and academics to realize what is driving the racial disparity. Many studies have found racial and ethnic disparities in obstetric care and resulted in unfavorable pregnancy outcomes. Using national data, a study found that 75 percent of Black deliveries occurred in 25 percent of hospitals whereas only about 18 percent of Whites delivered in that same portion of hospitals (Howell, Egorova, Balbierz, Zeitlin, & Hebert, 2016). Black-serving hospitals are having lower performance in providing emergency healthcare and women who deliver at these centers are more likely to have serious complications than mothers who deliver at white-serving hospitals (Annie Waldman, 2017; Creanga et al., 2014; Grobman et al., 2015; Howell et al., 2016).

Women who are from densely African American populated ZIP code, experienced longer hospitalizations with ectopic pregnancy than the others (Stulberg, Zhang, & Lindau, 2011). These studies suggest that delivery place matters and good quality of obstetric care measures are essential to track racial disparity at the healthcare facility.

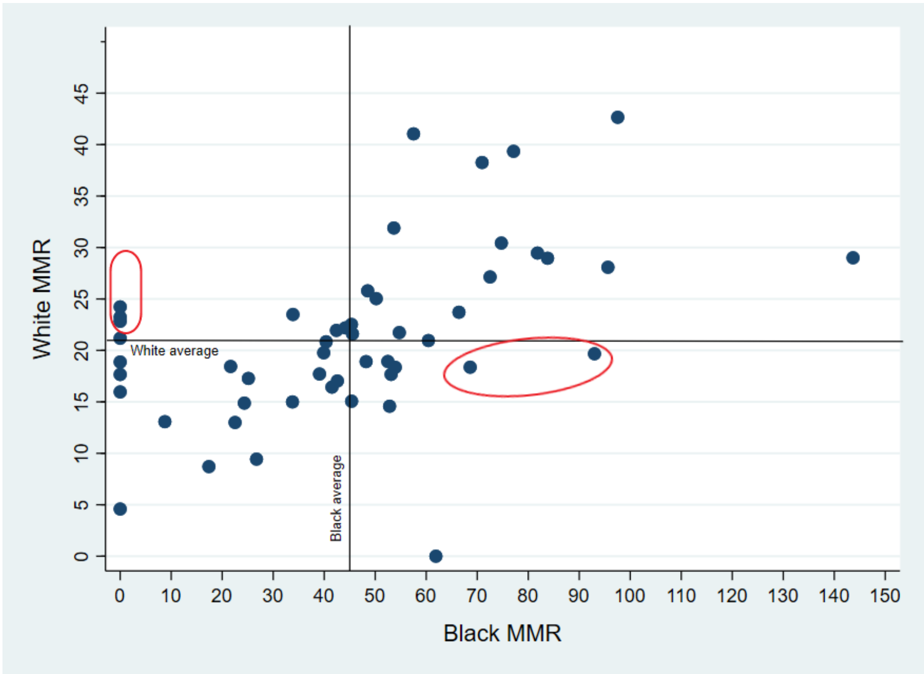


Figure 8. Association of Black and White Maternal Mortality Rates Across US States
Data Source: CDC WONDER online database

Figure 8 shows that there is only a weak association between black and white MMR. The most extreme racial disparities are observed in two locations, namely Iowa and Maine where above-average black maternal mortality is paired with below-average white maternal mortality (lower right-hand quadrant). Most notable are states in which a very low black MMR pairs with above-average white mortality (upper left-hand quadrant). These states include Vermont, New Hampshire, and South Dakota. They all have very small black populations. States with an above-average MMR for blacks and whites are mostly located in the South or the Midwest or the urbanized East (upper right-hand quadrant). States in this group are New Mexico, South Carolina, Oklahoma, Wyoming, Texas, Georgia, Louisiana, Arkansas, and Tennessee in the South region.

Indiana, Michigan, Missouri, and Kentucky in the Midwest area, as well as New Jersey is in the urbanized East area.

2.5 Spatial Variations of Maternal Mortality across the US

The fundamental causes of maternal mortality described in the section 2.1 and 2.2 do not just differ among countries, but they vary within countries as well. For instance, access to health care and racial composition differs across states (Swift, 2002). Evidence suggests that in southern states, the black population is especially lagging in the utilization of healthcare services (AHR, 2019; Collins & Thomasson, 2002). In 2007 overall in the US, about 31.1 percent of pregnant women experienced complications during hospitalized child delivery whereas the South experienced a higher percentage of 33.8 percent. In the West, the percentage was only 27 percent. Hence, Healthy People 2020's goal is to reduce overall regional disparities in terms of experiencing complications during hospitalized child delivery is within 28 percent by 2020 (Healthy People, 2020a).

In some states, Black women are more susceptible to die than white women due to pregnancy and there persists a gap even after controlling for socioeconomic status. It indicates there might be some spatial factors that are affecting the overall maternal deaths. The health of a mother differs between rural and urban counties in terms of availability of healthcare facilities and other amenities. Most counties adjacent to a metropolitan area experiences the good quality of health care and thus favorable health outcomes. Geronimus has found that, on average, African American women and those living in low-income rural areas experience worsening health profiles during their teens and young childhood.

These factors cumulatively contribute to their increased risk with advancing maternal age (Geronimus, 1996). Those cities and states with a high density of the black population have also the poorest maternal health outcomes. This pattern of crunch can be seen mostly in urban areas like New York, Washington DC, and throughout the US southern areas. For example, in 2013-2017, Louisiana had the highest MMR with 50 deaths, and Georgia had the second highest with 49 deaths per 100,000 live births in the country (AHR, 2020).

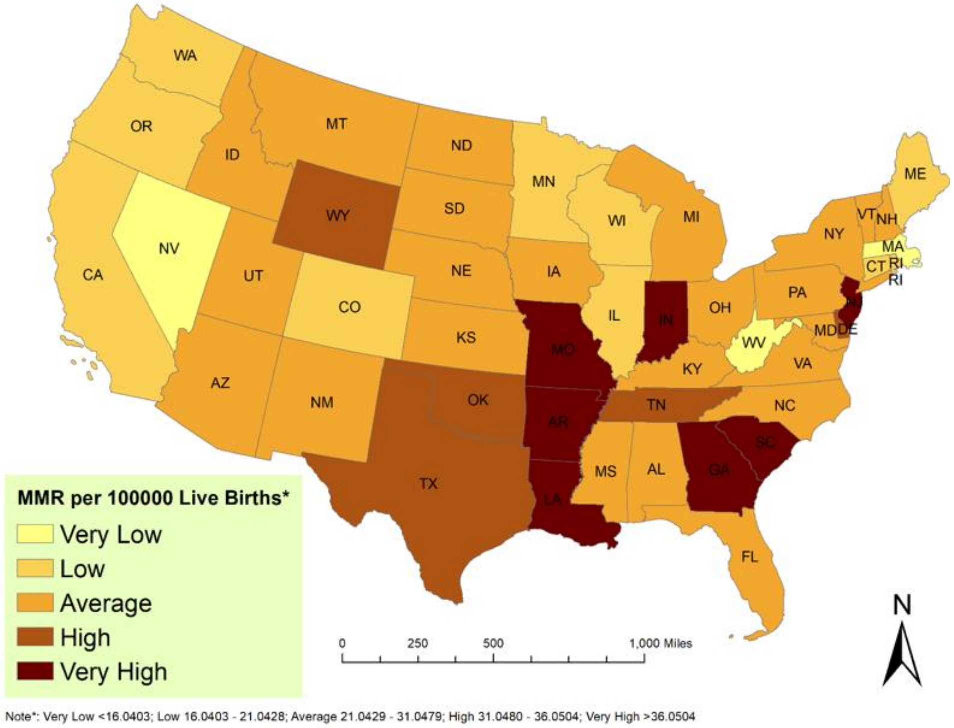


Figure 9. Racial Distribution of Maternal Mortality Rate in the US, 2012-2017
Data Source: CDC online database (CDC WONDER, 2020)

Figure 9 shows the spatial distribution of maternal mortality rates across US states. During 2012-2017, the maternal mortality rate varied considerably by the state of residence, ranging from less than 16 deaths for Nevada and West Virginia to a high of more than 36.0 deaths for Georgia, Louisiana, Arkansas, South Carolina, Indiana, and Missouri. Ten states exhibit at least a 50 percent higher maternal mortality rate than the national average during that period. States with at least 50 percent lower MMR than the national average are Washington, Maine, Oregon, California, Illinois, Wisconsin, and Connecticut.

In Figure 9, it is interesting to look at the distinct cluster of high maternal mortality rates in the South, Mid-West, and clusters of low maternal mortality rates along the West Coast and the North. This pattern has a significantly positive spatial autocorrelation coefficient of 0.184 based on the Queen Contiguity Matrix (Appendix, Figure 2).

As we see the clustered pattern of MMR across the US, we have divided the states into five regions (Appendix, Table 1). For each state, the race-specific MMR is shown in the Appendix (Figure 1). Here, Figure 10 illustrates the MMR distribution by race across different regions in the US. Women living West of Mississippi and in the Southern region have significantly higher risks of maternal death in all racial groups than women in other regions. The overall risk of maternal mortality is 33 percent higher in the Urbanized East region and two times higher in places West of Mississippi and in the South than in the West.

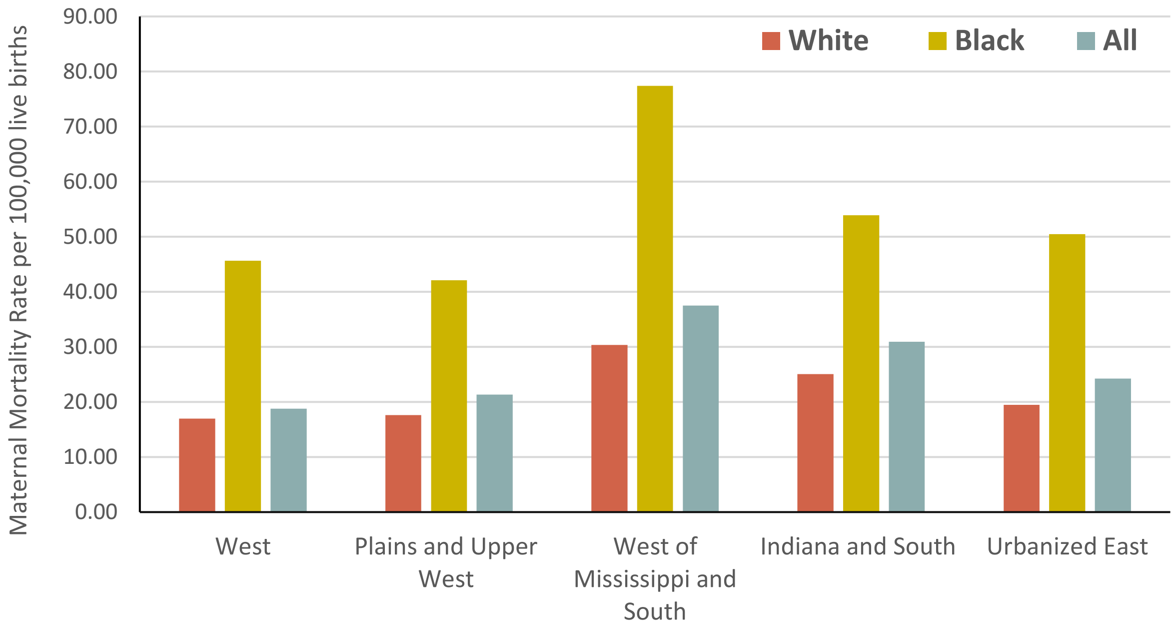


Figure 10. Geographic Disparities in MMR across racial groups, 2012-2017
Data Source: CDC WONDER online database (CDC WONDER, 2020)

The 50 states and District of Columbia exhibit a good deal of Spatio-temporal variation of their MMRs. However, the relative positioning of states to each other is very persistent and a little change can be identified in the relative differences in MMRs across states. A transitional matrix in Table 1 shows that states with a below-average MMR in 2012 have an almost 41 percent chance of also having a below-average MMR in 2017. States with medium MMR in 2012 have a 30 percent chance of increasing their MMR (high) in the later period. Results also shows that states with higher MMR in earlier-period have a 43 percent chance of also having a higher MMR in 2017.

Table 1. Transition Matrix* for States Maternal Mortality Rate from 2012 to 2017

2012 MMR	2017 MMR		
	Low	**Medium**	**High**
Low	pL/L = 0.41 Vermont, Alaska, Massachusetts, West Virginia, Hawaii, Wisconsin, Utah	pM/L = 0.47 Maine, North Carolina, Nevada, Kansas, Colorado, Connecticut, Virginia, Kentucky	pH/L = 0.12 New Mexico, Alabama
Medium	pL/M =0.30 California, New Hampshire, Nebraska, Delaware, Michigan, New York	pM/M = 0.40 Minnesota, Oregon, W. DC, Pennsylvania, Washington, Iowa, Illinois, Ohio	pH/M = 0.30 Montana, South Dakota, Idaho, Wyoming, Oklahoma, Georgia
High	pL/H = 0.21 North Dakota, Rhode Island, Florida	pM/H = 0.36 Maryland, Arizona, New Jersey, Texas, Mississippi	pH/H = 0.43 Tennessee, South Carolina, Louisiana, Arkansas, Missouri, Indiana

*Low: <average – 0.5 std; Medium: average ± 0.5 std; High: > average + 0.5 std

Data Source: CDC WONDER online database (CDC WONDER, 2020)

Considering the variation in MMRs throughout the space, it is needed to explore which contextual factors are contributing to this variation.

CHAPTER 3. DATA AND VARIABLES

3.1 Definition of Variables

This study analyzes publicly available data to identify factors associated with maternal mortality. In this analysis, we are not considering late maternal deaths (deaths within 43 days to less than one year after the termination of pregnancy

All vital statistics data for this study originates primarily from the data compilations of the CDC WONDER online database tool of births and death records for the years of 2012 to 2017. The outcome of interest is the state-level maternal mortality ratio. Maternal mortality variations across states are analyzed using MMR for state i = 1, 2, ….,51 as:

$$MMR_i(t) = \frac{No\ of\ Maternal\ Deaths\ in\ State_i\ (t)}{No\ of\ Live\ Births_i\ (t)} \times 100{,}000$$

This study considers-

Unit of observation (i) = 50 states of United States and Washington D.C
Year (t) = 2012-2017
Population of interest = women 15 - 49 years of age
Groups = all women, black women, white women

We hypothesize that the outcome variable, $MMR_i(t)$, is linked to maternal attributes, behavioral and structural factors; healthcare availability, and accessibility factors. We have obtained aggregated maternal death counts for all 50 states and the District of Columbia for each year, using the data extraction tool of CDC WONDER. As maternal death is a rare event, there is a significant year to year variability for many states. Information on states without maternal deaths or with fewer than 10 deaths express are suppressed due to confidentiality issues. To address this problem, we have extracted the suppressed count by aggregating the state with suppressed information with states having published information on maternal death counts. This technique has also been used to extract all other vital statistics data. To extract maternal attributes including socioeconomic indicators, we consider women who gave birth during the last 12 months and women age 15 to 49 years. For maternal characteristics, we employ the following variable: age, race (white and black), education. Concerning maternal behavioral factors, we examine prenatal care, smoking behavior during pregnancy (obtained from live birth files from CDC).

Table 2. Definitions of Variables and Corresponding Data Sources

Variable	Definition	Data Sources
MMR	Maternal Mortality Rate [per 100,000 live births]	CDC
Maternal Attributes		
BLACK	% births to black mothers (age 15-49 years)	CDC
TEEN	% teen births (age 15-19 years)	CDC
BIRTH40	% births to women aged 40 to 49	CDC
UNMARRIED	% unmarried mothers	CDC
AGE	Average age of mothers	CDC
COLLEGE	% mothers with some college and more education	Census ACS
LESSHS	% mothers with high school and less education	Census ACS
INCMOM	Per capita personal income of mothers [$1,000]	Census ACS
Behavioral Factors		
NOPRENATAL	% births without prenatal care (any time)	CDC
SMOKING	% mothers who smoked during pregnancy	CDC
Structural Factors		
TBR	Teenage birth rate [per 1000 teenage age of 15-20 years]	CDC
MOMUNINSURED	% mothers without insurance coverage	Census ACS
URBANMOM	% mothers living in urban area	Census ACS
DENSITY	Population density (per sq. mile)	Census ACS
PRIDOC	Primary care physician (per 10000 population)	KFF, Census ACS
BED	Number of community hospital beds (per 1000 population)	KFF
RCLINIC	Rural health clinic (per 100,000 rural population)	CMS
OBSGYN	Gynae and Obstetricians (per 10000 reproductive aged women)	BLS
N	All 50 States and District of Columbia	

A list of the variables including their definition and sources is provided in Table 2. We consider the percent of births by black women (BLACK) as a proxy to measure the racial effect. We also consider TEEN, BIRTH40, and UNMARRIED as the percentage of mothers age 40 and more, teen mothers with age 15 to 19 years and unmarried mothers as high-risk group associated factors with maternal death. Here education status is defined as the proportion of having less than a high school education (LESSHS) and as a proportion of having a college education (COLLEGE). NOPRENATAL is defined as the proportion of mothers without having prenatal care during pregnancy.

Besides, considering maternal characteristics and health behavior, we have included socioeconomic attributes and healthcare availability of different states as important predictors. To obtain healthcare availability, the number of Medicare and Medicaid certified rural health clinics are calculated per 100,000 state's rural population, and the number of hospital beds is calculated per 1000 population. Additionally, the number of primary healthcare physicians is calculated per 10,000 population of each state, and the number of Gynecologists and Obstetricians in active patient care is calculated per 10,000 reproductive-aged women (15-49 years).

The proportion of mothers without health insurance coverage (MOMUNINSURED) is considered as the healthcare accessibility indicators for the state's population. Additional data sources used in this study are the US Census Bureau's American Population Survey (ACS); The Henry J. Kaiser Family Foundation (KFF); Center for Medicare and Medicaid Service (CMS); and Bureau of Labor Statistics (BLS). All available information is for the years 2012 to 2017 and compiles into a pooled cross-sectional dataset with states as the unit of observation.

3.2 Summary Statistics

The salient descriptive statistics of the variables are summarized in Table 3. Due to missing values, the sample size has been reduced (all-female: 281, white: 273, Black: 273). It shows that the black MMR (45 deaths per 100,000 live births) is substantially higher (almost double) than the white MMR (26.05 deaths per 100,000 live births).

On average, about 15 percent of births are from black mothers (BLACK) and almost 16 percent of these individuals didn't have a high school education (LESSHS). Among blacks, 9 percent of mothers were still teenagers when they gave birth, compared to 5 percent of white mothers (TEEN). The Proportion of unmarried mothers is also higher in the black population (63 percent) than in the white population (34 percent). On average, white mothers are more aged and have a higher income than black mothers.

The variable NOPRENATAL and SMOKING indicates the disparity of health behavior and the higher prevalence of not visiting prenatal care during pregnancy (1 percent) among black mothers compared to white mothers. Since the analysis focuses on the state level variations in maternal mortality rate, structural variables like the proportion of mothers without health insurance coverage (UNINSUREDMOM), teenage birth rate of each state (TBR), mothers living in urban areas (URBANMOM) are important factors to measure the state's well-being.

Table 3. Summary Statistics of all female, white female, and black female for the year 2012-2017

Variables	All Female				Black Female		White Female		Race Gap	
	Mean	**Std.**	**Min**	**Max**	**Mean**	**Std.**	**Mean**	**Std.**	**Avg. gap**	**ttest**
MMR	26.50	14.12	0.00	88.76	40.93	39.57	21.23	12.62	24.06	6.16***
Maternal Attributes										
BLACK	15.19	12.38	0.73	56.58	-	-	-	-	-	-
TEEN	6.22	2.08	2.58	12.39	9.12	2.88	5.61	1.98	3.51	17.68***
BIRTH40	2.67	0.95	1.20	5.47	2.63	1.14	2.70	1.06	-0.07	-0.85
UNMARRIED	39.48	7.24	0.09	54.62	64.24	13.84	33.86	6.78	30.38	31.24***
AGE	28.24	1.01	25.93	30.76	27.02	1.10	28.48	1.13	-1.46	-7.49***
COLLEGE	64.64	6.43	46.01	84.45	51.60	22.68	68.23	8.11	-16.63	-12.07***
LESSHS	12.19	4.03	0.90	25.74	15.87	14.60	10.39	4.51	5.48	6.11***
INCMOM	22.74	6.80	10.88	56.76	16.31	9.04	24.92	10.24	-8.61	-9.82***
Behavioral Factors										
NOPRENATAL	1.38	0.95	0.19	5.40	2.24	1.48	1.14	0.92	1.1	9.42***
SMOKING	10.22	4.95	1.43	25.90	8.30	4.18	10.77	5.03	-2.47	-4.86***
Structural Factors										
TBR	23.98	8.44	8.06	47.35	33.56	11.10	21.55	8.42	12.01	15.09***
UNINSUREDMOM	13.54	7.20	0.57	35.10	11.66	13.29	12.34	7.19	-0.68	-0.57
URBANMOM	77.21	14.32	32.25	100.0	84.57	29.73	74.97	15.15	9.6	5.05***
DENSITY	409.19	1506.58	5.94	11367.27	133.11	734.81	237.45	632.42	-104.34	-1.86*
PRIDOC	13.42	4.67	6.71	42.51	359.49	4479.85	18.60	12.57	340.89	12.78***
BED	2.71	0.80	1.60	5.70	81.85	138.53	3.70	1.68	78.15	9.68***
RCLINIC	7.90	6.63	0.00	29.01	1044.5	1707.91	8.40	7.35	1036.1	10.23***
OBSGYN	6.71	3.76	2.32	35.02	118.75	157.58	10.96	18.33	107.79	12.62***
N	**281**				**273**		**273**			

Note: ***, ** and * represents 1%, 5% and 10% significance level respectively

On average, the teenage birth rate is higher among black females. The proportion of women without any health insurance coverage is higher among black women (12 percent). On average, 78 percent of mothers live in urban areas whereas the urban share of black mothers is higher (84 percent) than that of white mothers (74 percent). In the case of active primary care physicians (PRIDOC), there were 14 physicians, on average, per 10,000 residents, and 7 obstetricians per 10,000 reproductive-aged women in each state. There were 7 Medicare and Medicaid certified rural health clinics per 100,000 rural population on average in each state. The last column in Table 2 shows the black-white differences in means for all variables. They are significantly different from zero for almost all variables.

CHAPTER 4. METHODS

To address the research question, we start by estimating a linear regression model considering maternal mortality ratio as the dependent variable, MMR. In a first step, the dependent variable, MMR, is expressed as a linear function of the explanatory variables, $\boldsymbol{X}$. The linear predictors of the model include the variables describing maternal attributes, behavioral factors, and structural factors mentioned in Table 2. To explore if there is any regional effect on the MMR, we have also considered regional dummy variables to differentiate the regions across US.

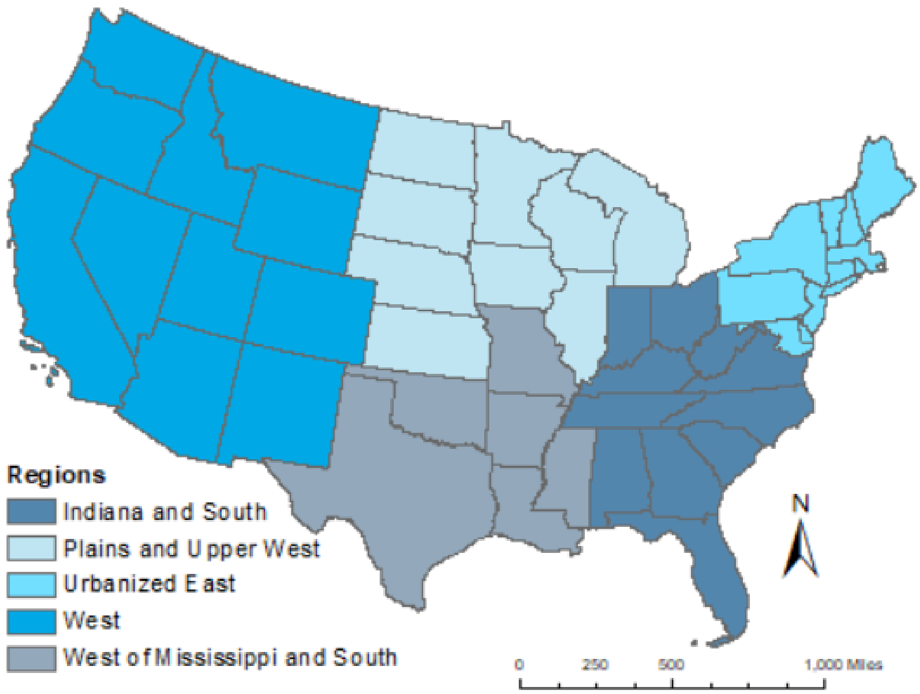


Figure 11. Regions Across United States

Based on the average MMR of 2012-2017, we have categorized all states into Plains and Upper East; Mississippi and west; Indiana and South; Urbanized East (Figure 11). The detail of these regions is shown in the Appendix Table 1.

The first model of Ordinary Least Squares (OLS) is specified as,

$$MMR_{it} = X\beta X_{it} + \varepsilon_{it} \quad \text{and} \quad \varepsilon \sim N(0, \sigma^2) \qquad (1)$$

Where, ***MMR*** denotes an n × 1 vector of dependent variable, $\boldsymbol{X}$ is a n × k matrix of independent variables (predictors), ε is a normally distributed error, β is a k × 1 vector of the regression parameter, and n denotes $i \times t$ (i = 51, t = 6).

Health outcomes may vary throughout different regions and such variations may be generated by some unobserved process of spatial nature (Waldorf & Chen, 2010). According to Waldorf and Chen, spatial dependence in a region may arise when its health outcomes and behaviors are correlated with those in the neighboring regions. The implied model (1) suggests that maternal death in a state is a function of local characteristics.

However, in a multi-regional setting health outcomes i.e., MMR may also be affected by the diffusion of norms and values (Rice & Smith, 2001). These may influence behaviors, like seeking prenatal care, utilization of primary health care, tobacco use, sexual behavior, and decisions about carrying a pregnancy to terms. The influence of norms, the behavior is not concentrated within a spatial boundary, but it may diffuse throughout the space. This diffusion results in spatial spillovers and the clustering of similar maternal mortality outcomes across space. From Figure 8, we already have seen the distribution of maternal deaths is in a clustered pattern.

Such type of spatial spillovers has implications for the specification of the maternal mortality models. According to Waldorf and Chen (2010), omitting spillovers from estimating the model may lead to erroneously attributing their impact on structural factors. Consequently, the estimation of the parameter will be biased, and the errors of the estimated model will be spatially autocorrelated. Spatial error is suggestive of omitted spatially correlated covariates that if left untreated would affect the results. Considering spatial dependence, the error terms across different spatial units are correlated in the spatial error model and the dependent variable in place i is affected by the independent variables in both places i and j in the spatial lag model.

Following Waldorf and Chen (2010), this study estimates a linear function of the predictor variables X in the first step to measure spatial correlation and spillover effects. If the residuals exhibit spatial autocorrelation, then on the second step, that spatial autocorrelation will be corrected by using either spatial lag (2) or spatial error model (3).

The general form of such models is:

Spatial Lag Model: $$Y_{it} = \rho W Y_{it} + \beta X_{it} + \varepsilon_{it} \quad \text{or} \quad Y_{it} = (I - \rho W)^{-1} \{X\beta + \varepsilon\} \qquad (2)$$

Spatial Error Model: $Y_{it} = \lambda W\varepsilon + \beta X_{it} + \varepsilon_{it}$ and $\varepsilon \sim \lambda W\varepsilon + \mu, \mu \sim N(0, \sigma^2)$ (3)

Here, $\boldsymbol{\rho}$ is the coefficient of spatial lag, $\boldsymbol{\lambda}$ is the coefficient of spatial autocorrelation in the error term, $\boldsymbol{WY}$ denotes the endogenous interaction effects among the response variable, and $\boldsymbol{W\varepsilon}$ denotes interaction effects among the error term. Here is this study, $\boldsymbol{W}$ is an exogenously specified n × n spatial weight matrix and is used to calculate the diffusion component.

In the case of pooled cross-sectional data, the weight matrix $\boldsymbol{W}$ is specified as a block-diagonal matrix with each of the 51×51 sub-matrices (50 states and Washington DC) along the diagonal being the first-order queen contiguity matrices. It is assumed that spatial diffusion does not extend beyond first-order neighbors (Waldorf & Franklin, 2002). Hence, $\boldsymbol{W}$ is considered to be a first-order spatial contiguity matrix as it is a good approximation of spatial linkages induced by a contagious diffusion process. Following Waldorf and Franklin (2002), after the row standardization, $\boldsymbol{W}$ takes the form of

$W_{ij} = 1/T_i$ if $i \neq j$ share a common border

$W_{ij} = 0$ otherwise

Where, a common border is defined as sharing at least one point, and T_i is the number of states bordering *i*.

Following Beron and Vijverberg (2004), this study has excluded Alaska and Hawaii in calculating weight matrix $\boldsymbol{W}$, as both of them are non-contiguous to any other state (Beron & Vijverberg, 2004). Table 4 shows neighbors summary of the contiguity matrix with each state having, on average, about four neighbors while some states sharing a border with as many as 8.

Table 4. Summary of Neighbors from Queen Contiguity-matrix

Minimum neighbors	1
Average neighbors	4.57
Maximum neighbors	8

The analysis of data has been performed using STATA/SE version 15.0 and GeoDa 1.14.0.

CHAPTER 5. RESULTS

The analysis begins by estimating an OLS model that expresses a state's MMR at time t as a function of the maternal attributes, behavioral factors, structural factors, and regional dummy variables mentioned in chapter 3. As maternal death is a rare event, not every state experienced it every year during the study period and some maternal attributes were also missing. Hence the sample size was reduced to 281 for all women model and 273 for race-specific models. Due to multicollinearity and insignificant effect on the MMR, we have dropped variables COLLEGE, AGE and TBR in the model specification.

5.1 Ordinary Least Square Results

Starting with the model for all women (1a), the variable BLACK enters the model to assess a possible race effect. The results summarized in Table 5 suggest that not having prenatal care, a mother being unmarried and uninsured are salient factors influencing variations in maternal mortality ratio. A state's MMR increases significantly with an increasing rate of not having prenatal care during pregnancy. Additionally, we observe regional variations. Mississippi and the Southern region has significantly higher maternal mortality rates than states in the West region (omitted region here). Having more obstetricians in the state reduces MMR, which seems logical. Results also suggests that the racial composition of the maternal population contributes significantly to MMR variations. The higher the state's percentage of black mothers, the higher the MMR.

Hence, to get a better handle on race effects, we have estimated separate models for black (1c) and white (1b) MMR. Unlike the overall MMR model, the racespecific estimations include URBANMOM variable (it was omitted in the overall model due to multicollinearity) and exclude DENSITY variable instead. Model 1b and 1c also exclude PRIDOC due to the multicollinearity with OBSGYN variable. And the estimation shows surprising results for white and black mothers (Table 5).

Comparing results between white and black mothers, the racial disparities are sizable. For black mothers, not having prenatal care and not having health insurance coverage are associated with high maternal mortality. Additionally, living in an urban area and the Mississippi South region has a high maternal death rate for them. Unexpected and counterintuitive, however are some of the results concerning MMR of white mothers. First, the percentage of teenage pregnancy is inversely related to MMR for white mothers. This may be due to the distributions within two categories which differ significantly by race such that the incidence of teenage pregnancy rates is much more common among blacks than among whites. And also maybe linked to strong selection effects among white teenagers choosing abortion in the case of an unwanted pregnancy.

Table 5. Maternal Mortality Ratio and Influencing Factors

VARIABLES	**All MMR (1a)**	**White MMR (1b)**	**Black MMR (1c)**
Maternal Attributes			
BLACK	**0.12**** (0.12)		
TEEN	**-3.06***** (0.91)	**-1.64**** (0.83)	0.09 (1.21)
BIRTH40	**-7.29**** (2.27)	**-3.11*** (1.78)	2.21 (2.94)
UNMARRIED	**0.36**** (0.17)	0.13 (0.16)	0.19 (0.27)
LESS HS	-0.13 (0.26)	-0.26 (0.23)	-0.12 (0.15)
INCMOM	0.26 (0.24)	0.05 (0.18)	-0.02 (0.26)
Behavioral Factors			
NOPRENATAL	**1.18*** (1.04)	1.10 (1.06)	**1.13***(1.68)
SMOKING	-0.28 (0.33)	-0.08 (0.23)	-0.35 (0.67)
Structural Factors			
MOMuninsured	**0.29*** (0.18)	0.04 (0.15)	**0.21*** (0.16)
URBANMOM	---	-0.07 (0.08)	**0.18**** (0.09)
DENSITY	**0.01*** (0.01)	---	---
PRIDOC	0.31 (0.66)	---	---
OBSGYN	**-0.45*** (0.27)	**-0.07*** (0.04)	**-0.09***** (0.03)
BED	1.34 (1.74)	-0.63 (1.03)	0.2 (0.04)
RCLINIC	0.08 (0.19)	0.01(0.15)	0.01 (0.00)
Regions			
Plain_upper WEST	**-8.95**** (3.53)	**-4.64*** (2.73)	-5.57 (8.00)
Mississippi_south	**9.16**** (3.98)	**12.39***** (2.99)	**27.41***** (16.55)
IN_south	3.32 (3.59)	**7.40***** (2.56)	6.53 (7.92)
Urbnzd_east	-7.13 (4.59)	-2.99 (3.42)	2.72 (7.58)
Constant	**36.33***** (11.12)	**40.70***** (18.59)	11.40 (21.01)
Observations	**281**	**273**	**273**
R-squared	**0.31**	**0.26**	**0.29**

Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Overall, we have found, teenage pregnancy is inversely related to MMR i.e., it has been decreased in 2017 than it was in 2012 whereas MMR experienced the opposite trend.

Second, the higher the percentage of older (age 40+) pregnant women, the lower the MMR. To explore the contributing factor behind this counterintuitive outcome, we have separately estimated descriptive statistics of their demographic factors and access to health care attributes (See Appendix Table 2). The results find that within this group of aged women, about 68 percent are white mothers. They have better income and high education which better explains that they might be more aware of health behavior and receive better healthcare being solvent economically.

5.2 Spatial Lag Results

Table 6. OLS and Spatial Models of Maternal Mortality Ratio

VARIABLES	**All MMR**	
	OLS (1d)	**Spatial Lag (1e)**
Maternal Attributes		
BLACK	**0.23**** (0.09)	**0.18**** (0.09)
TEEN	**-2.11**** (0.84)	**-2.05**** (0.81)
BIRTH40	**-3.47*** (2.04)	**-3.10*** (1.97)
UNMARRIED	**0.43**** (0.16)	**0.43***** (0.17)
LESS HS	-0.22 (0.26)	-0.19 (0.25)
INCMOM	0.17 (0.22)	0.18 (0.22)
Behavioral Factors		
NOPRENATAL	**1.36*** (1.01)	1.11 (0.98)
SMOKING	0.24 (0.27)	0.29 (0.26)
Structural Factors		
MOMuninsured	0.17 (0.16)	0.18 (0.15)
DENSITY	0.01 (0.01)	**0.01*** (0.01)
PRIDOC	**-1.99***** (0.51)	**-1.95***** (0.49)
OBS & GYN	-0.08 (0.25)	-0.07 (0.24)
BED	-0.02 (1.71)	-0.36 (1.64)
RCLINIC	0.03 (0.16)	0.03 (0.16)
Constant	**45.00***(**10.04)	35.10*** (12.20)
ρ		**0.14** (0.08)**
Observations	281	281
R-squared	0.25	0.26
Diagnostic	***test stat (OLS)***	***test stat (lag)***
Moran's I[2]	**0.06*****	
LM (Lag) test	**3.49****	
LM (Error) test	2.05	
Likelihood Ratio Test		**3.42****

Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

[2] The *p*-value is based on 999 permutations under the randomization assumption.

Results also show that the higher the availability of obstetricians, the lower the rate of MMR for both mothers. Further, Mississippi and the south region has more than two times higher positive effect on increasing black MMR than the white MMR.

Given that results indicate the region has a significant effect on maternal mortality ratio in the US, we sought to determine whether there were any state-level effects associated with MMR. There might be some small-scale spillover effects throughout the spatial sub-units and MMR may be affected by the diffusion of norms and values especially in the border areas. Hence, we have estimated the OLS model for overall MMR after removing regional dummy variables from the specification (Table 6). The new OLS estimation result (1d) shows almost the same effects on MMR as model 1a. The new results show the availability of primary care physicians has a significant negative effect on MMR. After correcting for spatial dependence (1e), we find insignificant effects of not having prenatal care during pregnancy but a significant positive effect of population density on MMR. The insignificant effect of access to health insurance and smoking during pregnancy is also surprising.

The diagnostics reveal that spatial processes cannot be ignored. Moran's *I* of the error terms is positively significant. The Lagrange Multiplier (LM) tests point in the direction of the spatial lag model as the proper significant specification. Interestingly, even after accounting for the spatial effects, the results of spatial lag model indicate that the BLACK variable continues to have a highly significant effect on MMR.

Hence, to handle the race-specific disparity even after controlling the spatial dependence, we have estimated separate models (1f -1i) for white and black mothers after removing the regional dummies. The results of Table 7 which are consistent with model 1a, the percentage of teenage pregnancy is no more significant in the new estimated results for white women (model 1f, 1g). Comparing the coefficients for black and whites, it turns out that the effects of not having access to health insurance coverage on MMR are substantially more important for blacks than for whites.

The effects of birth (aged more than 40 years) are negatively significant for whites even after controlling for spatial dependence, which is also the same as in model 1b. This result may be linked to strong selection effects and a good socio-economic profile of white women who are more than 40 years old as before. The ratio of not having prenatal care has a positively significant effect on MMR for both white and black mothers. Once again, the access to health insurance variables has a positive but insignificant association for white mothers.

Table 7. Race Specific OLS and Spatial Models of Maternal Mortality Ratio

VARIABLES	**White MMR**		**Black MMR**	
	OLS (1f)	**Spatial Lag (1g)**	**OLS (1h)**	**Spatial Lag (1i)**
Maternal Attributes				
TEEN	-0.23 (0.79)	-0.22 (0.75)	0.25 (1.22)	0.37 (1.18)
BIRTH40	**-3.35** (1.65)**	**-2.99** (1.57)**	0.02 (2.69)	0.58 (2.6)
UNMARRIED	0.04 (0.15)	0.04 (0.14)	0.30 (0.26)	0.22 (0.26)
LESS HS	-0.25 (0.24)	-0.25 (0.23)	-0.14 (0.15)	-0.14 (0.14)
INCMOM	-0.03 (0.18)	-0.03 (0.17)	0.04 (0.26)	0.04 (0.25)
Behavioral Factors				
NOPRENATAL	**1.87**** (1.09)	**1.13*** (1.04)	**1.14*** (1.68)	**1.02*** (1.64)
SMOKING	-0.16 (0.24)	-0.06 (0.22)	-0.87 (0.67)	-0.84 (0.65)
Structural Factors				
MOMuninsured	0.18 (0.15)	0.20 (0.14)	**0.34**** (0.16)	**0.31**** (0.16)
URBANMOM	**-0.12*** (0.08)	-0.08 (0.07)	0.12 (0.09)	0.14 (0.09)
OBSGYN	-0.03 (0.04)	-0.13 (0.69)	**-0.09***** (0.03)	**-0.09**** (0.02)
BED	0.03 (0.73)	-0.15 (0.12)	-0.031 (0.04)	-0.04 (0.04)
RCLINIC	-0.12 (0.13)	-0.22 (0.75)	-0.01 (0.01)	-0.01 (0.01)
Constant	**41.28***** (9.12)	**31.72***** (8.91)	20.63 (20.94)	16.96 (20.37)
ρ	**--**	**0.25***** (0.07)	**--**	**0.14**** (0.08)
Observations	273	273	273	273
R-squared	0.15	0.19	0.25	0.26
Diagnostic	***test stat (OLS)***	***test stat (lag)***	***test stat (OLS)***	***test stat (lag)***
Moran's I[3]	**0.13*****		**0.03*****	
LM (Lag) test	**11.44*****		**2.82****	
LM (Error) test	**8.36****		**9.75****	
Likelihood Ratio Test	**---**	**10.84*****	**---**	**3.09****

Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

As like previous results, the availability of obstetricians and not having access to health insurance have significant effects on the black MMR. Moreover, the variable URBANMOM becomes insignificant when compared to the a-spatial model for white maternal mortality.

The diagnostic result shows that for both white and black MMR, the a-spatial models yield significant positive spatial autocorrelation in the residuals for white and black mothers. The LM tests for both models point in the direction of a spatial lag model as the proper specification. In the spatial lag models for both white and black MMR (model 1g, 1i), the spatial autocorrelation coefficient, ρ, is significantly positive.

[3] The *p*-value is based on 999 permutations under the randomization assumption.

CHAPTER 6. CONCLUDING REMARKS

The general trend of pregnancy-related deaths has been increasing in recent years in the US. Some research found that it might be due to the increasing rate of using checkboxes in the death certificates to identify women who died during or anytime within a year-end of a pregnancy (Callaghan, 2012). But even after the adjustment with check box reporting errors, it has also found that the MMR is increasing and varied by a subgroup of causes of death, age, race, and Hispanic origin (Rossen et al., 2020). It is also already evident that racial/ethnic disparities in pregnancy-related mortality ratio have been increasing in recent years. Significant disparities still persist among groups with a higher education level, even in states with lower MMR (Petersen, Davis, Goodman, Cox, Syverson, et al., 2019). These differences reflect disparities in access to care, quality of care, and the prevalence of chronic diseases (Howell, 2018).

This analysis has addressed questions about whether racial and spatial variations persist even after considering the social, healthcare predictors of maternal mortality. This study is consistent with the existing findings of racial disparities in MMR. Additionally, we have contributed to the stream of existed literature with the findings that, even after controlling for spatial dependence throughout the US, there are significant disparities in the MMR. We have found that social attributes, including the area where a woman lives, have a significant effect on the MMR. Similarly, access to healthcare, availability of healthcare services also has remarkably significant effects on the MMR.

Results of the multivariate models suggest that the key variable responsible for high maternal death among black is, not having access to healthcare and prenatal care during pregnancy. For both groups, mortality decreases with the increasing availability of healthcare personnel. Health behavior of not having prenatal care might be attributed to the spillover effects throughout the areas and conducive to the increasing rate of MMR.

Preventing maternal death is a key tool that allows states to characterize and intervene in maternal mortality and morbidity. We must measure maternal mortality accurately, understanding the reasons behind pregnancy-related complications, and take appropriate actions to institute systems for prevention as we value the prevention of maternal deaths. Preventing maternal deaths can only be accomplished if the social, economic, and healthcare issues which contribute to women’s health are addressed at multiple levels. State and regional systems must be active in identifying all maternal deaths due to pregnancy, reviewing all factors associated with deaths, and circulating the findings, especially to those who are in charge of the good care of a woman during her pregnancy. The racial disparities in the relative importance of the root causes of maternal mortality suggest that different policies aimed at lowering MMR need to be designed for different population groups with developing access to care, confirming high quality of health care for women and warranting readiness to obstetric emergencies.

This study has an exploratory character and highlights several problems that arise when dealing with spatially aggregated data. Some states are quite small and do not provide reliable data for maternal mortality, especially when disaggregating by additional attributes such as race. Given that the US is an overall low mortality country, its spatial sub-units, such as the District of Columbia, may have extremely small, expected numbers of maternal deaths. Other states, such as Texas, California, New York, are quite big so that small-scale spillovers cannot be identified and internal heterogeneity remains undetected, thereby becoming prone to ecological fallacies. Given, the limitations, the outcomes of future research might be changed if all attributes are available.

APPENDIX

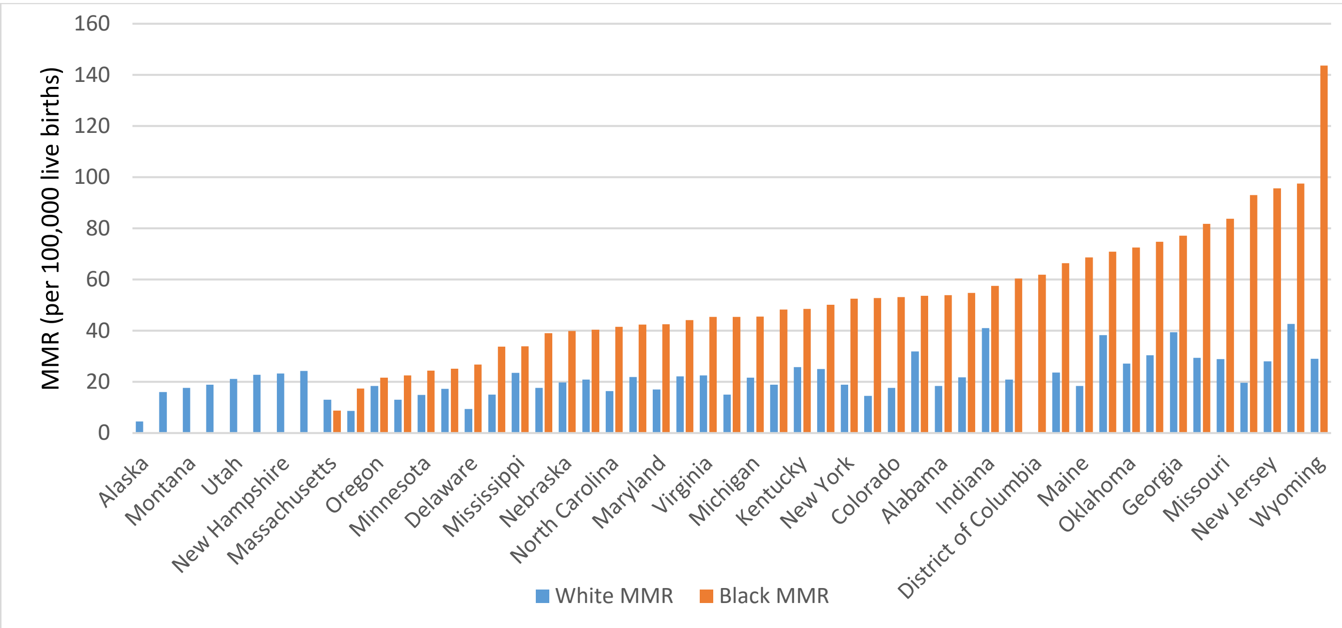


Figure A1. Black and White MMR across different states in the US (2012-2017)

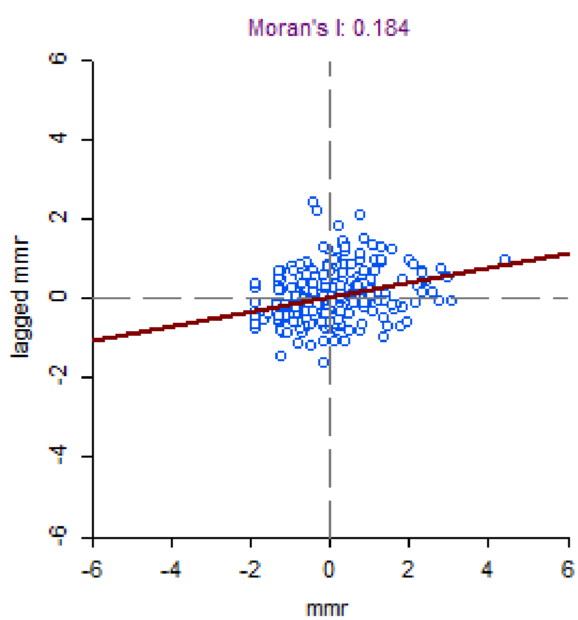


Figure A2. Moran's *I* Scatterplot for MMR

Table A1. Descriptive Statistics for Regions

Regions	**Definitions**	**Proportions**
West *(=1 or 0 otherwise)*	Washington, Oregon, California, Idaho, Nevada, Arizona, Utah, Montana, Wyoming, Colorado, New Mexico, Alaska	25
Plains and Upper West *(=1 or 0 otherwise)*	North Dakota, South Dakota, Nebraska, Kansas, Iowa, Minnesota, Wisconsin, Illinois, Michigan	18
West of Mississippi and South *(=1 or 0 otherwise)*	Oklahoma, Texas, Missouri, Arkansas, Louisiana, Mississippi	12
Indiana and South *(=1 or 0 otherwise)*	Indiana, Kentucky, Tennessee, Alabama, Georgia, South Carolina, Florida, North Carolina, Ohio, West Virginia, Virginia	22
Urbanized East *(=1 or 0 otherwise)*	Maine, New Hampshire, Vermont, Massachusetts, New York, Connecticut, Rhode Island, New Jersey, Washington DC, Maryland, Delaware, Pennsylvania	24

Table A2. Summary statistics for the pool of mothers aged 40 to 49 years

	All Female				**Black Female**		**White Female**	
Variables	**Mean**	**Std.**	**Min**	**Max**	**Mean**	**Std.**	**Mean**	**Std.**
COLLEGE	70.40	17.03	0.00	100.00	47.36	39.43	73.18	19.64
HS	29.60	17.03	0.00	100.00	22.80	28.63	26.34	18.77
INCOME	34800	17952	0	127018	21807	22524	36564	22017
UNINSURED	12.70	11.32	0.00	61.90	8.82	16.87	12.07	11.52

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