ABSTRACT

Title of Dissertation: EXAMINING THE IMPACT OF THE MARYLAND GLOBAL BUDGET MODEL ON SEVERE MATERNAL MORBIDITY DISPARITIES

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Maternal mortality and morbidity are at an all-time high in the United States, and minoritized groups are disproportionately affected. Severe maternal morbidity (SMM), the life-threatening events that occur during hospitalization for childbirth leading to major short- or long-term health consequences, has steadily increased over the past few decades, though approximately half of SMM events are considered preventable. Significant racial disparities exist, with non-Hispanic black women consistently afflicted with SMM rates two to three fold higher than peers. While clinical approaches are a mainstay in addressing the critical need to improve maternal health outcomes and the observed pernicious racial disparities, few strategies have focused on the role of healthcare payment and financing reforms. Value-based payment models (VBP) may be a critical policy lever to improve maternal health quality and advance maternal health equity; however, there is a dearth of evidence in this area. Applying a health equity lens, this innovative quasi-experimental methods study seeks to examine the impact of the Maryland Global Budget Model (GBM) on the SMM incidence of childbearing women in Maryland from 2011-2019. Due to increased care coordination and the redistributive effects of a fully prospective, all-payer, population-based global budget, it was hypothesized that GBM will lead to (1) improvements in population-level prenatal and perinatal health, thereby reducing occurrence of SMM, and (2) increased access and quality of care in safety-net or historically underserved settings, thereby decreasing SMM disparities. Applying causal inference methods, we examine change over time in overall SMM incidence (Aim 1), SMM black-white racial disparities (Aim 2), and prevalence of SMM-related comorbid conditions (Aim 3). Difference-in-difference models find a positive treatment effect of the MD policy intervention in significantly reducing SMM incidence, yielding a decline of 0.04 percentage points in SMM case rate (95% CI: -0.0414, -0.0428). A triple-difference model to assess heterogeneous treatment effect by black race finds evidence of an average treatment effect on the treated of -0.006 percentage points, indicating additional SMM reduction for black individuals receiving care in Maryland during the GBM era. It is also observed that GBM policy implementation impacts the population level SMM-predictive comorbidities, with a modest yet significant decline (-2.18e-11; $p<0.001$) in the post-period. Taken together, these findings suggest implications for population-level maternal health and health disparities that have not been previously identified. This work adds to the body of literature about the impact of value-based payment for public health impact and advancing equity in health.

EXAMINING THE IMPACT OF THE MARYLAND GLOBAL BUDGET MODEL ON SEVERE MATERNAL MORBIDITY DISPARITIES

by

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Dedication

I dedicate this to my dear husband, Zenas Mwine, and our two beautiful daughters, Zinnia Fatima and Maizah Joelle. Thank you for being the wind underneath my wings. You mean everything to me. I love you.

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List of Abbreviations

APM Alternative Payment Model

GBM Global Budget Model

HCUP Hospital Cost and Utilization Project

LCM Leonard Comorbidities

SMM Severe Maternal Morbidity

TCOC Total Cost of Care Model

VBP Value Based Payment

Chapter 1: Introduction

1. Background

1.2.1. The Crisis of Maternal Mortality and Severe Maternal Morbidity in the United States. The rates of maternal mortality and morbidity represent a significant clinical and public health crisis (Declercq & Thoma, 2023; Hoyert, 2024). Maternal mortality, defined as the death of a woman while pregnant or within 42 days of termination of pregnancy, from any cause related to or aggravated by pregnancy, is at an all-time high and has been on the rise in the past several years (Callaghan et al., 2012; Declercq & Thoma, 2023; Fingar & Heslin, 2018; Geller et al., 2004; Howell, 2018; Hoyert, 2024; *Insights into the U.S. Maternal Mortality Crisis*, 2024; Leonard et al., 2019). Non-Hispanic black (hereafter referred to as black) women are disproportionately burdened in comparison to women of other racial/ethnic groups (Callaghan et al., 2012; Howell, 2018; Leonard et al., 2019). In 2021, the maternal mortality rate for black women was 69.9 deaths per 100,000 live births, nearly three times the rate for non-Hispanic white women; in 2023, while the mortality rate decreased significantly for white and Hispanic women, it remained elevated for black women, more than triple the rate of their white counterparts (Hoyert, 2023, 2024). It is estimated that more than 80% of these deaths are preventable (CDC, 2025; *CDC Newsroom*, 2016). Even more prevalent than maternal mortality is severe maternal morbidity (SMM), a key maternal health indicator (American College of Obstetricians and Gynecologists and the Society for Maternal–Fetal Medicine et al., 2016; Fingar & Heslin, 2018; Geller et al., 2018; Hirai et al., 2022). It is estimated that for every maternal death, there are 70 incidents of SMM (Ahn et al., 2020). These unexpected and life-threatening events that occur during hospitalization for childbirth result in significant short- or long-term consequences to a woman's health, and are highly associated with maternal mortality, often preceding a maternal death (American College of Obstetricians and Gynecologists and the Society for Maternal–Fetal Medicine et al., 2016; Howell, 2018). Annually, more than 60,000 women in the US suffer from SMM events, and in similar pattern to maternal mortality, black women are disproportionally affected (Fleszar et al., 2023; Tangel et al., 2019). Recent evidence indicates black women are rated highest in 22 of 25 SMM indicators used by the CDC to monitor population maternal health (Howell, 2018).

Scholars have identified a multitude of factors at the patient (e.g., knowledge of warning signs), clinical (e.g., preconception, prenatal and antenatal care), neighborhood (e.g., transportation, food security), provider (e.g., untimely treatment), healthcare facility and system (e.g., hospital quality), structural (e.g., racism), and policy (e.g., unpaid medical leave) levels that contribute to the observed disparities (Brigance et al., 2022; Crear-Perry et al., 2021; Dude et al., 2022; E. Wang et al., 2020). Efforts to address maternal morbidity and mortality have largely focused on clinical approaches (*Eliminating Preventable Maternal Mortality and Morbidity*, 2025; *Establishing the Respectful Maternity Care Collaborative (RMCC) | PCORI*, 2021; Katon et al., 2021), with less attention given to investigating how health care payment policies and reforms could improve maternal health outcomes and promote equity (Stone et al., 2023). Recent innovation in health care payment models, specifically value-based care models, offer an opportunity to explore more population-based payment model on health outcomes (Health Care Payment Learning & Action Network (HCP-LAN), 2017). The maternal mortality and morbidity crisis in addition to the outsized burden on black women necessitates a multi-pronged, comprehensive, approach to systemically improve maternal health outcomes and reduce inequities. This dissertation seeks to fill this gap by evaluating the impact of value-based payment on maternal health and maternal health equity.

1.2.2. Value-Based Payment as a Tool to Advance Maternal Health Equity. The Affordable Care Act accelerated the adoption of value-based payment models (VBP) that pay providers for health outcomes, rather than the volume of services provided (Smith, 2021). Across the health system, VBP models have increased from 30% to 40% of all payments between 2016-2021 (*2022 APM Measurement Infographic - Health Care Payment Learning & Action Network*, 2022; Horstmann & Lewis, 2023), with an estimated 100 million patients now obtaining care under a VBP system (Abou-Atme et al., 2022). While each VBP model varies in how it shifts incentives from volume to value, generally, healthcare organizations are incentivized to meet various quality, cost, and/or equity goals via financial gain or loss (Health Care Payment Learning & Action Network (HCP-LAN), 2017). Existing evaluations of emerging VBP systems have focused on the extent to which they achieve total and average per-patient cost reductions and overall changes in population health (Smith, 2021). Overall, evidence on VBP ability to meet goals of reduced cost and increased quality is modestly positive; results on efficacy are mixed as impacts have often been less than expected, but it appears VBP is here to stay (Joynt Maddox et al., 2018; McWilliams et al., 2016; Shortell et al., 2015, 2019; Whaley et al., 2021). Though it has been largely ignored in the literature, increasing attention is being paid to the role that VBP systems play in achieving health and healthcare equity (Eschliman et al., 2023; Kwok & Léger, 2023). VBP models can be a powerful tool to advance health equity. Research suggests that health care payment and financing design can have a profound impact on health disparities (Conway & Satin, 2022; Eberth et al., 2022; Lin et al., 2022). It can be used to mitigate the social and economic causes of avoidable inequality, by shaping the distribution of resources between providers serving different communities, resourcing health-related social-services, determining the degree of service integration and provider accountability, and altering organizational dynamics (Allen et al., 2022; Eschliman et al., 2023; Frye et al., 2015; Kadakia & Offodile, 2023; Shortell et al., 2015). VBP models directly target these levers and thus have the potential of altering patterns of health equity. A recent review of the role of healthcare payment and financing in achieving health equity from the Agency for Healthcare Research and Quality (AHRQ) Health Equity Summit in July 2022 found that while there is limited evidence on which payment and financing reforms would best promote equity, policy initiatives that explicitly target the root causes of health inequity related to financing and payment, such as the differential distribution of resources between providers serving different communities, are needed to yield significant and sustainable reduction in disparities (Eschliman et al., 2023). There have been efforts to apply VBP models to the birthing population, including the recently announced CMS Transforming Maternal Health Model, starting in late 2024 (*Transforming Maternal Health (TMaH) Model | CMS*, 2025). Several states have also experimented with VBP models (*A Path toward Value Based Payment: Annual Update*, 2016; Heberlein, 2021; Medicaid And CHIP Payment and Access Commission (MACPAC) & Zettle, 2021). These models use payment to incentivize targeted quality improvements and, in some cases, to reduce costs (Medicaid And CHIP Payment and Access Commission (MACPAC) & Zettle, 2021). However, none directly connected payment to improvement in health. Overall, results are positive for cost containment and clinical quality improvement, but many of the program evaluations are based on limited outcome measures and it remains unclear if their results capture causal impacts (Berrien et al., 2015; Medicaid And CHIP Payment and Access Commission (MACPAC) & Zettle, 2021). As such, additional investigation into causal impacts of VBP on maternal health outcomes and equity are needed.

1.2.3. The Maryland Model as an Innovative VBP Approach. The state of Maryland has been a national leader in value-based payment since the 1970's. The state has evolved through four distinct periods with the goal of improving patients' health and constraining system costs (*Maryland All-Payer Model | CMS*, n.d.; Rajkumar et al., 2014). In the All-Payer Model (APM) period from 1977-2013, all public and private third-party healthcare payers were reimbursed at the same rate for hospital services (*Maryland All-Payer Model | CMS*, n.d.). All-payer rate setting directly addresses provider incentives to avoid disadvantage populations (i.e. Medicaid patients), a factor that AHRQ has identified as an important mechanism linking payment systems to healthcare equity. At first, this model lowered expenditures (Murray & Berenson, 2015). However over time, providers began to increase admission volumes because payments were based in fee-for-service. To address this, Maryland tested the Total Patient Revenue (TPR) System between 2010 and 2012 (Rotter et al., 2022). This three-year pilot program tested a global hospital budget system, with all payer rate setting, in 10 rural community hospitals (Mortensen et al., 2014; Done et al., 2019; Pines et al., 2019). Results were positive and the program was implemented across all hospitals in the state, under what is called the Global Budget Model (GBM) (Murray & Berenson, 2015; Haft et al., 2020; Rotter et al., 2022). This five-year initiative implemented a prospective population-based payment in the inpatient setting, such that hospitals followed a revenue budget covering all services for the year, independent of volume, in order to contain annual per capita hospital cost growth. The goal was to limit spending growth and improve hospital quality measures. The package of VBP reforms included under GBM represent the most value-aligned system under the Health Care Payment Learning Action Network Alternative Payment Model Framework (Health Care Payment Learning & Action Network (HCP-LAN), 2017). The subsequent transition in 2018 to the total system cost of care (TCC) model extended the GBM payment policies to other sites of care in the health system, such as outpatient and ambulatory sites. This ongoing model, slated to run through 2027, seeks to improve care coordination and system efficiency in the total healthcare system. So far, TCC has demonstrated success in managing system expenditure even during pandemic era shocks (Emanuel et al., 2022; Rotter et al., 2022).

Despite performing well in cost-savings and certain hospital-based quality metrics such as readmission rate, empirical evidence documenting the impact of the Maryland Model on healthcare equity or quality, on a non-elderly birthing population is limited (Sharfstein et al., 2018; Smith, 2021; Morrison et al., 2021; Emanuel et al., 2022). Available evidence is mainly focused on cost and utilization, with very few papers on quality, and even fewer focused on equity impacts. There is evidence that the Maryland Model has improved quality of care for Medicare beneficiaries in dramatically reducing incidence of preventable hospital acquired conditions, decreasing unnecessary admissions and post-discharge readmissions, improved glycemic control for diabetes patients, and increased centralization of care (Masters et al., 2022; Offodile et al., 2022, 2023; G. X. Wang et al., 2023; Yesantharao et al., 2023; Haber et al., 2019). However, studies of the impact of the Maryland Model on equity or on maternal healthcare are sparse. While there is limited evidence of the effect of the Maryland Model to neonatal and infant mortality rates (Xie et al., 2021), the preponderance of evidence examines utilization and cost for the Medicare population. This trio of dissertation studies aims to address this gap in our knowledge by examining the impact of the MD Model on obstetric population outcomes and disparities.

1.2.5. MD Model Mechanism of Impact. As seen in Figure 1, Maryland healthcare payment policies may be related with maternal health outcomes through a few possible causal pathways:

(1) Increased visit time length; (2) Increased care coordination; (3) Redistribution of resources. In the first pathway, increased time for patient encounters would arise as a result of the transition to the GBM, which no longer prioritizes high patient volume as in the APM. With less emphasis on the sheer number of patients, there would be less time pressure and providers able to allocate more time per visit. This could then result in increased patient-provider communication, and increased patient trust of providers and adherence to their advisements. These impacts would likely result in improved health status. In the second pathway, better care coordination would result as an effect of Maryland's fixed prospective hospital budgets, as there is a need to restrict spending and utilization in order to preserve hospital revenues. Care coordination practices like electronic health record sharing and inter-provider dialogue may facilitate better clinical case management. To this end, more collaborative medicine, patient-provider communication, preventive care maintenance, and population health activities, would lead to lowering rates of SMM. Lastly, the third pathway represents the Maryland Model's payment and delivery impacts on health equity; namely, that by requiring all-payer rate setting and annual hospital global budgets instated by an independent regulatory entity, the Health Services Cost Review Commission, there is an effective redistribution of resources to lower-resource areas. Redistributing resources such that low-resourced populations are not disproportionately burdened by the effects of historical unequal payment policies and marketplace dynamics (i.e., low Medicaid reimbursement rates; market concentration yielding monopolies/collusive oligopolies), patients are not blocked from accessing care due to prohibitive cost. This yields increased access to health resources and services. In a VBP scenario, SMM rate, as well as SMM-related comorbid conditions, would hypothetically decrease due to increased pregnancy health in the population resulting from increased population health activities and/or improved

clinical encounters, yielding an increased quality of obstetric care, and ultimately fewer cases of severe maternal morbidity. Disparities in SMM would hypothetically decrease due to increased proliferation of resources in previously deprived areas.

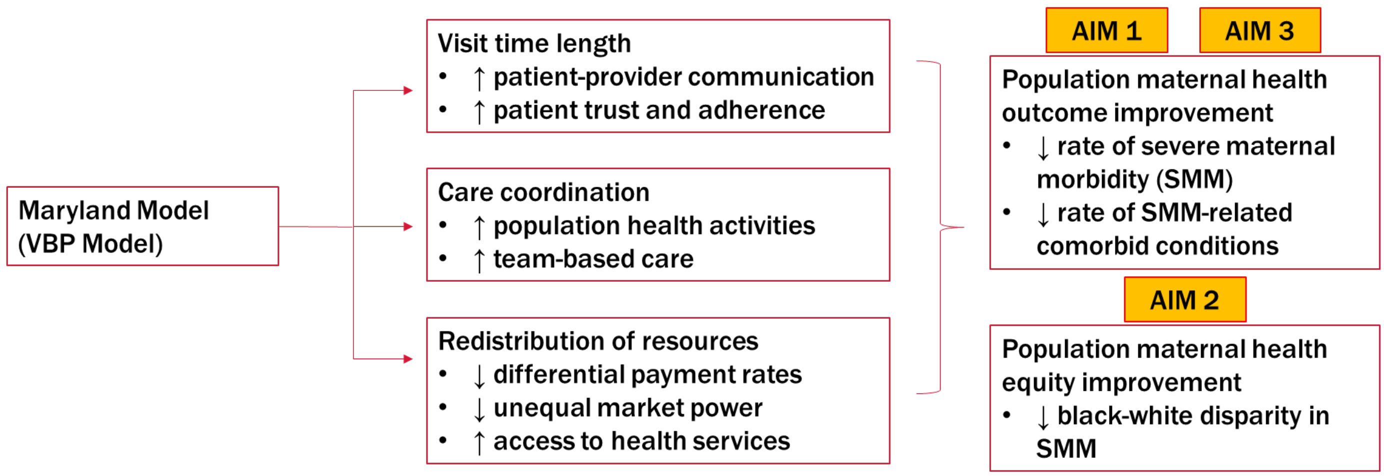


Figure 1. Conceptual Model

2. Objective and Rationale

In consideration of unacceptable rates of maternal death and morbidity, and particularly with respect to profound racial and ethnic disparities, it is essential to study how we may leverage health policy to alleviate these issues. The rationale for this trio of studies is informed by calls from numerous scholars and organizations asking for the establishment and evaluation of value-based payment initiatives to address maternal health outcomes and severe disparities (Avery et al., 2018; Eschliman et al., 2023; Kadakia & Offodile, 2023; Kwok & Léger, 2023; Stone et al., 2023). In addition to studying an urgent contemporary public health problem, these studies aim to provide more information about the non-financial, population health effects of VBP models.

To learn more about the impact of the Maryland Model on the health of birthing people in the state of Maryland over the past decade, this dissertation pursues the following aims:

(1) **Aim 1:** Impact of Global Budget Model on Severe Maternal Morbidity. The objective of the first study is to examine overall rates of SMM incidence Maryland, where the Global Budget Model was implemented, using Arizona, Kentucky, and New Jersey, all untreated by the GBM or any similar paradigm, as comparison states.

(2) **Aim 2:** Heterogeneous Treatment Effect by Race. The objective of the second study is to examine rates of SMM incidence by race, to determine if there is variation in treatment effect by racial subgroup. Given notable black-white disparities in SMM incidence nationwide, there may be evidence of a differential impact of GBM policy implementation on outcomes within the treated state of Maryland.

(3) **Aim 3:** Impact of Global Budget Model on SMM Precursors. Despite its deleterious impact and unnecessarily high incidence, Severe Maternal Morbidity is a relatively rare health outcome. By contrast, the various conditions associated with developing SMM, or the comorbidities shown to be predictive of SMM occurrence, are more prevalent and can provide important information of the population-level health status of pregnant people. The objective of the third study is to examine how SMM-predisposing comorbidities may be impacted by GBM implementation.

Chapter 2: Impact of GBM on Severe Maternal Morbidity

1. Overview

The objective of this work is to evaluate the impact of the Maryland Model on incidence of SMM in Maryland; I seek to characterize the overall impact of the Maryland Model on statewide SMM burden. Given the conceptual model described above, which details how a fixed, prospective hospital budget encourages better preventive care initiatives and redistributive effects that would alleviate inequity in health outcomes due to social determinants of health burdens, I predict that the GBM will result in fewer cases of SMM in Maryland with respect to comparison states. In other words, Aim 1 will test the following hypothesis:

H1: Overall Severe Maternal Morbidity incidence in Maryland will decrease after the novel Global Budget Model policy intervention in 2014; we will observe reduced SMM rates in the GBM era, attributable to this Maryland Model.

2. Methods

2.2.1 Data

Hospital Cost and Utilization Project (HCUP). Data for all aims comes from the 2011-2019 Healthcare Cost and Utilization Project (HCUP) State Inpatient Databases (SID). Sponsored by AHRQ, the SID tracks inpatient discharge records from community hospitals in each participating state; altogether, the SID encompass about 97% of all U.S. community hospital discharges (Agency for Healthcare Research and Quality, 2025). HCUP SID does not include unique patient identifiers; therefore, the unit of analysis is the hospital discharge and not the patient.

Study Population, Comparison Groups, and Policy Implementation Periods. The study population includes women aged 12-55 years who were hospitalized and discharged for a childbirth delivery between January 1, 2011 and December 31, 2019. These individuals were identified by their International Classification of Diseases (ICD)-9 or 10 diagnosis and procedure codes, depending on discharge year, as well as Diagnosis Related Group (DRG) codes using well-established methods of childbirth delivery identification (Kuklina et al., 2008; Hirai et al., 2022). Of note, data from Maryland patients excludes births at the rural hospitals exposed to the Total Patient Revenue (TPR) pilot in 2010 to eliminate heterogeneity in treatment timing; this comprised discharges from 10 of 46 Maryland hospitals, equaling approximately 12% of all discharges in the study period. Data also describes patients from a set of control states, including New Jersey, Arizona, and Kentucky. As in prior research (Offodile et al., 2022; Rotter et al., 2022; Offodile et al., 2023; Yesantharao et al., 2023), the selection of control states is based on their successful use in other evaluations, relatively similar policy environments (e.g., all expanded Medicaid under the ACA) and generally similar population-level sociodemographic features. The exposure period is divided into pre- and post-GBM period: the pre-period includes 2011-2014 and the post-period covers 2015-2019. Data for Aims 1 and 3 will include women of all races to maximize external validity and degrees of freedom; data for Aim 2 will be limited to black and white women to specifically examine black-white racial disparities.

2.2.2. Design and Estimation

<u>Study measures</u>

Dependent variable. The outcome of interest is SMM incidence. SMM will be operationalized as a composite, binary indicator of 21 conditions (e.g., acute kidney failure, eclampsia; see Appendix A for full list) and procedures that represent “near misses” of mortality in the hospital setting. Similar to current published reports and federal guidance about SMM incidence, blood transfusion is not included in the estimate (Health Resources and Services Administration, Maternal and Child Health Bureau, n.d.; US Department of Health and Human Services, n.d.). This variable is constructed from applicable ICD-9 and ICD-10 diagnosis and procedure codes (Fingar et al., 2006; Kuklina et al., 2008; Hirai et al., 2022).

Independent variable. The independent variable of interest is exposure to GBM during pregnancy. In this sample, it includes individuals living in the treated state, Maryland; those delivering prior to 2014 ("pre-period") are considered unexposed, and those delivering after 2014 ("post-period") are considered exposed.

Covariates. A rich set of covariates was compiled to account for individual (sociodemographic and clinical) and state-level heterogeneity. Sociodemographic covariates include age, race (e.g., Non-Hispanic black, Non-Hispanic white), Zip code-level income quartile, insurance payer (e.g., Medicaid, private insurance). Clinical covariates include type of birth (e.g., vaginal, caesarian), number of comorbidities (i.e., 24 diagnoses as detailed in Leonard et al., 2020; see Appendix B). State-level covariates include poverty level (i.e., percent of state population with income in the past 12 months below the Federal Poverty line), uninsured status (i.e., percent of noninstitutionalized civilian population with no health insurance), unemployment rate, supply of physicians (i.e., number of Family Medicine physicians and Obstetrician/Gynecologists per 10,000 population), state health policy (i.e., Medicaid income eligibility for pregnancy coverage, separate reimbursement for non-traditional pregnancy services [e.g., doulas]). State-by-year characteristics were sourced from the American Community Survey (state sociodemographic data), Area Health Resource Files (healthcare supply data), and Kaiser Family Foundation (policy data).

2.2.3. Study Design and Analytical Approach

The hypothesis was tested using a difference-in-differences approach, which compares changes in the outcome (i.e., SMM) over time (i.e., from before to after policy implementation), between a treated group (i.e., Maryland) and untreated group (i.e., comparison states of Arizona, Kentucky, and New Jersey). While there are versions of the difference-in-differences approach that exploit time heterogeneity by using units with staggered policy adoption, this paper employs the classic two-way fixed-effects model (de Chaisemartin & D'Haultfoeuille, 2019; Imai & Kim, 2021), where there is no variation in treatment timing.

For difference-in-differences (hereafter "DD") estimates to be causal, there are a few assumptions to be met, chiefly the Stable Unit Treatment Values Assumption (SUTVA), the parallel trends assumption, and no anticipation. SUTVA requires that (1) there is no spillover of treatment effect between groups, or no interference, and (2) that there is only one version of the treatment, or no hidden heterogeneity in treatment (Imbens & Rubin, 2015). In addition, it is critical that there be no confoundedness, or that potential outcomes do not vary by treatment group. To ensure unconfoundedness, the parallel trends assumption requires that the control group and treatment group are trending in the same direction, such that whatever happens in the control group after the intervention represents the counterfactual for the treated group; it represents what would have happened in the treated group in absence of treatment (Imbens & Rubin, 2015). This assumption of parallel trends in untreated outcomes allows estimation of the average treatment effect on the treated (ATT). Lastly, there is the assumption of no anticipation, or that the treatment has no effect before intervention occurs. If these assumptions are met, it is understood that the observed effect is caused by the treatment, because we have controlled for time-varying confounders in these ways, and the DD coefficient is interpreted as the average treatment effect on the treated.

For this study, the primary identifying assumption of the design (i.e. the parallel trends assumption) is that changes in the comparison states represent changes that would have occurred in Maryland, had GBM not been implemented.

The sample is described by treatment status across all years to understand the covariate distribution in Maryland and its comparators (Table 1). A covariate balance table is included to show the relative change of covariates over time in the sample, to help determine feasibility for inclusion in regression (Table 2). To assess the plausibility of the parallel trends assumption, overall SMM trends by treatment status is depicted to visually inspect outcome trends in the pre-period (Figure 1). Additionally, to examine if outcomes prior to implementation were evolving similarly in Maryland and the comparison states, a linear trend test is conducted using a regression model fit on pre-intervention data that interacts continuous time and a Maryland state indicator (Table 3). Finally, the difference-in-differences analysis (Table 4) is implemented with the following two-way fixed effects regression:

$$Yist = \beta TREAT*POSTst + \alpha AGEist + \alpha RACEist + \alpha INCOMEist + \alpha PAYERist + \alpha BIRTHTYPEist + \alpha BIRTHRISKist + \alpha TEACHINGist + \alpha BEDSIZEist + \alpha LOCATIONist + \alpha HOSPTYPEist + \tau t + \sigma s + \varepsilon ist$$

Where *Yist* is the outcome for group *i* at time *t* in state *s*. The models include state fixed effects (*σs)* to account for time-invariant state factors, year fixed effects (*τt*) to account for common trends across states, and the covariates described above. *β* is the difference-in-differences coefficient of interest and measures the impact of the program. This regression was implemented using a linear probability model, as is common in the health policy literature (A. Cameron & Trivedi, 2005).

Robust standard errors come from the Huber-White sandwich estimator (Bertrand et al., 2002; Freedman, 2006). While the difference-in-difference literature typically clusters standard errors to account for serial correlation, in this scenario, that approach is inappropriate due to the few total clusters and only one treated cluster, which cannot contribute any variance (A. C. Cameron & Miller, 2015; Rokicki et al., 2018; Ferman & Pinto, 2019). Typical approaches to clustering fail in this situation and the literature has not come to a consensus on alternative methods (Ferman & Pinto, 2019; MacKinnon & Webb, 2020). Robust standard errors are appropriate under the assumption that the states are fixed and not sampled from a super-population of states (Ferman & Pinto, 2019; Rokicki et al., 2018).

Also included as part of the main results is an event-study specification, which allows for granular examination of the group differences over each time unit (i.e., year over year), instead of pre- versus post-periods only. This provides crucial information about the magnitude of change of the treatment effects in each post-period time unit. I conduct an F-test for change over time in the pre-period.

Lastly, to assess the stability of findings, two robustness checks were conducted: (1) examining treatment effect before ICD-10-CM transition of October 2015 (i.e., evaluating post-period trend from October 2014 – October 2015) and (2) examining the full post-period of 2014-2019 with year 2016 removed (i.e., dropping 2016 and assessing for treatment effect).

3. Results

Table 1A. Demographic and clinical characteristics of women who gave birth in Maryland, Arizona, Kentucky, and New Jersey, 2011-2019.

	Treated State: Maryland (n= 521,434)	**Control States: Arizona, Kentucky, New Jersey** (n= 2,058,793)	**p-value**
Severe Maternal Morbidity			0.000
Yes, %	0.48	0.38	
No, %	99.52	99.62	
Age			0.000
24y and younger, %	18.32	23.81	
25-34y, %	54.28	53.00	
35-44y, %	20.35	16.87	
45y and older, %	7.05	6.31	
Married			0.000
Yes, %	56.11	43.53	
No, %	43.89	56.47	
Race/Ethnicity			0.000
Non-Hispanic White, %	39.43	54.22	
Non-Hispanic Black, %	32.93	10.23	
Non-Hispanic Other, %	13.42	11.42	
Hispanic, any race, %	14.46	24.13	
Income Quartile			0.000
Q1: $1 - $47,999, %	7.75	30.17	
Q2: $48,000 - $60,999, %	6.51	22.11	
Q3: $61,000 - $81,999, %	28.94	19.53	
Q4: $82,000+, %	56.49	26.79	
Missing, %	0.32	1.39	
Primary Payer			0.000
Medicaid, %	41.02	41.57	
Private Insurance, %	54.34	51.02	
Self-Pay, %	1.29	3.37	
Other, %	3.33	4.02	
Missing, %	0.02	0.02	
Birth type			0.000
Vaginal, %	57.78	56.52	
Caesarian section, %	34.38	33.35	
Unknown delivery type, %	7.84	10.12	
Leonard et al (2020) Comorbidity Index			0.000
None, %	56.97	62.35	
Low (1 condition), %	32.46	28.70	
Moderate (2 conditions), %	9.11	7.56	
High (3+ conditions), %	1.46	1.39	

Source: Data extract from 2011-2019 Healthcare Cost and Utilization Project (HCUP) State Inpatient Databases (SID) for Maryland, Arizona, Kentucky, and New Jersey. Study sample includes women, aged 12-55 years, inhabiting states that were either in the treatment group (MD), or in states that were not treated (AZ, KY, NJ).

Table 1B. Socioeconomic and policy characteristics of Maryland, Arizona, Kentucky, and New Jersey, 2011-2019.

	Treated State: Maryland (n=521,434)	**Control States: Arizona, Kentucky, New Jersey, New York** (n= 2,058,793)	**p-value**
Poverty			0.000
Population with income below FPL, %	9.70	14.39	
Health Coverage			0.000
Uninsured civilian noninstitutionalized population, %	7.73	10.87	
Joblessness			0.000
Unemployed population, %	6.37	7.32	
Healthcare Supply			0.000
Providers per 10,000 population, %	3.77	3.31	
Prenatal Medicaid Coverage			0.000
Income Eligibility Criteria, % FPL	259.3	185.3	

Source: Data extracts from 2011-2019 American Community Survey, Area Health Resource Files, and Kaiser Family Foundation for mean rates of covariates across all years in Maryland, Arizona, Kentucky, and New Jersey. Study sample includes women, aged 12-55 years, inhabiting states that were either in the treatment group (MD), or in states that were not treated (AZ, KY, NJ). "Providers" includes MDs practicing Family Medicine and/or Obstetrics and Gynecology. "FPL" is Federal Poverty Level.

Table 1A and 1B report significant differences between Maryland and the comparison states for all individual-level and state-level covariates. The birthing population in Maryland was found to be overall older, more likely to be married, and more likely to be of Non-Hispanic black race (all $p<0.000$). Compared to Arizona, Kentucky and New Jersey, birthing people in Maryland are generally wealthier, and are also more likely to be privately insured, as fewer people were covered by Medicaid in Maryland relative to the other states (41.02% vs. 41.57%; $p<0.001$). Findings of clinical status show a greater proportion of people in Maryland with comorbid conditions than in comparison states (estimate for 1 comorbidity: 32.46 vs. 28.70; $p<0.001$). At the state level, there is less poverty, uninsured status, unemployment, and a greater number of physicians per capita in Maryland than the comparison states.

Table 2. Covariate balance of demographic characteristics over study period.

	Difference-in-Differences Interaction Term Coefficient
SMM	-0.0003
Age	0.0098
Marital Status	-0.0027
Race/Ethnicity	0.0305
Income	0.0741
Payer	0.0137
Birth Type	0.0197
Comorbidities	0.0179
Poverty	0.0095
Uninsurance	0.0207
Unemployment	0.0109
Providers	0.0224
Medicaid Coverage	0.0467

Source: Data extract from 2011-2019 Healthcare Cost and Utilization Project (HCUP) State Inpatient Databases (SID) for Maryland, Arizona, Kentucky, and New Jersey. Study sample includes women, aged 12-55 years, inhabiting states that were either in the treatment group (MD), or in states that were not treated (AZ, KY, NJ).

Table 2 shows the results of individual regressions of each covariate against the DD interaction term to identify if they are changing significantly from year to year. Here, coefficients are relatively small, indicating that change over time is minimal, and covariates are balanced.

Figure 2. SMM status in GBM-treated and untreated states.

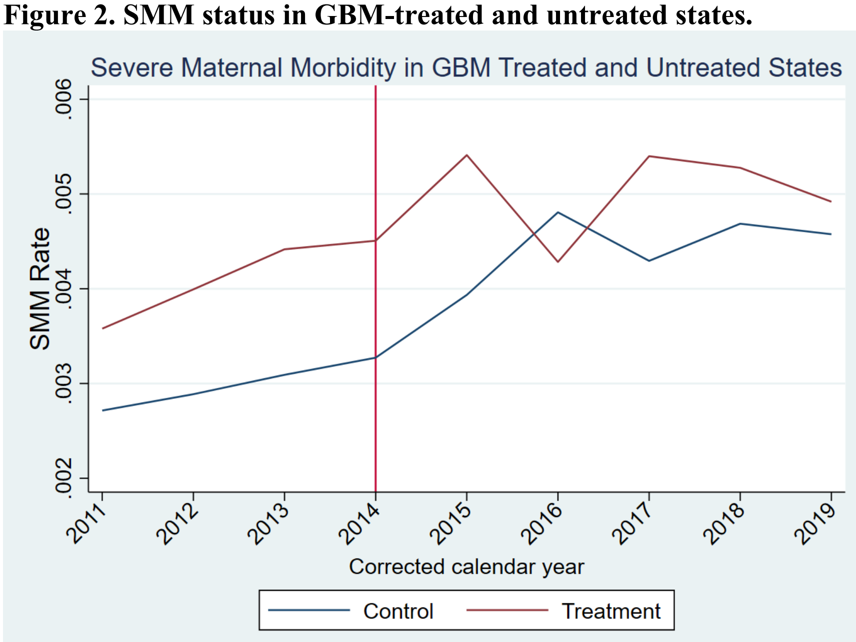


Table 3. Differences in pre-period linear trend in SMM rate between treatment groups.

	Coefficient (SE)	p-value
Treatment Group	0.0012874 (1.28e-15)	0.000

To assess parallel trends in the pre-period, Figure 2 provides visual confirmation of similar outcome trends in years prior to the policy intervention. Although Maryland has higher SMM incidence than the control states, it is evident they were trending in the same direction. Table 3 reports the difference in outcome between treatment groups before policy intervention. Though there is significant difference in SMM rates between groups (p-value <0.05), the relatively modest rate change over time (0.0013) suggests that it is fairly constant during the pre-period, indicating that there was not an anticipation effect or spillover of the intervention into the pre-period.

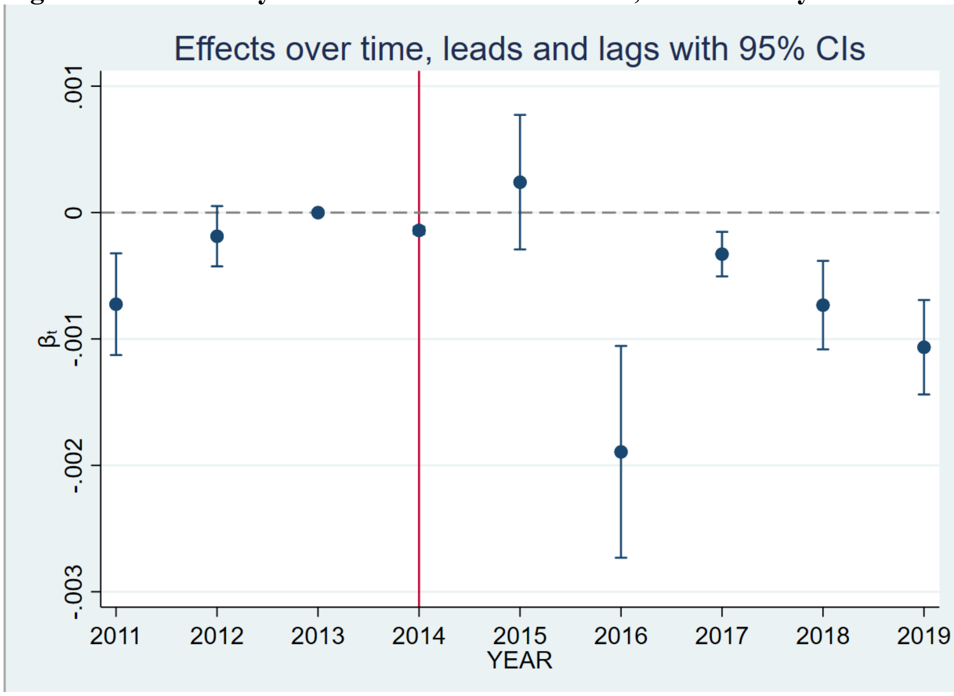
Table 4. DD estimates from unadjusted and adjusted linear probability models.

	Pre-period mean in treated group	Unadjusted model	Adjusted model
	0.0041438	---	---
DD Interaction Term Coefficient (SE)	---	-0.0003448 (1.15 e-06)	-0.0004213 (3.54 e-06)
DD Interaction Term 95% Confidence Interval	---	-0.0003471, -0.0003426	-0.0004282, -0.0004143

Source: Data extract from 2011-2019 Healthcare Cost and Utilization Project (HCUP) State Inpatient Databases (SID) for Maryland, Arizona, Kentucky, and New Jersey. Study sample includes women, aged 12-55 years, inhabiting states that were either in the treatment group (MD), or in states that were not treated (AZ, KY, NJ). "DD" means difference-in-differences. Table estimates use robust standard errors.

Table 4 describes the change between pre- and post-period in the GBM-treated group, Maryland. Prior to Global Budget Model implementation, approximately 0.41% of the birthing population in Maryland experienced SMM events. The DD coefficients above represent the change in SMM after GBM implementation, controlling for state and time fixed effects in the unadjusted model, and in the adjusted model, controlling for state and time fixed effects, and other covariates (e.g., race/ethnicity, age, income), respectively. After the policy implementation, there was an approximately 0.034 – 0.042% decrease in SMM in the treated state.

Figure 3. Event study of SMM incidence over time, difference by treated status.



In Figure 3, it is observed that a treatment effect occurs after GBM implementation in 2014, and this effect is most pronounced in 2016, with continued decrease in SMM in subsequent years. In an F-test of the joint significance of pre-period coefficients, there is no significant difference between years (p= 0.0334), indicating that the time points 2 and 3 years before the intervention year 2014 were not significantly different change in SMM rate. However, Figure 3 shows that after the GBM policy implementation, there was statistically significant change in SMM rate, year after year.

Table 5. DD estimates from sensitivity analyses.

	Pre-period mean in treated group	Adjusted model: Jan 2011-Oct 2015 (Pre ICD-10-CM Transition)	Adjusted model: Jan 2011-Dec 2019, 2016 Removed
	0.0041438	---	---
DD Interaction Term Coefficient (SE)	---	-0.0009 (2.68 e-06)	0.0006 (1.88 e-06)
DD Interaction Term 95% Confidence Interval	---	-0.00090, -0.00089	0.00062, 0.00063

Figure 4. Treatment effect without inclusion of year 2016.

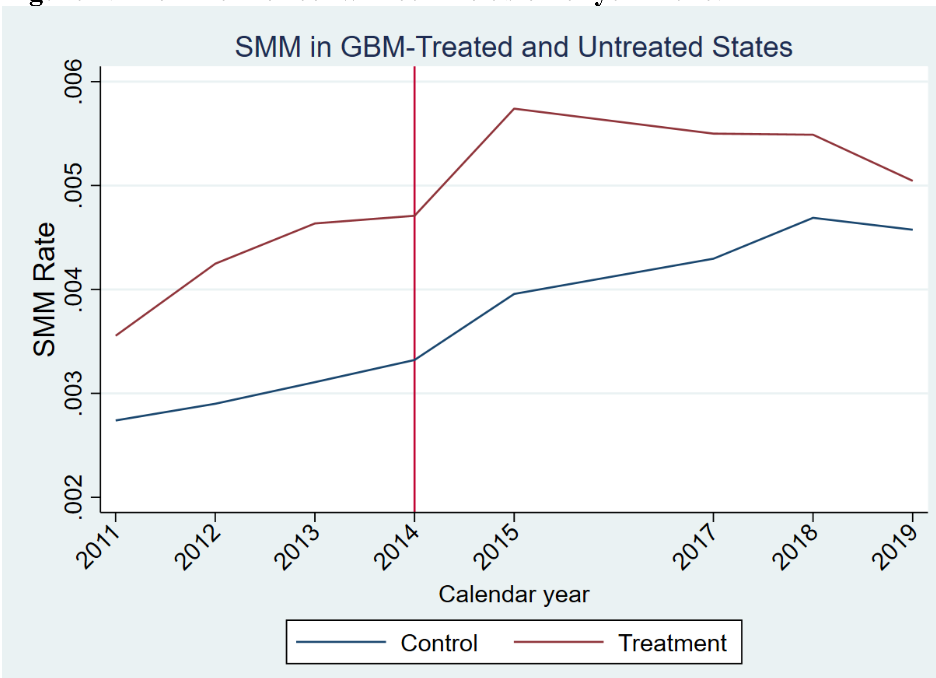


Table 5 describes the DD estimates for different model specifications. When the post-period is limited to Jan 2014 – October 2015 (the start of the ICD-10-CM code transition), the DD coefficient is -0.0009 ($p<0.0001$); there is a decrease in SMM rate, prior to the ICD transition. When the post-period does not include 2016, the DD coefficient from the fully adjusted model is 0.00074 ($p<0.0001$). This indicates an increase in SMM rate in the post period when 2016 is not included.

4. Discussion

The purpose of this study was to examine the impact of a novel value-based payment policy on severe maternal morbidity. Solving the crisis of SMM is an urgent public health priority, necessitating the investigation of potential novel policy-based solutions that lie outside of the usual range of ideas targeting quality of and access to prenatal and postpartum medical care (Brigance et al., 2022). In acknowledgement of the reality that health is shaped by more than just biology, this study was designed to examine the potential impact of state fiscal hospital policy, as a structural force, on maternal health. When first established, the stated intent of the Global Budget Model was not expressly to improve maternal health outcomes (Haber et al., 2019; *Maryland All-Payer Model | CMS*, n.d.; Morrison et al., 2021). However, given that childbirth is the primary reason for inpatient stay (Project (HCUP), 2011), it stands to reason that changes in hospital payment expected to alter utilization, quality, and health outcomes in other populations would also do so in the obstetric population. As such, we crafted this study to examine downstream impacts of the Maryland Global Budget Model. Using causal inference methods, we observed a decrease in the statewide rate of SMM in Maryland that can be reasonably attributed to the GBM policy implementation, in accordance with the satisfied assumptions of the difference-in-differences method.

Maryland is a unique state relative to peers, often described as "America in miniature" for its demographic and geographic diversity (Kelly, 2021). As such, it can be hard to find a perfect comparison group for it; we saw that Maryland differed from a diverse set of comparison units in Arizona, Kentucky, and New Jersey on each individual- and state-level socioeconomic and policy characteristic. Maryland is, overall, more racially diverse and has higher socioeconomic indicators than its study peers. Still, because of the use of two-way fixed effects regression, which controls for time-invariant state-level factors, and time-varying state-year-level factors, we are sure that we account for state-level trends across the years, so that estimates do not suffer from bias resulting from a compositional shift in population characteristics or policy shocks. Importantly, preliminary DD analyses, including covariate balance test, linear trend test, visual parallel trend inspection, and event study, altogether indicate there to be no SUTVA violations, identifiable parallel trends and no anticipation effect observed. Thus, all necessary identifying assumptions are satisfied and we retain high confidence in our causal estimate.

In our results, we observe a significant decrease in SMM rate in Maryland following policy implementation, notably in the year 2016, where the decline is most stark. The robustness checks conducted (Table 5; Figure 4) indicate that SMM rate was already statistically trending downward prior to the ICD-10-CM code switch, suggesting that the code changes may not have been the reason for the observed treatment effect. However, 2016 is the main driver of the effect in the post period, as seen in Table 5 estimates, where the DD coefficient is in fact positive for the SMM rate of change over time after policy implementation.

There are several factors which may impact reported instances of SMM in the post-period. First, there was a transition from International Classification of Diseases, Ninth Revision, Clinical Modification, to the Tenth Revision (ICD-09-CM to ICD-10-CM) in October 2015, such that inpatient data was coded using ICD-09-CM schema from January 1 to September 30, 2015 and ICD-10-CM schema from October 1 to December 31, 2015; subsequent years employ ICD-10-CM code nomenclature. This switch represented a major change in how hospitals conducted business, requiring alterations to system infrastructure, the need for additional training and education, productivity losses, and contract renegotiations (Rezaeiahari et al., 2022). Due to this change, which not only re-labeled diagnoses and procedures in a 1:1 trade, but also assigned additional codes in some cases and removed or consolidated codes in other cases, there was the potential for change in SMM estimates because of how the component parts were now being captured in the record. The number of clinical diagnosis codes in ICD-10-CM is nearly five times the number of diagnosis codes in ICD-9-CM, which creates a potential for misrepresentation of SMM trends, due to the substantial difference in coding detail and granularity (Metcalfe et al., 2021). In fact, a 2021 study examining the impact of the ICD coding system transition on incidence of SMM in hospital discharge data found a significant decrease in SMM from 2012 to 2017 (Metcalfe et al., 2021). Using a segmented regression approach on HCUP National Inpatient Sample data, study authors found that the coding change led to an immediate decrease of 2.26 cases per 1000 obstetric deliveries ($p<0.001$); when excluding blood transfusion, this was a less radical decrease of 0.60 cases per 1000 ($p<0.001$). However, another study of the ICD transition impact to SMM rates (Hirai et al., 2022) found that overall rates, excluding blood transfusion, increased from 2012 to 2019, and were not associated with the ICD-10-CM transition; of all states, only one (Tennessee) had a significant decrease over the study period which was associated with the coding transition. Similarly, a study in the obstetric population of the coding transition impact to pregnancy identification showed that translation of existing ICD-9-CM algorithms into ICD-10-CM codes were consistent in identifying pregnancy episodes across the ICD transition period (Sarayani et al., 2020). In an analysis of Arkansas all-payer claims data which examined incidence of non-transfusion SMM following the ICD-10-CM switch found a higher rate of SMM post-ICD-10 implementation (Rezaeiahari et al., 2022). Notably, this study differs from our design in that it measures the impact of the coding change during the postpartum period, or up to 42 days post-birth, and not only diagnosis codes from the delivery hospitalization. As such, while they find evidence of increased SMM rate after the ICD-10 switch, this is likely due to their significantly longer interval of observation. Evidence suggests that more SMM occurs in the postpartum period than on the day of delivery itself, which may explain they observe an increase in SMM in the post-ICD-10-CM era.

The ICD-10-CM coding switch may help to partially explain the significant decrease in SMM in the post-period, in that providers, payers, clearing houses, billing services and anyone needing to adhere to the Health Insurance Portability and Accountability Act (HIPAA) necessarily had to implement a new, more detailed coding mechanism; adjustment is to be expected, and this may reflect in SMM estimates in late 2015 through early- to mid-2016. However, sensitivity analyses are robust to this potential influence (Figure 4); examination of SMM after policy implementation in 2014 but before the ICD-10-CM switch in October 2015 indicates a significant decline in SMM rate even before the code transition takes effect.

Another potential rationale for this large observed effect is changes in the ability to measure SMM. Hirai and colleagues (2022) found that the nationwide SMM increase over the period from 2012-2019 occurred mainly for metropolitan residents in high volume hospitals, suggesting there may have been improved diagnostic ascertainment through quality improvement activities, rather than actual increases in SMM. Because there were also not concurrent increases in hospital-based mortality accompanying the SMM increases, it may support the idea that SMM was able to be better identified, or that there were increases in less severe cases.

An additional consideration is the composition of the sample, including a change to population fertility. In September 2014, Maryland's Medicaid program began reimbursing separately for immediate postpartum long-acting reversible contraception (IPP-LARC); this marked a shift from reimbursement as part of the global delivery fee to a separate payment, which has been a critical step to improving IPP-LARC implementation (Steenland et al., 2022). Steenland and colleagues found evidence of increased postpartum LARC provision with this new payment scheme, such that more people with Medicaid-paid births were able to receive IPP-LARC. Importantly, this timing is concurrent with GBM implementation; it is possible that increases in IPP-LARC could have led to less future state-level pregnancy in subsequent years (i.e., in 2015, 2016). However, Steenland et al. observed mixed results in Maryland, which showed statistically significant estimates in unadjusted regression models but not in models controlling for births per quarter, or models excluding observations from low-volume facilities. Yet even if there were reductions in state-level fertility, this doesn't necessarily mean there would be reduced SMM; importantly, Steenland and colleagues find that following Medicaid policy change, only 10% of the hospitals provided more than 1% of birthing people with IPP-LARC. Given this finding, it is unlikely that fertility effects from IPP-LARC are great enough to reduce SMM so drastically.

Medicaid expansion is another factor that could affect maternal health outcomes. Given the available evidence indicating that lack of insurance leads to reduced access to care and poor maternal outcomes, it follows that expansion of health insurance may improve maternal health outcomes (McWilliams, 2009). Current literature informs us that Medicaid expansion is significantly associated with lower maternal mortality compared to non-expansion states (Eliason, 2020), that it led to reductions in postpartum hospitalization (Steenland & Wherry, 2023), increases in preconception care, folic acid and postpartum contraception (Myerson et al., 2020), increased access to prenatal care (Harvey et al., 2021), and reduction in SMM (Guglielminotti et al., 2021). In consideration of these recent findings, it is possible that the effect is partially explained by the ACA expansion; however, Maryland was not unique in this policy factor, as New Jersey, Arizona, and Kentucky also expanded Medicaid in 2014 at the same time as Maryland. Still, Maryland had a more generous level of income-based qualifying criteria, allowing those with incomes about 250% greater than the Federal Poverty Level (FPL) to be eligible for pregnancy coverage, while the control states allowed those with about 185% of the FPL, on average, to be eligible for Medicaid. With more broad eligibility cutoffs, there may be a greater proportion of Maryland residents who are positively impacted by prenatal care engendered by access to care via insurance coverage, relative to the other states, which may facilitate a decrease in SMM.

Overall, the present study identified a statistically significant reduction of 0.0421 percentage points (95% CI: 0.04143, 0.04282; $p<0.001$), indicating less severe maternal morbidity disease burden in the population exposed to the global budget model policy intervention. In support of the stated hypothesis, we find the GBM did contribute to a decrease in SMM incidence in Maryland, in both adjusted and unadjusted models. For people delivering babies in Maryland, there is a significant reduction in risk of developing SMM, due to exposure to the GBM-treated environment. At a population level, this finding suggests that states with a value-based payment model comparable to Maryland's GBM may produce an improvement in state-level SMM rates, and that at an individual level, living or receiving care in a state with a comparable payment and delivery model may lead to better maternal health.

Notably, other states have implemented payment-focused solutions to address maternal morbidity, though they are categorized as Pillar 2 ("Fee-for-Service, Link to Quality and Value") in the Health Care Payment-Learning Action Network Alternative Payment Model Framework (Health Care Payment Learning & Action Network (HCP-LAN), 2017). In a Medicaid and CHIP Payment and Access Commission study of state Medicaid programs using VBP for maternity services which focused on three types of models (i.e., episodes of care, pay for performance, and pregnancy medical homes), they examined the process of model design and implementation, and reviewed data on their efficacy. Authors found that states designed models mainly to incentivize targeted quality improvements and sometimes to reduce costs; this yielded mixed results in achieving targeted quality measures, which focused more on patients receiving treatment at the standard of care (e.g., payment for patients attending their 6w postpartum visit) than on broadscale, population-level maternal health targets (e.g., reduction of SMM rate). Similarly, a 2020 review of Medicaid policies, programs, and initiatives to improve maternal health found that most state Medicaid programs (n=41) did implement payment policies to address maternal health; the majority were programs to encourage postpartum use of long-acting reversible contraception, and about one-third were payment reductions intended to discourage particular interventions, such as early elective delivery (Medicaid And CHIP Payment and Access Commission (MACPAC), 2020).

Here, we evaluate the most innovative and population-based VBP model in the United States – the Maryland Model(Health Care Payment Learning & Action Network (HCP-LAN), 2017; Smith, 2021). Although there are existing state-level VBP initiatives for maternal health, these models are built on fee-for-service architecture (e.g. episode-based payments for procedures, shared savings with upside risk only) (Heberlein, 2021; Medicaid And CHIP Payment and Access Commission (MACPAC) & Zettle, 2021; Stone et al., 2023). To date and to our knowledge, there has not been a study of the impact of a fully prospective, population-based global budget system on maternal health. Other states have similar HCP-LAN Category 4 APMs (i.e., Population-Based Payment); Vermont has its ongoing all-payer accountable care organization demonstration (due to end December 2026), and Pennsylvania has its rural health model (ended December 2024), but thus far, there have been no evaluations of maternal health impacts (Centers for Medicare & Medicaid Service (CMS), 2024; NORC, 2025). As well, there are evaluations of the Maryland Model, but in reports of Maryland's Global Budget Model and its successor, the Total Cost of Care (TCOC) Model, there have not been evaluations of maternal health. Although reduction of SMM is a stated quality goal for TCOC, these analyses have not been conducted (Peterson et al., 2024; Rotter et al., 2022). As such, our current study offers new insights into the impact of this policy implementation.

Despite this novel finding, there are a few limitations worthy of discussion. One, we observed a significant treatment effect; importantly, we do not examine directly the mechanism by which this result was produced. In the conceptual model, the idea is that any one, two, or three of the proposed potential pathways could separately or together generate a positive maternal health effect. However, this study does test these mechanisms, and the precise way that GBM led to the reduction in SMM to occur is unknown. To replicate Maryland's findings in other settings, it will be important to know what are the specific features of the GBM that made the SMM rate decline. Two, and related to the first limitation, this VBP model may have a positive impact on population health by decreasing SMM incidence, but external validity of these positive findings may be limited by the specificity of this policy intervention for the setting in which it developed. There may be Maryland-specific factors that enable GBM to have a certain impact that would not occur elsewhere due to context dependence. Three, HCUP data is limited to hospital-associated outcomes; it is possible that this data does not capture all occurrences of SMM and may underestimate the true estimate. Pregnancy is generally nine months and the postpartum period may range from six weeks to three months, representing up to one year of care; however, much of this care does not occur in the hospital setting. Future studies will aim to characterize the impact of Maryland policy on the full duration of pregnancy.

Relatedly, how the exposure variable is conceptualized may be a point of discussion. The independent variable of interest is exposure to the GBM during the pregnancy, but it may be better considered as exposure at the expected time of conception (to capture the whole pregnancy course). This is a function of state and year of conception. Conception dates are not directly observed in HCUP but may be inferred based on discharge dates and ICD coding indicating gestational age. Because that inference is inexact, the models in this study examined exposure based on date of discharge. We opt not to exclude cases discharged in the first nine months 2014, even though they may have had less than 40 weeks of GBM exposure. Though these likely had conception dates prior to GBM implementation, it is unclear how much exposure to GBM is necessary to observe an effect; in other words, is there a critical point during the pregnancy for which exposure to GBM is needed? Given that pregnancy is nine months, for the earlier births, it is possible that this could be better conceptualized as a dose-response or continuous exposure. Future analyses will explore this further.

Lastly, there are analysis limitations. As with many causal inference analyses, there may be difference-in-difference selection bias. While comparison states adhere to standard causal inference assumptions, we acknowledge the selection of comparison groups in a nonrandom way does introduce bias. Finally, typically difference-in-difference estimation uses clustered standard errors, but because there is only one treated state, robust standard errors were used here; future work will explore alternative bootstrap methods for clustering.

Despite study limitations, the current work is important for what is known about VBP and SMM. This study expands the current literature on Maryland's healthcare payment system that has overwhelmingly been focused on Medicare and has completely ignored birthing populations. The state of Maryland is an ideal focus for this research because of its unique history of healthcare payment experimentation, commitment to innovation in healthcare improvement, as well as its great diversity; with more than six million people living in urban, suburban, and rural areas, this study examines value-based payment policy impact in a wide range of environments.

Chapter 3: Heterogeneous Treatment Effects by Race

1. Overview

The objective of Aim 2 is to estimate the impact of the MD model on Black-White disparities in severe maternal morbidity. This aim will investigate the impact of the Maryland Model on maternal morbidity inequities. Specifically, this aim will examine if the Maryland Model reduces black-white disparities in SMM, as part of the larger goal to determine the novel state healthcare payment policy impact to maternal health equity. Given the conceptual model described in Chapter 1, which details how a fixed, prospective hospital budget encourages better preventive care initiatives and redistributive effects that would alleviate inequity in health outcomes due to social determinants of health burdens, it is predicted that GBM implementation will result in lower SMM incidence for black women compared to white women. Specifically, the hypothesis is:

H2: In Maryland, black-white racial disparities in SMM incidence will significantly decrease after GBM implementation, due to the Maryland Model.

2. Methods

Analyses are conducted on the same dataset of HCUP state inpatient data constructed for Aim 1, but are limited to discharges of non-Hispanic black and non-Hispanic white individuals. Descriptive differences in covariates between racial groups are described (Table 1). To test for differential treatment effect of GBM by race, this study employs a difference-in-difference-in-differences, or triple difference (DDD) model. The DDD model is an extension of the difference-in-differences method which employs a third difference, by examining another group, time period, or feature of groups (e.g., race) which defines a subgroup (Yue et al., 2018). The addition of this third difference allows for a more focused and nuanced estimation of the treatment effect, by assessing for possible confounding or examining heterogeneous impact of the treatment in different subgroups (Gruber, 1994; Angrist & Pischke, 2008; Olden & Møen, 2022).

Both Gruber (1994) and Walker (2013) indicate that the identifying assumption of this DDD estimator is that there be no other factors, no "contemporaneous shock" that could impact the difference in relative outcomes of the treatment group. In other words, there should be nothing else that can cause a difference in outcomes occurring at the same time as the intervention. Subsequently, Olden and Møen (2022) formally show that a parallel trend assumption, like the one for the DD approach, is needed to infer causality. As with traditional difference-in-differences, the parallel trend assumption must be satisfied for the DDD estimator to be interpreted as a causal effect; however, there are now three differences. Although the DDD estimator can be considered as the difference between two DD estimators (Equation 1), it does not require two separate parallel trend assumptions for causality; rather, only one parallel trend assumption in ratios is needed. Olden and Moen (2022) show that this is because the difference between two biased difference-in-differences estimators will be unbiased as long as the bias is the same in both estimators. If this is the case, the bias will be differenced out when the triple difference is computed, which means only one parallel trend assumption, in ratios, must be met (Olden and Møen, 2022).

Equation 1:

$$\hat{\beta}_7 = [(\bar{Y}_{T=1,B=1,Post=1} - \bar{Y}_{T=1,B=1,Post=0}) - (\bar{Y}_{T=0,B=1,Post=1} - \bar{Y}_{T=0,B=1,Post=0})] - [(\bar{Y}_{T=1,B=0,Post=1} - \bar{Y}_{T=1,B=0,Post=0}) - (\bar{Y}_{T=0,B=0,Post=1} - \bar{Y}_{T=0,B=0,Post=0})].$$

For this study, the comparison is between the black treated individuals in Maryland to white treated individuals in Maryland, those outcome differences are compared to the differences between a set of black untreated and white untreated individuals in the control states. What is measured is the changes in treatments' relative outcomes by race in Maryland, compared to states that did not implement GBM. As such, the parallel trend test for Aim 2 will require the relative outcomes of black and white deliveries in the treated state to trend in the same way as the relative outcomes of black and white deliveries in the untreated states. If this is satisfied, then the coefficient on the DDD term can be causally interpreted as the average treatment effect on the treated in the subgroup modeled as "1".

The approach for this aim modifies the regressions from Aim 1 by fully interacting a binary race indicator with the difference-in-differences interaction term, the state fixed effects, and the year fixed effects. The regression takes the form:

$$Y_{it} = \alpha + \gamma_i TREAT + \gamma_t POST + \beta_1 TREAT*POST + \beta_2 TREAT*BLACK + \beta_3 POST*BLACK + \beta_4 TREAT*POST*BLACK + u_{it}$$

In this regression, $\beta 4$ measures if the Maryland Model moderates racial disparities in outcomes. The regression allows state and year fixed effects to vary by race. I modify the pre-treatment testing strategy described for Aim 1 by including the full set of race interactions in the linear trend test.

<u>*3. Results*</u>

In this sample of states, black and white individuals giving birth vary greatly on all socioeconomic and clinical indicators. Though black women are less than one-quarter of the sample (22.5%), they have twice the incidence of SMM as white women (64 cases in 10,000 vs. 32 cases in 10,000; $p<0.000$). White women tend to be older and more often married, as well as live in zip code areas with higher median household income. Deliveries by black women are financed by Medicaid about 55% of the time, relative to about 31% of the time for white women, who tend to be privately insured more than their counterparts (64% vs. 39%; p<0.000). Rates of C-section are greater amongst black women, as are rates of comorbidities.

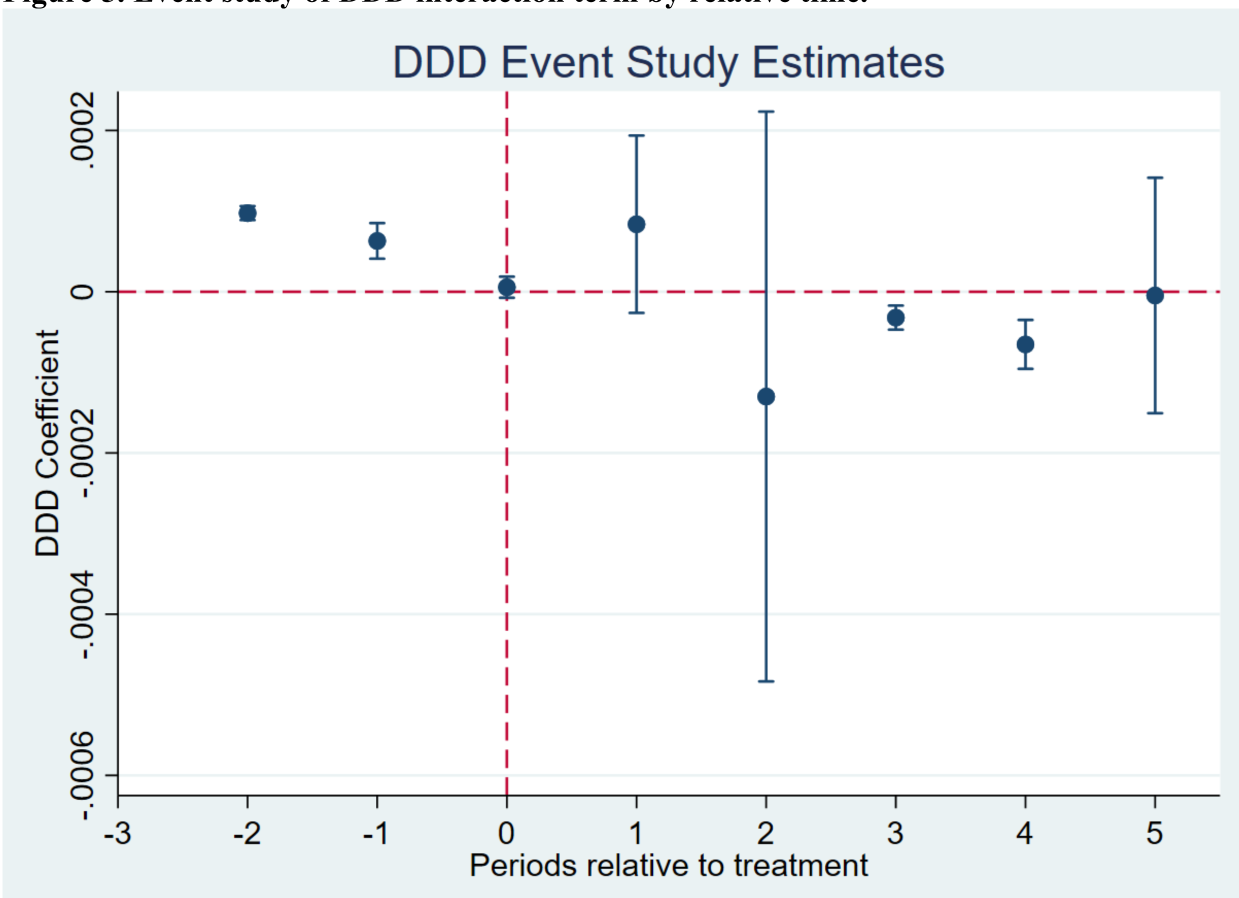
Table 6A. Demographic and clinical characteristics of women who gave birth in Maryland, Arizona, Kentucky, and New Jersey, 2011-2019.

	Black (n=382,265)	**White** (n= 1,320,643)	**p-value**
Treatment Group			0.000
GBM-Treated (MD), %	44.92	15.48	
GBM-Untreated (AZ, KY, NJ), %	55.08	84.52	
Severe Maternal Morbidity			0.000
Yes, %	0.64	0.32	
No, %	99.36	99.68	
Age			0.000
24y and younger, %	28.50	19.93	
25-34y, %	49.64	55.14	
35-44y, %	16.33	17.99	
45y and older, %	5.52	6.95	
Married			0.000
Yes, %	27.34	50.82	
No, %	72.66	49.18	
Income Quartile			0.000
Q1: $1 - $47,999, %	31.32	22.01	
Q2: $48,000 - $60,999, %	15.90	19.28	
Q3: $61,000 - $81,999, %	24.58	21.26	
Q4: $82,000+, %	27.68	37.45	
Missing, %	0.52	0.82	
Primary Payer			0.000
Medicaid, %	54.96	30.57	
Private Insurance, %	39.05	63.94	
Self-Pay, %	2.67	1.57	
Other, %	3.31	3.92	
Missing, %	0.02	0.01	
Birth type			0.000
Vaginal, %	55.08	56.62	
Caesarian section, %	37.75	33.32	
Unknown delivery type, %	7.17	10.05	
Leonard et al (2020) Comorbidity Index			0.000
None, %	57.55	62.64	
Low (1-5 conditions), %	31.81	28.80	
Moderate (6-10 conditions), %	8.92	7.32	
High (10+ conditions), %	1.72	1.24	

Source: Data extract from 2011-2019 Healthcare Cost and Utilization Project (HCUP) State Inpatient Databases (SID) for Maryland, Arizona, Kentucky, New Jersey, and New York. Study sample includes women, aged 12-55 years, inhabiting states that were either in the treatment group (MD), or in states that were not treated (AZ, KY, NJ).

Because it is unnecessary to demonstrate two parallel trends tests, rather, it is important to ensure that there are parallel trends in ratios, I conduct an event study of the change in outcome over time by regressing SMM onto an interaction term of treatment, race, and relative time. This allows for examination of pre-treatment differences by viewing the trends with respect to treatment and race over time.

Figure 5. Event study of DDD interaction term by relative time.



In examination of the pre-period trends, an F-test was done to determine if there is a significant difference between coefficients in the lead times before treatment. The F-test of joint significance yields a p-value of p=0.001, indicating that there is a statistical change between coefficients in the pre-treatment time period. This test provides information that the two and three years before the intervention year of 2014 had significantly different changes in SMM rate.

Importantly, this does not necessarily nullify the parallel trends assumption, but it does suggest that perhaps the treatment effect is not only due to policy change, if there were already changes in the outcome occurring before the treatment year.

Because DDD can be conceptualized as the difference between two difference in differences, SMM outcomes are examined by race; i.e. morbidity differences amongst only black birthing people by treatment status, and morbidity differences amongst only white birthing people by treated status.

Figure 6A. SMM outcomes by black race.

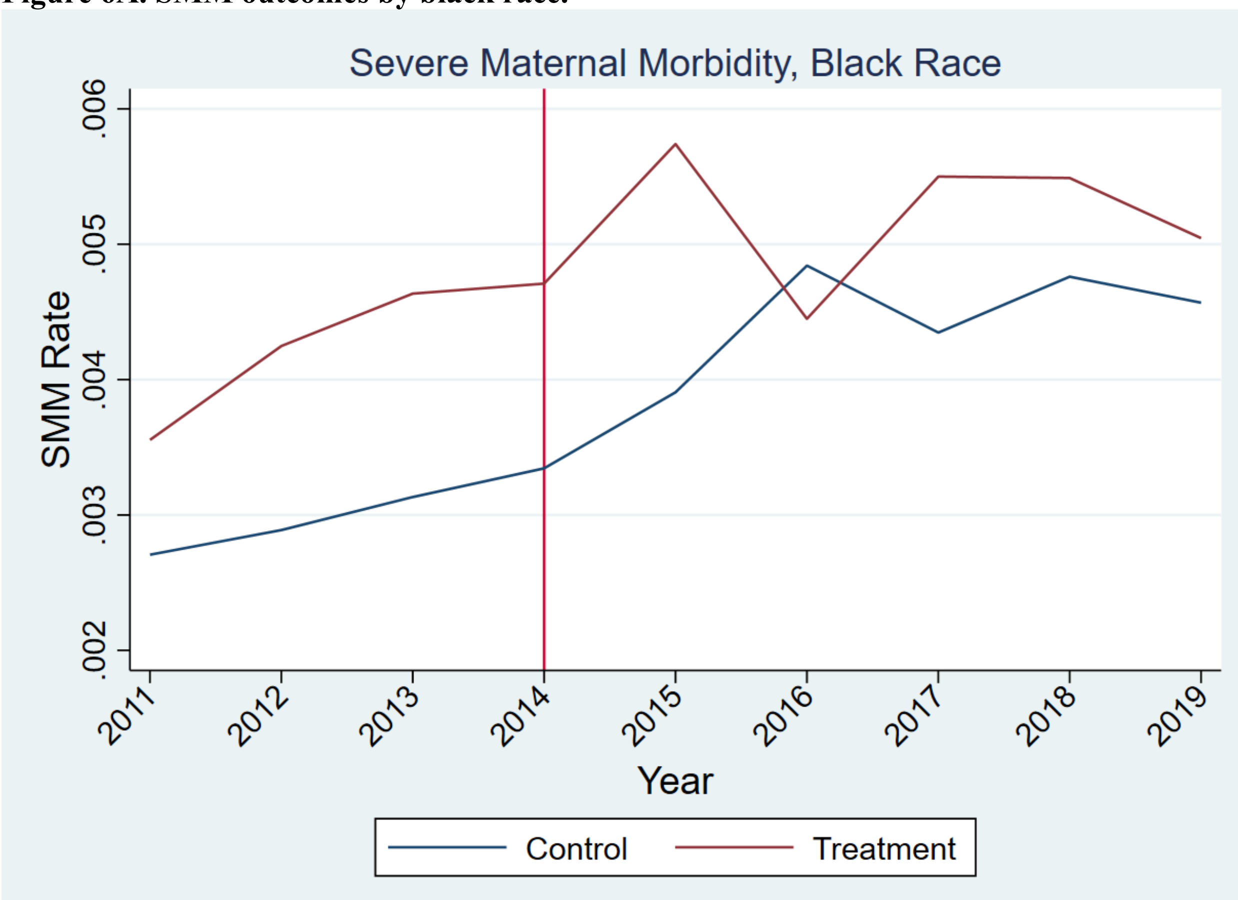


Figure 6B. SMM outcomes by white race.

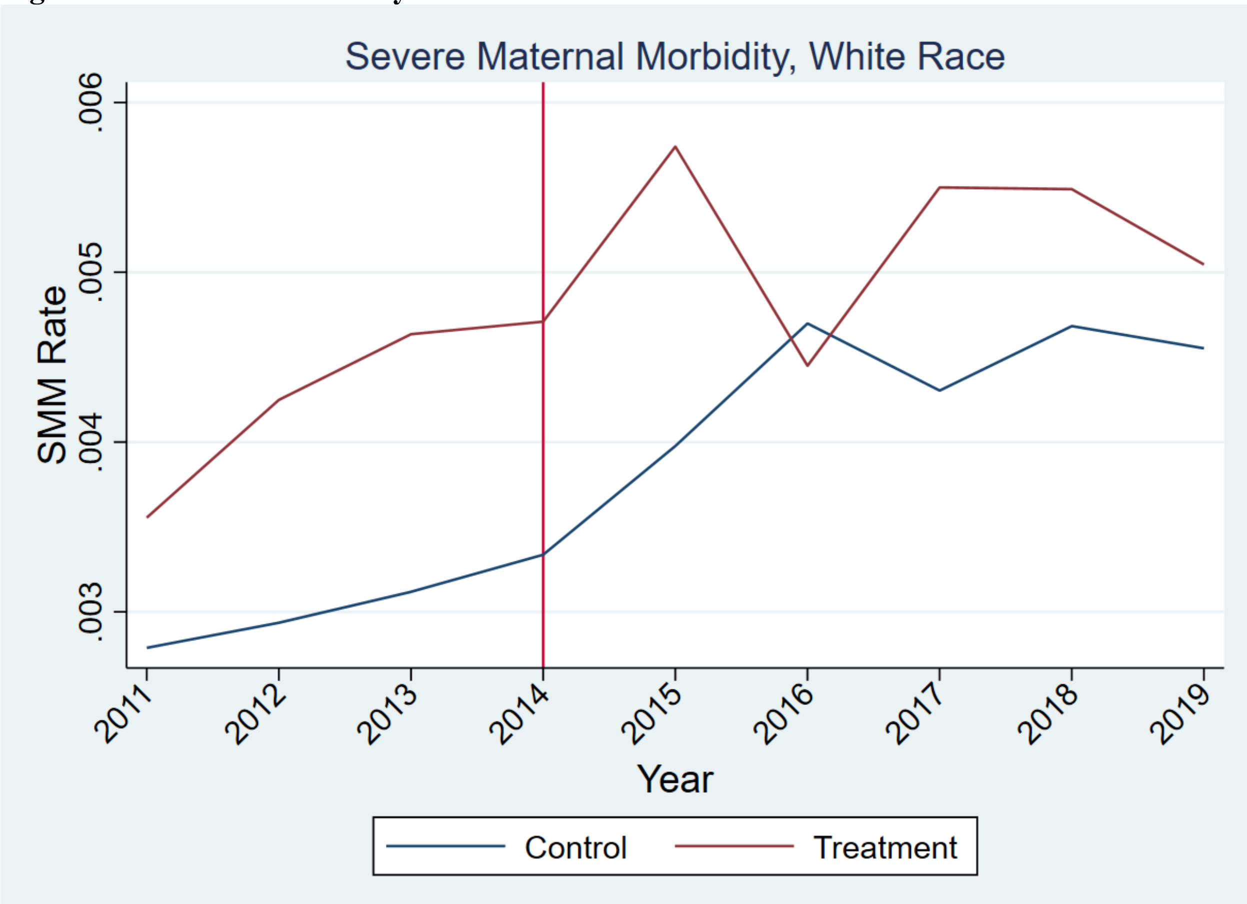


Table 7. DD Coefficients by Race

	Black	White
Unadjusted DD Interaction Term Coefficient	-0.0003582	-0.0002771
95% Confidence Interval for Interaction Term	(-0.0003645, -0.0003519)	(-0.0002815, -0.0002726)

Table 2 describes the treatment effect separately by race. Amongst black individuals only, across treated and untreated environments, we see an effect for reduction in SMM of 0.036 percentage points. Likewise, amongst white individuals only, across treatment status, we see an effect for reduction in SMM of 0.028 percentage points. Taken together with the event study, these tests provide evidence of parallel trends in effect of treatment by time across the third dimension of binary race.

Table 8. DDD estimates from unadjusted and adjusted linear probability models.

	Pre-period mean in treated group	Unadjusted model	Adjusted model, individual-level covariates	Adjusted model, full set of covariates
	.0039943	---	---	---
DDD Interaction Term Coefficient	---	-0.0000811	-0.0000818	-0.0000633
DDD Interaction Term p-value	---	0.000	0.000	0.000

Source: Data extract from 2011-2019 Healthcare Cost and Utilization Project (HCUP) State Inpatient Databases (SID) for Maryland, Arizona, Kentucky, New Jersey, and New York. Study sample includes women, aged 12-55 years, inhabiting states that were either in the treatment group (MD), or in states that were not treated (AZ, KY, NJ). Treated group "DDD" means difference-in-difference-in-differences. Full set of covariates includes individual-level and state-year covariates.

The triple difference estimator, which here represents the average treatment effect on birthing people of black race, receiving hospital care in the treated state, after the policy implementation, indicates a statistically significant reduction in SMM incidence of approximately 0.81 cases per 10,000 population ($p<0.000$). In all tested models, including without covariates (to verify true relationship) and with covariates (to account for omitted variable bias, and to control for compositional effects), the DDD term is significant at the level of $p=0.05$. The reduction in SMM is additive for this subgroup; in other words, this is an effect observed on top of the effect identified in Aim 1, which found a reduction in SMM incidence for anyone in the treated state, irrespective of black race status.

4. Discussion

This study builds off findings in Aim 1, where the objective was to understand if the Maryland Global Budget Model had a causal influence on the rate of change in severe maternal morbidity in Maryland. For Aim 2, this relationship is explored further, by assessing racial differences in policy treatment effect. With the understanding that health is impacted by underlying structural forces, fundamental causes, we undertook this inquiry to assess the potential impact of fiscal hospital policy as a structural force, in combination with racism, that could potentially alter maternal health outcomes. Employing a triple-difference model, where race is interacted with treatment and time, as well as the full set of race interactions and individual- and state-level covariates, it was possible to observe heterogeneity in treatment effect. Various specifications of the triple-difference model indicate that there is an increased effect of treatment by racialization, whereby black women giving birth in Maryland have an additional case rate reduction of 0.006-0.008 percentage points, compared to black women who were untreated.

In this study, as in the previous study (Aim 1), we observed large effect in the post-period year 2016. In addition to the potential of the ICD-10-CM coding transition to impact SMM rate, which was not found to be the case in our sensitivity analysis, there may be other reasons for this observed effect, whereby black women have increased reduction in SMM after 2014. One rationale includes the potential for a heterogeneous response by hospitals. As was described in Masters et al. 2022, it is possible that some hospitals respond more to GBM than others; some sites may invest more in quality of care, or other site-specific initiatives to improve care and constrain cost by attempting to keep their population healthier. If these such hospitals are the same ones that serve predominantly black patients, it may explain the observed treatment effect. In the current study, this cannot be tested without doing qualitative work on the specific programs and practices occurring at each state hospital, but this is a potential avenue for future research.

Another possible explanation for the effect seen in Aim 2 is the impact of Medicaid expansion. Given the consensus that lack of insurance leads to reduced access to care, and poor maternal outcomes, expansion of health insurance may improve maternal health outcomes, and particularly so considering the higher preponderance of uninsured black women relative to white women. This implies that the potential for a positive effect of expanded insurance will be more impactful in a population with a greater proportion of black people (Solomon, 2021). In fact, in a study that demonstrated reduced maternal mortality following Medicaid expansion, treatment effects were concentrated among Black mothers, supporting the idea that expansion may contribute to narrowing the black-white gap in maternal mortality (Eliason, 2020). Thus, as with Aim 1, it could be an ACA effect. This study was not designed to elucidate the exact mechanism for how it would cause the effect. But reading other similar studies evaluating the GBM impact on health outcomes can provide some insight into potential mechanisms. In subsequent studies, will work to glean the reasoning for our observed treatment effect.

Examining the impact of treatment on SMM by race, as two separate difference-in-differences, also shows that there is a decrease in SMM incidence of 0.036 in black birthing people living in the treated state relative to counterparts in untreated states, compared to a decrease of 0.028 in white birthing people in the treated state. This means the reduction in SMM is greater for the black subgroup than the white subgroup, which tentatively suggests the GBM implementation may have a positive effect of reducing the black-white disparity. However, even with the significant observed treatment effect, given that the rate of SMM incidence is twice as high in this sample of black women relative to white women (0.64 versus 0.32; $p<0.000$), this GBM policy is but one small lever to address maternal health racial disparities, given the magnitude of difference.

In light of historic increases in SMM in the past decade, with particular burden for non-Hispanic black women and other groups such as Native American/American Indian, this study aimed to better understand if there was a differential treatment effect by race. Current available data show that black women are heavily impacted by SMM, and so far, solutions have remained elusive. Studies have examined the impact of home visits (McConnell et al., 2022), of access to federally qualified health centers (Gourevitch & Hatfield, 2023), of telehealth and mobile app interventions (Park et al., 2018; DeNicola et al., 2020), of group support (Matthews et al., 2021). But there have modest improvements in SMM for black women, if at all. The issue of race, of why SMM impacts black women significantly more than their counterparts, is the experience of racialization and racism which is pervasive across space and time, affecting health via multiple levels of segregated environments (White & Borrell, 2011; White et al., 2012) as well as throughout the life course, from preconception, to prenatal, intrapartum, and postpartum stages (Braveman & Barclay, 2009; Mishra et al., 2010; Zambrana & Williams, 2022). Furthermore, it is happening at multiple planes of existence: discrimination at the level of the individual, structural or institutional racism, and cultural racism (Jones, 2018; Williams et al., 2019; Yearby et al., 2022). Because it has been well-documented that there are multiple avenues for race to affect health, it is important to examine this in depth, due to high likelihood of race group differences. Here, we find that black women are helped by the implementation of GBM. The treatment effect is a modest reduction, but relative to the disease, which is rare, it could be a meaningful decline.

In consideration of current available evidence, overall, our result is not atypical; it appears that other groups find that disparities are impacted by Maryland's GBM. In hospital quality metrics of unplanned readmissions, preventable admissions, and timely follow-up, CMS finds there were reductions in racial and geographic disparities (CMS, 2024). However, literature addressing the impact of Maryland's GBM on non-utilization-focused, clinical racial disparities is relatively limited. There is evidence that the MD model has improved quality of care for

Medicare beneficiaries in dramatically reducing incidence of preventable hospital acquired conditions, decreasing unnecessary admissions and post-discharge readmissions, improved glycemic control for diabetes patients, and increased centralization of care(Haber et al., 2019; Kadakia et al., 2023; Offodile et al., 2023, 2022; G. X. Wang et al., 2023; Yesantharao et al., 2023). Studies of the impact of the MD model on equity are sparse. A 2022 report on the effects of Maryland's GBM on vulnerable Medicare subpopulations in the state found that dual-eligible enrollees, those with disabilities, and beneficiaries with multiple chronic conditions had greater reductions in expenditures and utilization than their counterparts, suggesting that hospitals might have focused on high-cost, high-need patients as they altered their delivery of care (Masters et al., 2022). They also identified a significantly lower 14-day follow-up rate for dually enrolled, disabled, and non-White beneficiaries. As well, a 2023 observational cohort study examining diabetes care improvements after several years of the GBM in western Maryland reported significantly improved patient-reported outcomes and reduced A1c measurements following policy implementation (G. X. Wang et al., 2023).

Other studies have examined the impacts of GBM on outpatient care, with some attention paid to subgroup differences. A study investigating the effects of GBM on emergency department (ED) visits found significant declines in both ED visits and hospitalizations in Maryland, compared to New York and New Jersey; there were also decreases in revisits after the GBM was introduced, and these outcomes varied by racial/ethnic and payer group (Galarraga et al., 2022). Specifically, there were findings of uneven subgroup impacts by race, with greatest observed ED visit return decline in non-Hispanic whites, and similar trends in non-Hispanic blacks, while Hispanics did not have improvement in ED revisit rate, leading to an increased ED return disparity gap for this group. Authors postulate it may be due to “unique social barriers experienced among Hispanics/Latinos and/or an absence of linguistically and culturally appropriate services to improve outcomes for this population".

In a different assessment of the impact of GBM on ED utilization which was stratified by socioeconomic status, researchers found that ED visit volume was relatively unchanged over the time period, but there was a significant decrease in hospitalization from the ED and in amount of uninsured patients; these effects were most pronounced in EDs serving a greater proportion of low-SES patients (Pimentel et al., 2017). However, this study used only a convenience sample of 11 EDs (less than one-third of state total) and did not use causal methods, but rather associations comparing outcomes pre- and post-implementation. As well, they sought to examine the joint effects of ACA implementation and GBM implementation, making it hard to fully understand how Maryland GBM singularly impacts equity.

Finally, one study examining impact of GBM in obstetric-related population focused on the rate of NICU admissions and infant mortality following policy implementation, finding significant reduction of NICU admissions, but no statistical change in infant or neonatal mortality (Xie et al., 2021). Altogether, we situate our work in a landscape of Maryland GBM evaluations that are primarily focused on outcomes of quality and cost containment, with less emphasis on equity and/or maternal health improvement. In this way, the current study adds a novel perspective to the literature by focusing on maternal disparities. Importantly, subgroup analyses by race and ethnicity underscore the necessity of investigating outcome disparities for minoritized groups when evaluating policy changes. Although there is interest in studying the plethora of new alternative payment models being tested currently, paying special consideration to the performance of these programs, not only in the aggregate, but also looking specifically at disparities between groups by socioeconomic status, race, payer, and geography is critical to ensure that models are designed in a way that doesn't worsen disparities, and that neglected groups are also seeing advancements in outcomes.

This study helps us to better understand impact of GBM on SMM disparities. Although other work calls for the targeted focus of alternative payment models for equity in maternal health outcomes (Eschliman et al., 2023; Stone et al., 2023), currently, it is not very available in the literature. This paper represents one of the first to specifically evaluate whether the implementation of a population-based VBP model can be useful in addressing health disparities. The evidence presented here shows that there may be opportunities for alleviating race-based inequity.

Limitations in this study echo those from Aim 1, namely that there is no examination of the precise mechanism leading to the observed effect; this is a study of whether the treatment leads to changes in SMM rate, not how it may do so. Further research will explore the particular factors mediating the change. Additionally, the observed findings may be setting-specific, in that there are some unique Maryland-specific context factors which permit the treatment to be impactful in the original Maryland environment; this context dependence represents a threat to external validity. Also important to note is a limitation of the study empirical approach; a triple difference model was used to delineate the treatment effect differences by race group. However, in an event study examination of the pre-period trends, the F-test for joint significance yielded a significant p-value, indicating that there was a statistical change between coefficients in the two and three years before GBM implementation. By itself, this does not necessarily violate the parallel trends assumption, but is evidence to suggest that perhaps the treatment effect is not only due to policy change, as the trends in the pre-period are different.

Although there is apparent potential for value-based payment to address health inequities, it is not a panacea for advancing health equity; it is important to note that such complex issues as maternal morbidity inequities will not be fully resolved via healthcare payment policy alone (Kwok & Léger, 2023). Additionally, policies that achieve equity in healthcare may not be sufficient to achieve equity in health outcomes; this work is a small part of a larger, multifaceted effort. Lastly, it is known that SMM impacts not only black women disproportionately, but also Native American women, yet in this paper, we chose to only examine black-white disparities. Future studies will examine the impact of model on other racial groups.

Chapter 4: Impact of GBM on SMM-Related Comorbid Conditions

1. Overview

For the final aim, the objective is to evaluate the impact of the MD model on occurrence of SMM-related comorbidities. As SMM is a serious yet relatively rare outcome, it is important to understand predisposing factors that may lead to its development during pregnancy. In health services research, it is common to consider comorbid conditions which already exist, or may worsen the severity, or hasten the time to outcome. Often, Elixhauser or Charlson Comorbidity indices are used (Charlson et al., 1987; Elixhauser et al., 1998), but for this work, neither is appropriate given their explicit exclusion of pregnant people. Bateman and colleagues (2013) developed a comorbidity measure that is widely used, but outcome is not SMM per se, rather, it measures things that predict maternal end organ failure, including death (Bateman et al., 2013). As the focus of this work is SMM, we examine comorbidities as defined by Leonard et al., which are specifically as indicators of the propensity to develop SMM. These Leonard comorbidities, which include 24 diagnoses, maternal age and BMI, have been demonstrated to be significantly predictive of future SMM incidence (Leonard et al., 2020). As such, this aim will investigate the impact of the Maryland Model on comorbid conditions acting as precursors to SMM. Specifically, this aim will examine if the Maryland Model reduces prevalence of Leonard comorbidities, as part of the larger goal to determine the novel state healthcare payment policy impact to population maternal health. Given the conceptual model described in Chapter 1, which details how a fixed, prospective hospital budget encourages better preventive care initiatives and increased population health focus that may yield increased maternal health outcomes, I predict that GBM implementation will result in lower prevalence of Leonard comorbidities over time. Specifically, I hypothesize:

H2: In Maryland, SMM-predisposing comorbid conditions will significantly decrease after GBM implementation, due to the Maryland Model.

2. Methods

As in Aim 1, this study makes use of the well-established two-way fixed effects difference-in-differences estimator, where the outcome is regressed onto treatment and time interaction, indicators for treatment, time period, and other covariates. In this study, Leonard comorbidity (hereafter referred to as LCM) is the outcome; I explore model specifications with binary variables to determine general status of comorbid conditions (i.e., Is there presence of any comorbid condition, Yes/No) and if there is any comorbidity, if it is a preexisting or pregnancy-onset condition. The LCM conditions include 24 different indications, derived from medical comorbidities, comorbidities related to the current pregnancy, previous cesarean birth, and maternal age (Leonard et al., 2020). These are a diverse set of conditions that can be categorized as (1) chronic or endogenous conditions, such as asthma and sickle cell disease, which are in place pre-conception and may be triggered or worsened during pregnancy, but are not caused by pregnancy, and (2) newly arising or exogenous conditions, such as placenta previa and gestational diabetes, which have their onset during the pregnancy, yet are not very well predicted by patient behavioral factors, and are rather often the result of chance genotypes. These are defined in Appendix C. To assess the plausibility of the parallel trends assumption, I graph overall LCM trends by treatment status to visually inspect outcome trends in the pre-period. Additionally, I examine if outcomes prior to implementation were evolving similarly in

Maryland and the comparison states using a regression model fit on pre-intervention data that interacts continuous time and a Maryland state indicator (i.e., linear trend test). Finally, I implement the difference-in-differences analysis. I also include as part of the main results an event-study specification, which is useful for examination of group differences over each year. In this way, I assess the magnitude of change and have a more detailed view of the treatment effects in each time unit. Lastly, I conduct an F-test for change over time in the pre-period.

<u>*3. Results*</u>

Figure 7. Comorbidity status in GBM-treated and untreated states.

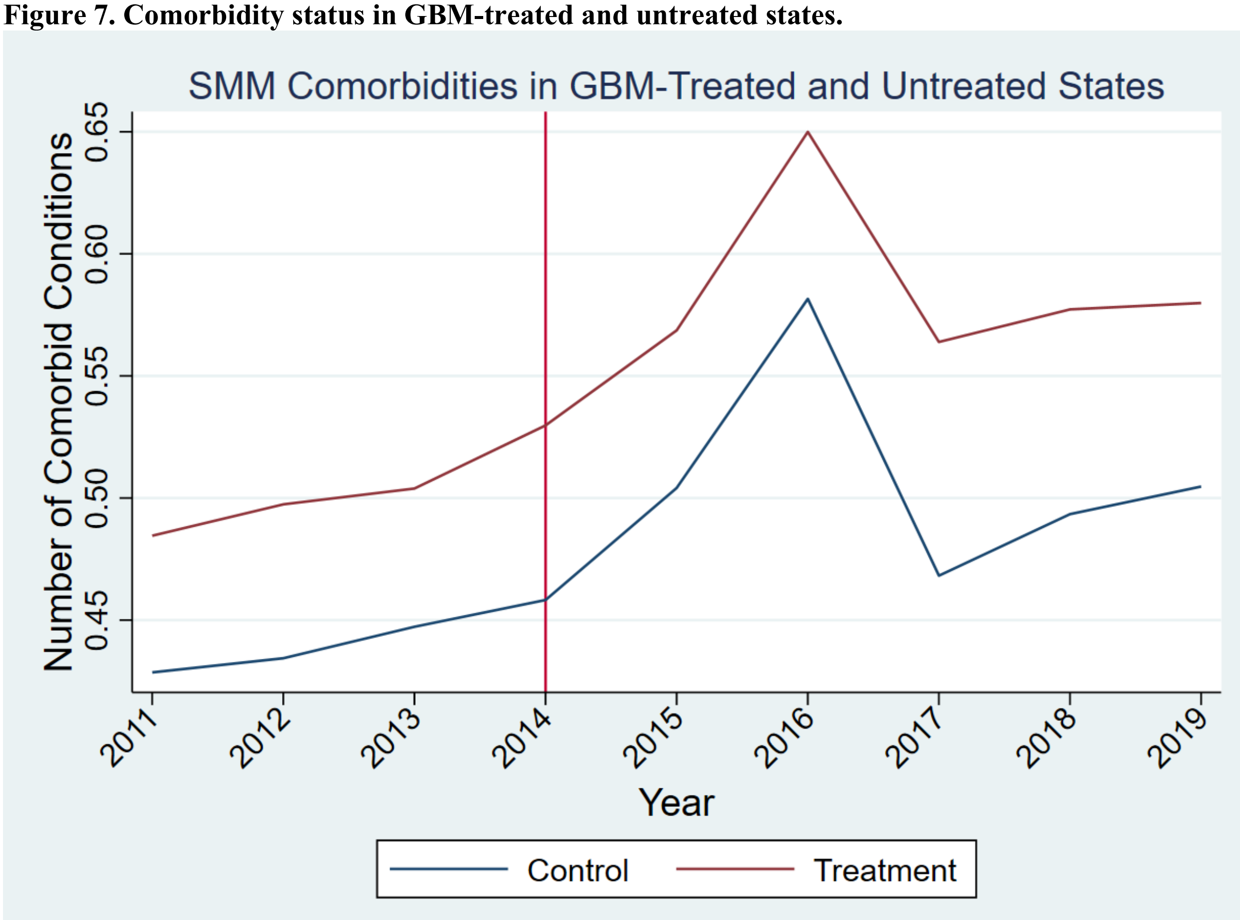


Table 9. Differences in pre-period linear trend in comorbidity rate between treatment groups.

	Coefficient (SE)	p-value
Treatment Group	-0.0101037 (3.76e-13)	0.000

In Figure 7, we observe parallel trends by eye, as treatment and control groups trend similarly in the same direction. Table 1 gives the difference in outcome between treatment groups before policy intervention. In Table 9, although there is significant difference in SMM rates between groups (p-value <0.05), the change over time is small (0.011), suggesting that it is relatively constant during the pre-period. This finding suggests there was not an anticipation effect, as the change over time between groups was relatively constant.

Table 10A. DD estimates from unadjusted and adjusted linear probability models examining presence of any comorbidity.

	Pre-period mean in treated group	Unadjusted model	Adjusted model, individual-level covariates	Adjusted model, full set of covariates
	0.3868	---	---	---
DD Interaction Term Coefficient (SE)	---	0.0258 (0.0018)	-1.46e-12 (3.83e-14)	-7.80e-12 (9.32e-14)
95% Confidence Interval	---	0.0201, 0.0315	-1.54e-12, -1.39e-12	-7.61e-12, -7.98e-12

The difference-in-differences estimator, which here represents the average treatment effect of policy treatment in births occurring in Maryland, the treated group, indicates a statistically significant relationship between LCM prevalence and treatment over time. However, this relationship varies depending on presence of covariates. In the unadjusted model, there is an increase in Leonard comorbidities after GBM takes effect. In the adjusted models, the interaction term coefficient indicates a decrease in LCM occurrence (p<0.001). In all tested models, the DD term is significant at the level of p=0.05; Table 10A uses the coefficient from the adjusted models, including covariates to account for omitted variable bias, and to control for compositional effects.

Table 10B. DD estimates from unadjusted and adjusted linear probability models examining presence of preexisting comorbid conditions.

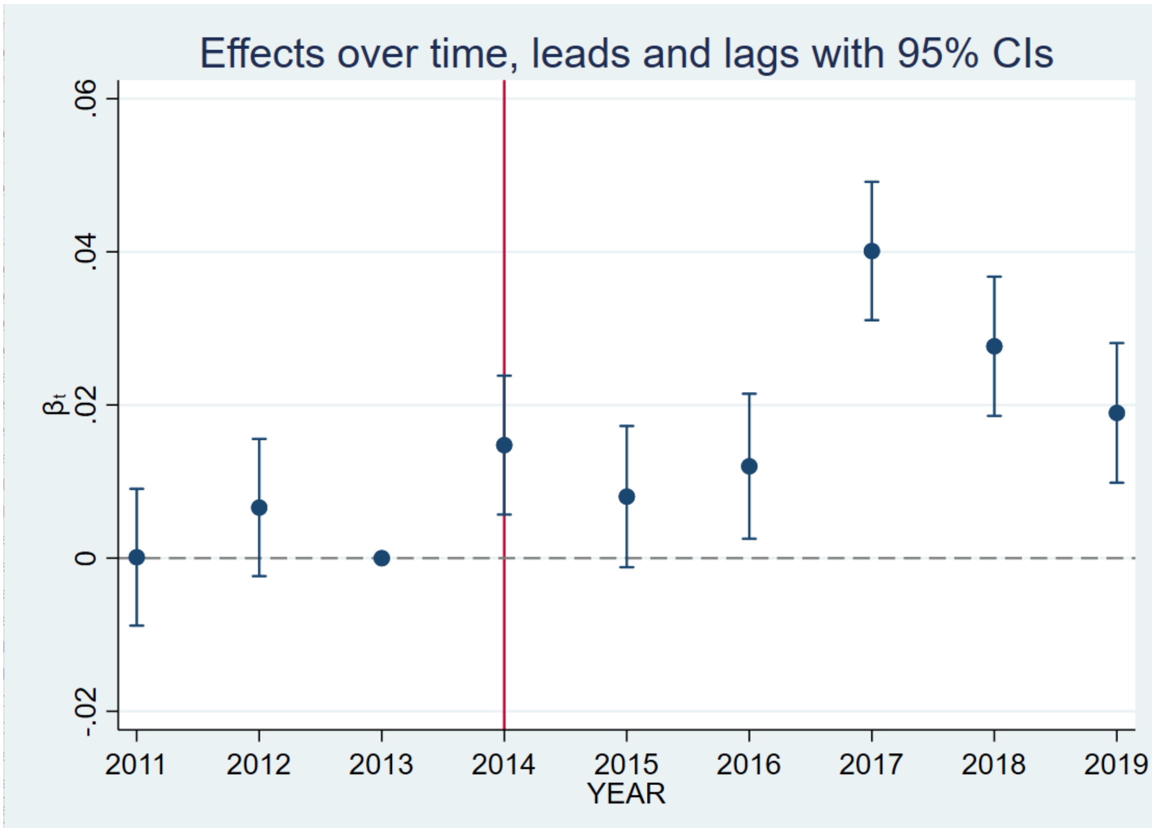
	Pre-period mean in treated group	Unadjusted model	Adjusted model, individual-level covariates	Adjusted model, full set of covariates
	0.3396	---	---	---
DD Interaction Term Coefficient (SE)	---	0.0635 (0.0016)	0.0461 (0.0007)	- 0.0194 (0.0017)
95% Confidence Interval	---	0.0605, 0.0665	0.0447, 0.0474	-0.0228, -0.0161

Table 10C. DD estimates from unadjusted and adjusted linear probability models examining presence of pregnancy-onset comorbid conditions.

	Pre-period mean in treated group	Unadjusted model	Adjusted model, individual-level covariates	Adjusted model, full set of covariates
	0.0894	---	---	---
DD Interaction Term Coefficient (SE)	---	-0.0486 (0.0009)	- 0.0539 (0.0008)	0.0144 (7.10e-14)
95% Confidence Interval	---	-0.0505, -0.0467	-0.0556, -0.0523	0.0104, 0.0184

In Tables 10B and 10C, we observe similar trends to table 10A, which represented GBM impact to overall presence of comorbidity during pregnancy. Table 10B describes the difference-in-difference estimate of GBM impact to presence of preexisting conditions, such as preexisting diabetes mellitus and chronic renal disease. In the pre-period, approximately 34% of people in the treated group had a preexisting LCM condition. The unadjusted model indicates an increase in conditions following policy implementation, and after adjusting for relevant individual-level covariates, there is still an increase in preexisting comorbidities (DD estimate: 0.0461; 95% CI: 0.0447, 0.0474). However, when including other community and state-level covariates, there is a decrease in preexisting LCM conditions in the treated group of about 1.9% (DD estimate: -0.0194; 95% CI: -0.0228, -0.0161). Table 10C describes the causal estimate of GBM impact to presence of pregnancy-onset LCM conditions, such as placenta accreta or gestational diabetes. Prior to GBM implementation, about 9% of birthing people in Maryland experienced these types of conditions. After policy implementation, the unadjusted model and model with only individual-level covariates shows a decrease in pregnancy-onset comorbid conditions, but the fully adjusted model indicates a slight increase, by approximately 1% (DD estimate: 0.0144; 95% CI: 0.0104, 0.0184).

Figure 8A. Event study of change in overall comorbidities by treatment timing for each time interval.



In Figure 2A, the trend of overall LCM conditions is depicted in each time period. An F-test to examine pre-period trends is conducted to determine if there is a significant difference between coefficients in the pre-period years. The F-test of joint significance yields a p-value of p=0.2504, indicating that there is no statistical change between coefficients in the pre-treatment time. This test provides information that the two and three years before the intervention year of 2014 did not significantly differ in rate of LCM.

Figure 8B. Event study of change in preexisting LCM comorbidities by treatment timing for each time interval.

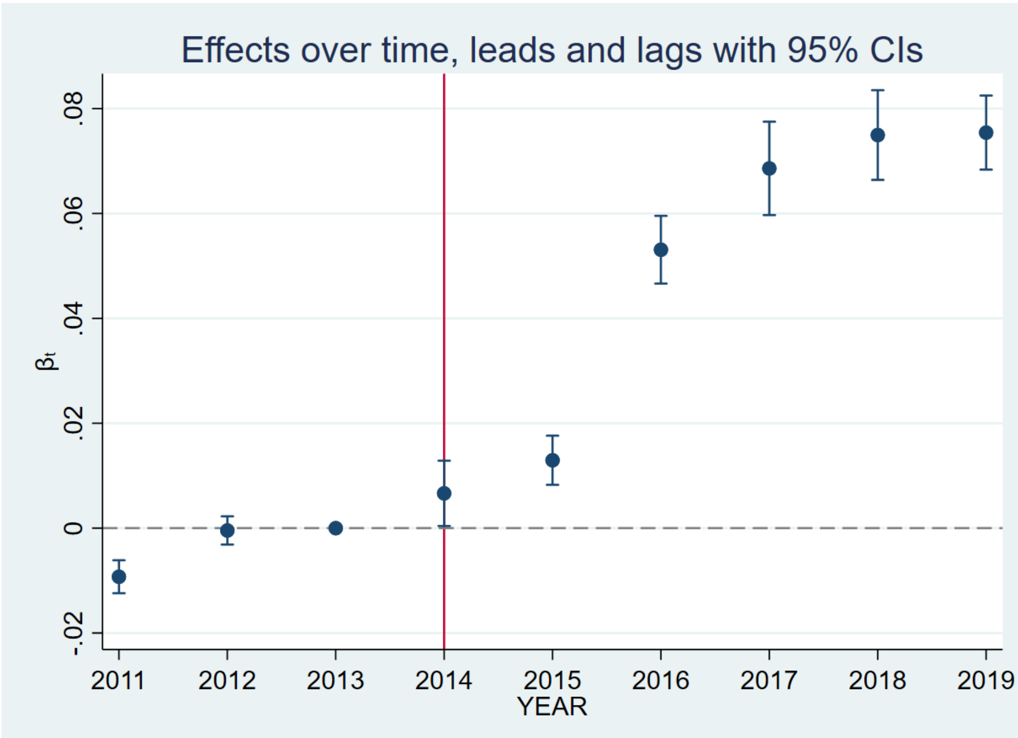


Figure 8C. Event study of change in pregnancy-onset LCM comorbidities by treatment timing for each time interval.

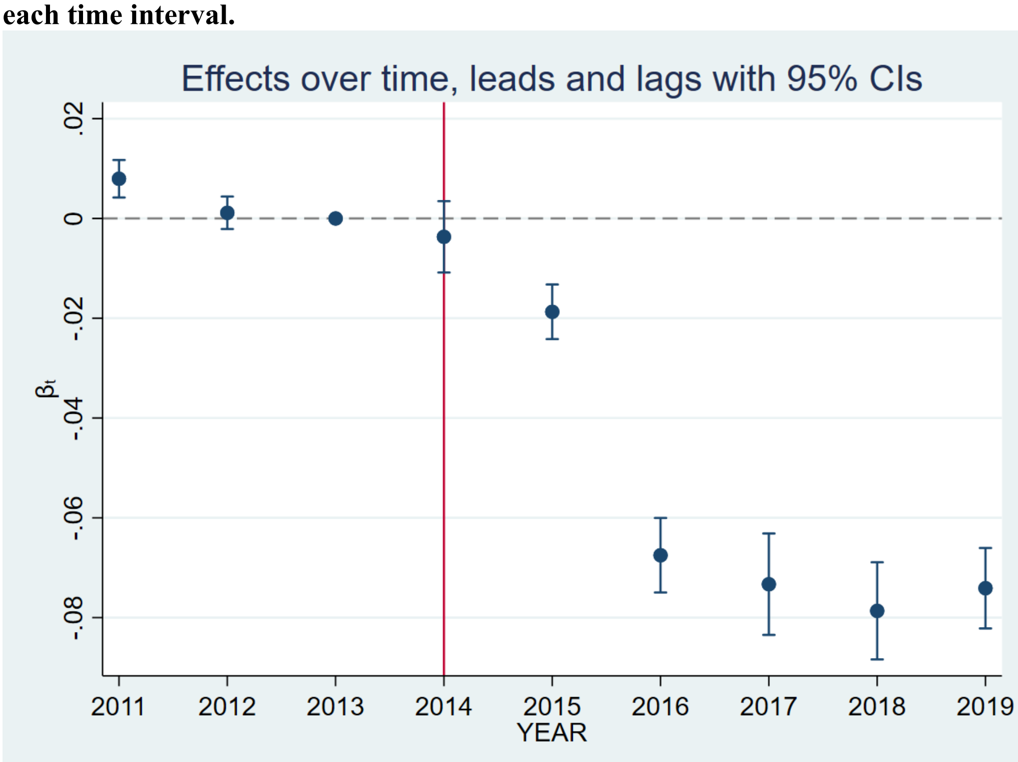


Figure 2B and 2C depict trends of preexisting and pregnancy-onset LCM conditions, respectively, over the study period, using the fully adjusted models for each. In Figure 2B, there is a significant increase in comorbidity after the policy implementation. In Figure 2C, there is a significant decrease in pregnancy-related comorbid conditions after the intervention year, with greatest decline between year 2015 and 2016.

4. Discussion

This study sought to examine the impact of the Global Budget Model on an indicator of maternal health, Leonard comorbidities, or the 24 conditions associated with high risk of developing SMM. Comorbidities are an interesting and useful study outcome because SMM is a relatively rare occurrence, but these comorbidities which are shown to be predictive of SMM are more common, thus easier to measure; importantly, it is standard practice in health services research to account for these conditions to avoid bias from confounding (Bateman et al., 2013; Leonard et al., 2020). Additionally, prevalence of these conditions informs us about the general maternal health status of the population, so we examine them here. The goal of this study was to evaluate if there was any population-level change in disease burden of these comorbid conditions, after the introduction of the policy intervention. Analysis using two-way fixed effects regression showed that following GBM implementation, there was a significant decrease in population-level comorbidity related to SMM. Most birthing people in this sample do not have any SMM-related comorbidity, yet there was a very modest reduction in overall occurrence following the treatment. This effect was observed for different configurations of the outcome variable. Amongst those with preexisting comorbid conditions, which was nearly one-third of people birthing in Maryland, fully adjusted model showed an approximately 2% decrease in instances of preexisting LCM conditions in the post-GBM era. Amongst those with pregnancy-onset comorbidity, which was less than 10% of the population, the fully adjusted model showed a slight increase in instances of LCM conditions after the policy implementation.

Overall, findings show that SMM-predictive comorbid conditions decreased after policy introduction in 2014, in support of the predicted hypothesis of significant decrease of comorbid conditions after GBM implementation. One possible theory to explain the observed effect is that, per the conceptual model detailed previously, GBM impacted quality of hospital care and promoted health-improving preventive care practices, yielding better population maternal health, as evidenced by lower rate of Leonard comorbidities. Policy implications are that in other settings with similar HCP-LAN Category 4 (i.e., "Population-Based Payment") alternative payment models similar to GBM, there may be opportunity for improvements in maternal health via reduced population-level SMM-related comorbidities. The event study for this research question indicated an appreciable non-zero increase in the outcome measure in the post-period, followed by a steady decrease. Of note, this pattern echoes the event studies in Aims 1 and 2; specifically, there is an increase in prevalence of SMM-related comorbid conditions in the early pre-period, just after 2014 policy implementation, followed by a dramatic decline in 2016.

This study has a few limitations to note. First, there were reporting differences in International Classification of Diseases (ICD) during the study period. Given the transition from ICD-9 to ICD-10 coding schema in October 2015, there is a potential for measurement error. A recent report found that the October 2015 transition to ICD-10 codes did not influence changes in overall SMM rates, suggesting that researchers need not be overly concerned about measurement error due to coding changes (Hirai et al., 2022). To protect against this, we cross-referenced ICD-9 and ICD-10 code lists as described in other published studies to minimize potential for mismeasurement. Second, as in Aims 1 and 2, because of similar quasi-experimental methods used in each study, there are the same limitations of difference-in-difference selection bias (non-random comparison group selection) and potential standard error bias (use of Huber White sandwich estimator instead of cluster-robust standard errors).

Lastly, the study outcome variable, Leonard comorbidities, includes conditions that are not uniform in their timing; some conditions arise during the pregnancy (i.e., placenta previa, preeclampsia), while others are chronic and are in place at time of conception (i.e., asthma, sickle cell disease, heart disease). As such, the interpretation of any increase or decrease in comorbidities is not simply describing maternal health status or preparedness for safe birthing but is also a non-specific measure of general health of the population. Notably, some of the conditions are ones that a person may be born with and are not modifiable (i.e., sickle cell disease), or are not easily modifiable and are also not indicators of health behavior or social determinants, but are truly an effect of biology (cases where there is an outsized impact of genetics, as with pregnancy-related hypertension or gestational diabetes). Because this wide variety of conditions is included, one may wonder if it is a useful outcome measure. As our aim was to assess the impact of payment policy on maternal health outcomes beyond SMM, we decided to more closely look at the amount of comorbid conditions in the population. However, it can be argued that, as these comorbidities are highly predictive of SMM, they may operate as a mediator in the causal chain between the independent variable, Maryland's GBM, and the dependent variable, severe maternal morbidity. In the proposed conceptual model, the GBM is hypothesized to impact SMM incidence by way of increased quality of care, due to better care coordination, increased visit time length, and more focus on primary and preventive care services. In this pathway, these improved health system factors would ostensibly result in better outcomes due to overall improvements in baseline health status, which implies reduced morbidity generally, which may be represented as comorbidities. As LCM can be potentially viewed as a mediating factor, in that it can explain how policy implementation can impact the outcome of SMM, it may be considered an inadequate or inappropriate outcome to measure on its own. Yet, we chose to include it here as the main outcome of this aim because of interest in better understanding how the Maryland policy change impacts overall health in the target population of child-bearing individuals. Given the composition of LCM as including both potentially preventable and non-preventable conditions, we wanted to understand how GBM may affect other pregnancy complications that are more sensitive to prenatal management. Here, we learned that preexisting conditions increased, while pregnancy-associated conditions were reduced.

From these analyses, we learn more about the impact of the Maryland GBM to population health, and expand the evidence base beyond reporting of cost savings or quality targets such as readmissions. Though necessary to track for healthcare system transformation and quality improvement, it is also critical to study the large-scale health impacts of value-based payment models, to understand the policy implications for public health.

Chapter 5: Conclusions

1. Policy Implications

The purpose of this trio of studies was to examine the population maternal health effects of implementing a novel population-based VBP model. As severe maternal morbidity disproportionately affects women from racial and ethnic minorities and people with chronic diseases (Fingar & Heslin, 2018; Tangel et al., 2019; Crear-Perry et al., 2021; Dude et al., 2022; Hoyert, 2024), these studies sought to assess for a treatment effect on SMM incidence (Aim 1), followed by a differential treatment effect by race (Aim 2), and finally for a treatment effect on presence of comorbid conditions (Aim 3). In Aim 1, we observed a decrease in the statewide rate of SMM in Maryland that can be reasonably attributed to the GBM policy implementation. In Aim 2, we observe heterogeneity in treatment effect, with black women giving birth in Maryland having additional SMM rate reduction. In Aim 3, models suggest a significant decrease in population-level comorbidity related to SMM. Altogether, findings demonstrate strong and consistent evidence of a treatment effect on maternal health outcomes, including SMM incidence and SMM-related comorbidity prevalence, from the implementation of the Global Budget Model.

Considering pernicious racial disparities in severe maternal morbidity and mortality, the findings from Aim 2 invite additional questions and calls for further inquiry. Not only is there a significant reduction in SMM incidence observed in the study from Aim 1, but there is also an additional effect observed in Aim 2, whereby persons of black race receiving care in Maryland have the primary SMM reduction observed in Aim 1 and also experience the added effect of the triple difference estimate observed in Aim 2, which gives even more reduction in SMM. There is something important happening here which warrants further study. Given the potential for meaningful public health implications, it is critical to understand specifically what causes this effect. In this study population, while black women had greatest reduction in SMM compared to women in other groups and other states, black women also had the highest base rate of SMM incidence, at 0.64%, or twice that of their white counterparts. In light of the SMM crisis at hand, there is potential to leverage this for real population health change. If we can understand this effect better, it can be scaled up to optimize the conditions of the mechanism to truly narrow the disparity in SMM.

This study expands knowledge beyond cost and utilization, in examining the population health and equity outcomes resulting from the Maryland Model. Existing evaluations assess success at cost-containment and specific clinical quality measures; likewise, evaluations of other state-based VBP maternal health programs do not directly connect payment to health improvement, but to cost reduction and targeted quality improvements (Medicaid And CHIP Payment and Access Commission (MACPAC) & Zettle, 2021). In evaluations of Maryland's Global Budget Model and its successor, the Total Cost of Care (TCOC) Model, there have not been evaluations of maternal health. Although reduction of SMM is a stated quality goal for TCOC, these analyses have not been conducted (Peterson et al., 2024; Rotter et al., 2022). In contrast, the current work directly links the VBP model in Maryland to health improvement and equity, contributing to the maternal health literature.

Importantly, as CMS begins to incentivize states to adopt GBM-like systems for the explicit goal of achieving health equity via the Achieving Healthcare Efficiency through Accountable Design (AHEAD; previously "All-Payer Health Equity Approaches and Development") Model and other pilot programs, there is great use for this analysis (*Achieving Healthcare Efficiency through Accountable Design (AHEAD) Model | CMS*, 2025; Gondi et al., 2024). It informs on how these VBP programs may be useful for addressing SMM and other population health issues, in the obstetric population and beyond. Specifically, in the dissertation studies presented here, we see the impact of GBM to health equity, by reducing the black-white disparity in SMM in decreasing SMM rate more substantially for black women in Maryland. This finding highlights the potential for alternative payment models such as the Maryland GBM model to impact health equity. As described by Centers for Medicare and Medicaid Innovation, global budgets can be a critical tool not just for cost containment and revenue generation, but also to invest in population health, primary care, behavioral health, and health equity, giving rural and urban safety-net hospitals, in particular, financial stability and flexibility (CMMI, 2024). To address the issue of unequal market power amongst different provider types (i.e., where larger health systems in less competitive markets have greater power to negotiate favorable payment rates, thereby altering access to care for different patient populations), all-payer rate setting and hospital global budgeting policies can be impactful by controlling these market dynamics through an independent regulatory system (Eschliman et al., 2023). These studies provide evidence to support these possibilities of global budget models in potential for achieving equity using VBP, to aid in determining feasibility of broader adoption of VBP for maternal health.

2. Future Research

This work is an essential first step to measure the impact of value-based payment on maternal health outcomes and health equity. Moving forward, it will be crucial to expand beyond the hospital setting to study the impacts on other healthcare environments. As Maryland is currently in the TCOC model demonstration, which builds upon GBM to other sites of care, including primary care settings, an examination of the TCOC impacts to the quality and equity of maternal health and healthcare will be important for understanding of how care during pregnancy may be impacted. Future research will aim to capture all aspects of birthing people's care, including prenatal care, and care received for non-delivery pregnancy events (e.g., counseling, laboratory testing). With additional years of data, a clearer picture of the impact of the TCC model can be achieved. Importantly, this study seeks to characterize whether the MD model causally affected maternal health, but does not explore the mechanisms of action. Future work will include qualitative research activities to collect and assess perspectives of patients, providers, and administrators involved in the process of providing and receiving care in the state of Maryland since the GBM took effect.

Future studies to examine the impacts in other states with similar models will be imperative to characterize the true relationship of value-based payment systems and severe maternal morbidity. Currently, the AHEAD model demonstration is underway, in which Maryland is the sole occupant of the first cohort. These studies, which tell the story of Maryland's VBP policies for maternal health, may provide context for other states intending to enter into the AHEAD model cohorts.

Ultimately, these findings can be used to increase our knowledge of how value-based payment may improve health equity in Maryland and beyond. This evidence can be foundational for other studies of alternative payment models that consider wider health, healthcare, and social implications to help inform state, federal, and local policies to improve health equity.

Appendices

Appendix A. Severe Maternal Morbidity, Diagnoses and Procedures

DX: Diagnosis, PR: Procedure

Acute myocardial infarction (DX)
Aneurysm (DX)
Acute renal failure (DX)
Adult respiratory distress syndrome (DX)
Amniotic fluid embolism (DX)
Cardiac arrest/ventricular fibrillation (DX)
Conversion of cardiac rhythm (PR)
Disseminated intravascular coagulation (DX)
Eclampsia (DX)
Heart failure/arrest during surgery or procedure (DX)
Puerperal cerebrovascular disorders (DX)
Pulmonary edema and Acute heart failure (DX)
Severe anesthesia complications (DX)
Sepsis (DX)
Shock (DX)
Sickle cell disease with crisis (DX)
Air and thrombotic embolism (DX)
Hysterectomy (PR)
Temporary tracheostomy (PR)
Ventilation (PR)

Appendix B. Leonard et al. (2020) SMM-Related Comorbid Conditions

DX: Diagnosis, PR: Procedure

Placenta accreta spectrum (DX)
Pulmonary hypertension (DX)
Chronic renal disease (DX)
Bleeding disorder, preexisting (DX)
Cardiac disease, preexisting (DX)
HIV/AIDS (DX)
Placenta previa, complete or partial (DX)
Preeclampsia with severe features (DX)
Anemia, preexisting (DX)
Twin or multiple pregnancy (DX)
Placental abruption (DX)
Preterm birth (less than 37 wk) (DX)
Gastrointestinal disease (DX)
Preeclampsia without severe features or gestational hypertension (DX)
Asthma, acute or moderate–severe (DX)
Substance use disorder (DX)
Connective tissue or autoimmune disease (DX)
Chronic hypertension (DX)
Preexisting diabetes mellitus (DX)
Neuromuscular disease (DX)
Major mental health disorder (DX)
Thyrotoxicosis (DX)
BMI (kg/m2) at delivery 40 or greater
Previous cesarean birth (DX)
Maternal age 35y or older
Gestational diabetes mellitus (DX)

Appendix C. SMM-related comorbid conditions characterized by preexisting or pregnancy-onset status.

Preexisting comorbidities:
Preexisting diabetes
HIV/AIDS
Previous C section
Pulmonary hypertension
Asthma
Preexisting bleeding disorder
BMI
Preexisting cardiac disease
Chronic renal disease
Connective tissue or autoimmune disease
Substance use disorder
Maternal age
Preexisting anemia
Gastrointestinal disease
Major mental health disorder
Neuromuscular disease
Thyrotoxicosis

Pregnancy-onset comorbidities:
Gestational diabetes
Twin/multiple pregnancy
Chronic hypertension*
Placenta previa, complete or partial
Preeclampsia with severe features
Preeclampsia without severe features of gestational hypertension
Placental abruption
Placenta accreta spectrum
Preterm birth

*This is included as a pregnancy onset condition because of how it is defined in Leonard et al. 2020, where gestational hypertension is coded together with chronic hypertension.

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