NBER WORKING PAPER SERIES

MARIJUANA LIBERALIZATION POLICIES AND PERINATAL HEALTH

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Working Paper 29296
http://www.nber.org/papers/w29296

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
September 2021

The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research. This work was supported by the National Institute on Drug Abuse P30DA040500 and K01DA051777, the Gerber Foundation GF192350, and the Robert Wood Johnson Foundation RWJF77962. We thank Clément de Chaisemartin, David Roodman, Michelle Marcus, David Bradford, and seminar participants at Cornell University's Department of Policy Analysis and Management, Indiana University's O'Neill School, Weill Cornell Medicine, the American Society of Health Economists Annual Meeting, American Economic Association's Annual Meeting, and the Southern Economic Association Annual Meeting for helpful comments and suggestions. All errors are our own.

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NBER Working Paper No. 29296
September 2021
JEL No. I0

ABSTRACT

We studied the effect of marijuana liberalization policies on perinatal health with a multiperiod difference-in-differences estimator that exploited variation in effective dates of medical marijuana laws (MML) and recreational marijuana laws (RML). We found that the proportion of maternal hospitalizations with marijuana use disorder increased by 23% (0.3 percentage points) in the first three years after RML implementation, with larger effects in states authorizing commercial sales of marijuana. This growth was accompanied by a 7% (0.4 percentage points) decline in tobacco use disorder hospitalizations, yielding a net zero effect over all substance use disorder hospitalizations. RMLs were not associated with changes in newborn health. MMLs had no significant effect on maternal substance use disorder hospitalizations nor on newborn health and fairly small effects could be ruled out. In absolute numbers, our findings implied modest or no adverse effects of marijuana liberalization policies on the array of perinatal outcomes considered.

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1 Introduction

As of 2021, 36 states and the District of Columbia adopted medical marijuana laws (MMLs) authorizing physicians to recommend marijuana for patients with eligible health conditions. A subset of 19 MML states have subsequently adopted recreational marijuana laws (RMLs) allowing individuals ages 21+ to possess, use, and supply limited amounts of marijuana for recreational purposes [1]. The proliferation of marijuana liberalization policies coincides with a shift towards positive perceptions and use of marijuana among pregnant women [2], who may seek marijuana recreationally or medically to alleviate nausea and other conditions in pregnancy [3, 4, 5]. Past-month marijuana use among pregnant women increased 103% between 2003 and 2017, nearly twice the growth among the general U.S. population [6, 7, 8, 9]. Marijuana use during pregnancy is concerning because of potential adverse consequences on perinatal health. While causality is difficult to establish, descriptive studies have found that marijuana is associated with impaired judgement and anemia in mothers, stillbirth, low birth weight, low gestational age, and developmental disorders [10, 11, 12, 13, 14]. The American College of Obstetricians and Gynecologists (ACOG) discourages physicians from prescribing marijuana during preconception, pregnancy, or lactation and recommends that pregnant women or women contemplating pregnancy discontinue using marijuana [15]. Despite these recommendations, most states adopting marijuana liberalization policies are silent regarding marijuana use during pregnancy.

Marijuana liberalization may affect perinatal health through intensive or extensive margin changes in maternal use of marijuana and other substances that are complements or substitutes of marijuana. Changes may occur through legal market responses affecting marijuana supply, potency, prices, and access; the diversion of legally produced marijuana; consumer perceptions about marijuana safety, stigma, psychoactive benefits, and therapeutic efficacy; healthcare provider preferences around recommending marijuana versus substitute prescription drugs; criminal justice responses affecting risks of prosecution; and illicit drug market responses affecting the supply, potency, or prices of illegally produced marijuana and other substances [16]. Marijuana liberalization may also affect the demographic composition of newborns through increases in the number of women who become pregnant by inducing risky sexual behaviors along with greater substance use [17]. These general equilibrium effects make the impact of marijuana liberalization policies on perinatal health theoretically ambiguous, and potentially different from findings in descriptive epidemiological studies of prenatal marijuana use.

Previous studies of marijuana liberalization policies primarily focus on the impact of MMLs on teenagers and adults. Research on teenagers generally finds no association between MMLs and marijuana or other substance use [18, 19, 20, 21, 22, 23, 24, 25]. Research on adults while somewhat inconclusive, generally finds growth in marijuana use along with decreases in opioid and tobacco use, which might suggest substitutability [18, 26, 27, 21, 23, 28, 29, 30, 31, 17, 32, 33, 34, 35, 36, 37, 38]. The handful of existing RML studies find growth in marijuana use among adults but inconclusive evidence for teenagers [39, 40, 41, 42, 43]. A scarce body of evidence examines the impact of these policies on pregnant women. One MML study using a difference-in-differences (DID) design found no changes in self-reported marijuana use in a sample of pregnant women (N=11,700), but did find greater marijuana use in a larger and better powered sample of women with children (N=117,600) [44]. Another MML study using DID found a 33% increase in treatment admissions for marijuana use disorder among pregnant women [45]. A related MML study using

DID found birth rate increases along with greater risky sex behaviors [17]. Evidence of the impact of RMLs on pregnant women comes from single-state, descriptive studies. These studies have found increases in measures of prenatal marijuana use, including self-reports and drug testing in biological specimens [46, 47, 48, 49]. The literature largely ignores the effect of marijuana liberalization on newborns. One MML study using DID found small growth on birth weight but no changes in other outcomes [50]. RML studies are also based on single-state, descriptive evidence and findings suggest little-to-no-changes in newborn outcomes [51, 47, 48, 52].

This study provides the most comprehensive evidence to date of the effect of marijuana liberalization policies on maternal substance use disorders and newborn health. We pooled restricted data from the 2007-2019 National Vital Statistics System Natality Files (NVSS) and the 2007-2018 Healthcare Cost and Utilization Project State Inpatient Databases (HCUP-SID) [53]. Maternal substance use disorders were measured as hospitalizations involving marijuana use disorder, opioid use disorder, alcohol use disorder, stimulant use disorder, tobacco use disorder, and any substance use disorder, occurring during the perinatal period. Newborn health was measured as low birth weight, low gestational age, prenatal exposure to noxious substances, neonatal drug withdrawal syndrome, fetal alcohol syndrome, and respiratory conditions, among others. Our identification strategy relied on a DID design that exploited the staggered implementation of MMLs and RMLs across states and years. DID coefficients were estimated with a variety of established and novel estimators, including static two-way fixed effects, dynamic event study, and the heterogeneity robust multiperiod estimator [54]. We extended our analysis to consider treatment effect heterogeneity across subpopulations defined by maternal age, race and ethnicity, and health insurance. There is mounting evidence to suggest that the effects of marijuana liberalization may be heterogeneous across these subpopulations. Previous studies have documented higher marijuana use during pregnancy among mothers younger than 20 years old, non-Hispanic White and Black, and with Medicaid [55, 56, 57, 58]. Evidence suggests that birth outcomes vary across these demographics as well [59]. Additionally, we extended our analysis to consider the time when medical and recreational marijuana dispensaries became operational, as prior research suggests that legalization by itself may be an inadequate measure of access [21].

Our study contributes to the growing literature on marijuana liberalization policies in three important ways. First, we focused on pregnant women and their newborns, a vulnerable population frequently cited in debates around marijuana liberalization but for which empirical evidence is currently lacking [60]. More broadly, there is scant research on RMLs due to their relative recentness. As RMLs proliferate, generating empirical evidence is important for informing future legislation. This study provides the first population-level estimates of the association between RMLs and perinatal health. Second, conducting research on the effects of state policies on illegal substance use during pregnancy is challenging due to a lack of large, representative data with reliable measures of illegal substance use in this population. Existing data are either based on a single state, on small sample sizes which hinder analyses of low-frequency outcomes, or on self-reported measures of illegal substance use that are known to suffer from underreporting [61, 62, 58]. Underreporting might be especially significant for pregnant women, who could face legal consequences with child protective services in states that consider prenatal drug use child abuse or neglect [63]. We addressed these data challenges with HCUP-SID containing detailed health information for a near universe of hospitalizations in the 34 states for which we were able to obtain data.[1] Substance use-related diagnostic codes in HCUP-SID

[1]Pooling hospital discharge data from such a large number of states entailed vast financial resources, time effort, and collaboration across multiple organizations. We are extremely grateful

were designated by healthcare providers during a patient's hospital stay, and thus not self-reported. Notably, our outcomes captured intense maternal substance use which was most relevant for adverse perinatal health, as opposed to light to moderate use. Lastly, we applied a novel multiperiod DID estimator that corrects for bias arising from treatment effect heterogeneity in often used two-way fixed effects DID estimators and conducted a simulation to show that the estimator's standard errors may allow for inference in the presence of a small number of treated clusters [54].

Using the multiperiod DID estimator, we found that the proportion of maternal hospitalizations involving marijuana use disorder increased by 23% (0.3 percentage points) in the first three years after RML implementation, with larger proportional effects among pregnant women who were 21 to 44 years old, White or Hispanic, Medicaid beneficiaries, or lived in states authorizing commercial sales of marijuana. This growth was accompanied by a 7% (0.4 percentage points) decline in the proportion of maternal hospitalizations involving tobacco use disorder. There was no significant effect of RMLs on the proportion of maternal hospitalizations involving opioid, stimulant, alcohol, or any substance use disorder. RMLs were not associated with statistically significant changes in newborn outcomes. We found no association between MML implementation and perinatal health outcomes, and can rule out proportional increases as small as 2.7% (0.2 percentage points) in low gestational age, 3.5% (0.2 percentage points) in low birth weight, and 0.95% (0.1 percentage points) in respiratory conditions. In absolute numbers, our findings implied modest or no adverse effects of marijuana liberalization policies on the array of perinatal health

to the Weill Cornell Medicine Center for Health Economics of Treatment Interventions for Substance Use Disorder, HCV, and HIV center, RTI International, the Agency for Healthcare Research and Quality, Louisiana Department of Health, Delaware Department of Health, Pennsylvania Health Care Cost Containment Council, the Robert Wood Johnson Foundation, and the University of North Carolina Wilmington's Cameron School of Business for their support.

outcomes considered. We caution that our findings reflect the association between *marijuana liberalization policies* and perinatal health, and therefore should not be interpreted as reflecting an epidemiological association between *prenatal marijuana exposure* and perinatal health, do not reflect all outcomes that could be affected by marijuana liberalization policies, and need not generalize to all subpopulations.

The paper proceeds as follows. Section 2 describes marijuana liberalization policies and previous literature. Section 3 describes data sources and methods. Section 4 presents results and Section 5 discusses policy implications and concludes.

2 Background

2.1 *Marijuana liberalization policies*

The U.S. Federal government classifies marijuana as a controlled substance in Schedule I. Substances in this schedule have no accepted medical use, a lack of accepted safety, and a high potential for abuse [64]. At the state level, however, 36 states and the District of Columbia have passed medical marijuana laws and a subset of 19 MML states have subsequently passed recreational marijuana laws as of 2021 [1].

MMLs remove state penalties for the possession, use, and supply of marijuana for medicinal purposes under specified circumstances [65]. Patients must have a qualifying condition and written certification from a licensed medical professional. Qualifying conditions often include cancer, multiple sclerosis, HIV/AIDS, hepatitis C, chronic pain, and nausea, among others. RMLs further liberalize marijuana by allowing individuals ages 21+ to possess, use, and supply marijuana for recreational purposes [65]. There is considerable variation in MML and RML provisions across states. Laws vary in limits set on the products and amounts of medical or recreational marijuana that may be possessed, as well as in the establishment of systems of marijuana production and distribution. For instance, early adopting MML states initially relied on home cultivation as the source of medical marijuana by setting a limit on the number of plants that a patient or caregiver may grow. More recently, many states have established formal licensing and regulation of dispensaries through which marijuana is sold to medical and recreational users.

2.2 *Marijuana use during pregnancy*

Marijuana is the most commonly used illicit drug during pregnancy [7], with an estimated 7.1% of pregnant women self-reporting past month marijuana use in 2017 [8]. True prevalence, however, is likely higher due to underreporting [61, 62, 58] with one study finding that pregnant women are about twice as likely to screen positive for marijuana via drug test than self-reported measures [62]. Another study using a sample of low-income postpartum women who gave birth in an urban medical center found that 11% self-reported marijuana use in the past 3 months but 28% screened positive for marijuana use [61]. Similarly, in a sample of pregnant women going to a university-based prenatal care clinic, 29% screened positive for marijuana at initial visit [58]. About one-third of women using marijuana at the onset of pregnancy continue using it [66], but use decreases as pregnancy progresses [67].

Demographic and socioeconomic factors are related to marijuana use in pregnancy. Compared to pregnant women who do not use marijuana, those who do are more likely to be younger, African American, unemployed, of lower income and education, unmarried, and uninsured or publicly insured [9, 68, 56, 57, 58]. A large proportion of pregnant women self-reporting past month marijuana use also use tobacco (60%), alcohol (40%), or illicit drugs (17%) [57]. While the prevalence of self-reported marijuana use is lower in pregnant women relative to nonpregnant women, conditional on marijuana use, pregnant women are likely to use it more frequently. Among women self-reporting past year marijuana use, 48% of pregnant and 33% of nonpregnant women use it for at least 100 days, and 18% of pregnant and 11% of nonpregnant women meet DSM-IV criteria for marijuana use disorder [57].

Several factors likely influence the decision to use marijuana in pregnancy. Pregnant women may seek marijuana recreationally for its psychoactive properties or medically for its therapeutic properties, including but not limited to its antiemetic properties that may help alleviate nausea and vomiting in pregnancy [3, 4, 69, 5]. Indeed, observational studies document that pregnant women who experience these symptoms are significantly more likely to use marijuana than those who do not [3, 4, 70]. One study found that 69% of dispensaries in Colorado recommended marijuana for treating nausea in pregnancy [71]. Perceptions about marijuana safety are also likely key factors in the decision to use of marijuana. Perceived harm from light marijuana use is low, with 70% of pregnant and nonpregnant women believing there is no or slight risk from using marijuana 1 to 2 times per week [57]. Beliefs about marijuana's harm are related to use, with women who believe marijuana is not harmful being less likely to stop using in pregnancy [66].

Physicians may be inadequately prepared to counsel pregnant women about marijuana use. In one study, audio recordings of 468 first obstetric encounters revealed that providers failed to respond to pregnant women's disclosure of marijuana use in 48% cases. When the provider did respond, they focused on general statements without specific discussions on the risks of marijuana use in pregnancy or warnings that use detected at the time of delivery could initiate child protective services involvement [72]. Recent surveys of physicians, residents, pharmacists, and pharmacy students show that providers have low self-rated knowledge about aspects of marijuana use in the medical setting such as efficacy and side effects [73, 74, 75, 76, 77, 78]. Medical professionals overwhelmingly state a need for more education on the use of medical marijuana [79, 74, 75] and not knowing where to get such information [78].

2.3 *Marijuana use during pregnancy and newborn health*

Marijuana use during pregnancy may affect newborn health through marijuana's effect on maternal health and behaviors or through direct exposure to marijuana in utero. Delta-9-tetrahydrocannabinol (THC), the principal psychoactive component of marijuana, is highly lipophilic and can cross the placenta [80, 69]. THC's potential to harm infant health occurs through its impact on the endocannabinoid system, which appears around day 16 of human gestation and is thought to be important to proper early brain growth and development [69]. Additionally, exposure to nonpsychoactive cannabidiol has been found to increase permeability of the placental barrier, potentially increasing infants' exposure to other substances [81].

Animal studies demonstrate negative effects of THC in experimentally controlled settings. Exposing pregnant mice to THC reduces body size and birth weight in offspring and increases risk of fetal mortality and immune dysfunction [82, 83, 84, 85]. Adverse effects are largest when in utero exposure occurs early in the pregnancy or with higher THC doses [83]. Isolating the effect of marijuana use during pregnancy on newborn health is difficult in human studies given numerous co-occurring factors such as socioeconomic status and other substance use [15, 68, 56, 57]. Current evidence of this association is somewhat mixed. While some studies find no association once confounders are controlled for [86, 87, 88, 58], especially tobacco use, others do find an increased risk of low birth weight (LBW), low gestational age (LGA), small for gestational age (SGA), stillbirth, and neonatal intensive care unit (ICU) admissions, among others [89, 90, 12, 11, 91, 13, 92]. Using data on over 600,000 Canadian women and a matching design that adjusts for tobacco and other substances, the most robust study to date finds that marijuana use during pregnancy is associated with higher risk of LGA, SGA, placental abruption, ICU admission, and a lower 5-minute APGAR score [13]. Long-term impacts of marijuana use during pregnancy have also been documented, with studies finding higher risk of impaired brain development, behavioral problems, and deficit in school achievement [93, 94, 95].

2.4 *Conceptual framework*

The net effect of marijuana liberalization policies on perinatal health is theoretically ambiguous. Marijuana liberalization may *worsen* perinatal health through intensive or extensive margin growth in maternal use of marijuana and other substances (for medical or recreational purposes, legally or illegally obtained) that are complements to marijuana. Previous studies have documented increases in marijuana use among adults after MML and RML implementation [27, 17, 29, 26, 23, 45, 31, 44, 96, 28]. Increases in substance use may result from greater access to medical or recreational marijuana or diverted marijuana initially intended for medical purposes, from reductions in perceived risk, fear, or stigma of marijuana use, from changes in criminal justice and healthcare provider practices, from increasing beliefs that marijuana is efficacious for treating select conditions, and from illicit drug market responses increasing the supply and potency or decreasing the prices of marijuana and other illegal substances. Consistent with these mechanisms, previous studies have found greater marijuana use and perceived availability in MML states with dispensaries, which facilitate access to marijuana [21, 45, 44, 32, 23]. Previous studies have also found increases in beliefs that marijuana use is safe [66, 97], and increases in the potency and reductions in prices of illegal marijuana [16, 98, 99]. Among reproductive age women, marijuana liberalization might increase the number of women who become pregnant by inducing risky sexual behaviors along with greater substance use [17], which may affect the demographic composition of newborns.

In contrast, marijuana liberalization policies may *improve* perinatal health through better management of nausea, weight gain, pain, anxiety, sleep, and other maternal conditions; the availability of safer marijuana products; or decreases in the use of harmful substances that are substitutes to marijuana. The impacts of marijuana liberalization on alcohol and tobacco use remain uncertain [100]. Alcohol use has been shown to fall after MML implementation [101, 102]; however, other research finds that MMLs increase adult binge drinking [27] and the presence of dispensaries and home cultivation are positively associated with alcohol use among adults [103]. Evidence for tobacco is less inconclusive, with studies generally finding modest declines or no effects in tobacco measures [100]. One study found that MMLs reduce tobacco use by 1 to 1.5 percentage points in the general adult population [26]. Previous research has also found that the use of prescription drugs for which marijuana could serve as a clinical alternative decreases after MML implementation, including prescription drugs for treating pain, nausea, anxiety, depression, and psychosis [104]. A vast literature documents decreases in opioid use in the general population following MMLs [33, 34, 35, 36, 37, 38, 26]. Marijuana liberalization policies may also lead to improved perinatal health if they induce greater prenatal use surveillance or reduced fear of disclosing substance use to healthcare providers. Increased identification of maternal SUD could lead to greater SUD treatment utilization that may improve perinatal health. Depending on what mechanisms dominate, marijuana liberalization may worsen or improve net perinatal health.

The effects of MML and RMLs may vary due to the heterogeneous nature of the laws, as well as differences in the costs and benefits of marijuana consumption and production. First, MMLs and RMLs target different populations by design. As such, MMLs should primarily affect individuals with an approved medical condition, while RMLs could affect marijuana use in the population of adults 21+ [1]. Provider involvement associated with MMLs may offer some protection against potentially adverse effects of marijuana use, which may not occur for RMLs. Furthermore, providers in MML-only states may act as gatekeepers, preventing some women from accessing legal marijuana. Effects may also vary based on the stringency of MML or RML regulations, including recreational or medical dispensaries, taxes on consumption, licensing and other costs of entering the legal market, among others. Second, policies may affect certain populations differently. Evidence suggests marijuana use is more prevalent among younger mothers, non-Hispanic White and Black mothers, and mothers covered by Medicaid [57]. It is unclear whether pre-existing patterns may be exacerbated by marijuana liberalization. However, liberalization policies may not directly affect certain populations, such as individuals under 21 years old, who cannot legally purchase recreational marijuana. Access to substance use disorder treatment, perceived health risk, and fear of punishment associated with marijuana use varies across subpopulations [105, 106]. For example, Native and Black mothers often experience greater SUD-related child welfare system involvement [107].

3 Empirical strategy

3.1 *Data sources*

3.1.1 *Outcome variables*

Healthcare Cost and Utilization Project (HCUP). We analyze restricted hospital discharge data from HCUP, a family of national and state healthcare databases developed through a federal-state-industry partnership sponsored by the Agency for Healthcare Research and Quality (AHRQ). HCUP includes the largest collection of longitudinal hospital data in the United States, with all-payer, encounter-level information. We rely on the 2007-2018 HCUP State Inpatient Databases (HCUP-SID) for select states, although our panel of states is unbalanced as we could not obtain all years of data for some states (see Appendix Table 9). HCUP-SID are state-specific files that contain a near census of inpatient discharge records and provide demographic and healthcare information for patients. Demographic information includes date of birth, age, race and ethnicity, sex, and geographic area. Race and ethnicity are missing for about 10% of our sample. Healthcare information includes the primary expected payer (Medicaid, private insurance, other) and ICD-9/ICD-10 diagnostic and procedure codes associated with the discharge.[2] The unit of observation is an individual's hospital discharge. We use the state and year-quarter of discharge to match observations with the policies and control variables. Some states that do not participate in HCUP directly provide researchers with access to their inpatient discharge records. We combine HCUP-SID with hospital data from non-participating states (Louisiana, Delaware, Pennsylvania) for a total of 34 states,

[2] In the fourth quarter of 2015, diagnostic and procedure codes changed format from the International Classification of Diseases, 9th Revision to the 10th Revision

including 13 switching MML states and 9 switching RML states.

We generate two samples, one of maternal hospitalizations during pregnancy, delivery, or the postpartum period, and the other of newborn hospitalizations. We identify these samples using age (0 for newborns and 15-44 for mothers) and biological sex (female for mothers), as well as primary and up to 35 secondary ICD-9/ ICD-10 diagnostic and procedure codes in Appendix Table 10. The primary diagnosis represents the condition established by healthcare providers to be chiefly responsible for the patient's admission to the hospital. Secondary diagnoses are concomitant conditions that coexist at the time of admission or develop during the hospital stay. We also rely on HCUP generated variables flagging a birth record corresponding to a newborn or a mother. We draw a 60% random sample by state and year for each population to reduce computational load.

Maternal outcomes include indicators of substance use disorder, drug use disorder, marijuana use disorder, opioid use disorder, alcohol use disorder, tobacco use disorder, stimulant use disorder and drug use complicating pregnancy, childbirth or the puerperium. Drug use disorder is a composite variable indicating any marijuana use disorder, opioid use disorder, stimulant use disorder, hallucinogen use disorder, sedative, hypnotic or anxiolytic use disorder, or other specified/unspecified drug use disorder. Substance use disorder is a composite variable indicating any drug use disorder, as well as any tobacco use disorder or alcohol use disorder. Specific ICD-9/ICD-10 diagnostic codes are in Appendix Table 11 and follow standard definitions established by AHRQ and the Centers for Medicare and Medicaid Services (CMS) Chronic Conditions Data Warehouse.[3] The prevalence of marijuana use disorder among pregnant women in the 2015-2018 National Survey of Drug use and Health

[3]https://www.hcup-us.ahrq.gov/reports/statbriefs/sb_mhsa.jsp.

was 1.3%,[4] which is comparable with the 1.56% prevalence of marijuana use disorder among pregnant women in our HCUP sample during the same period.

Newborn outcomes include indicators of exposure to noxious substances (defined as narcotics, hallucinogens, cocaine, anti-infectives, diethylstilbestrol, anticonvulsants, alcohol, tobacco, among other substances) via placenta or breast milk, neonatal drug withdrawal syndrome (NDWS), fetal alcohol syndrome (FAS), slow growth, respiratory conditions, feeding problems, and congenital anomalies (see Appendix Table 12). While these outcomes are selected based on previously established associations with prenatal exposure to drugs [108], not all are associated with prenatal exposure to marijuana. For instance, exposure to noxious substances via placenta or breast milk may, at most, partially reflect prenatal exposure to marijuana. Moreover, NDWS and feeding problems are primarily associated with prenatal exposure to opioids and FAS with prenatal exposure to alcohol [108]. Nevertheless, these outcomes could be affected by marijuana liberalization policies if these policies induce changes in substances that are complements or substitutes of marijuana.

National Vital Statistics System Natality Files (NVSS Natality). We analyze restricted 2007-2019 NVSS Natality Files. This microdata provides rich demographic and health information for nearly all births occurring in the United States and are based on information abstracted from birth certificates filed in vital statistics offices of each state and the District of Columbia. Demographic data include date of birth, maternal age, educational attainment, marital status, live-birth order, race and ethnicity, sex, and geographic area. Health data include items such as birth weight, gestation length, and prenatal care, among others.

We identify singleton hospital births and drop those with missing information on

[4] https://rdas.samhsa.gov/#/survey/NSDUH-2015-2018-RD04YR

year and month of birth, birth weight, and gestation length. Outcomes of interest include the proportion of births with low birth weight (< 2,500 grams), very low birth weight (< 1,500 grams) and low gestational age (< 37 weeks), all major risk factors for infant mortality and long-term morbidity [109].[5] The unit of analysis is the state-year-quarter of conception. We calculate the estimated quarter and year of conception for each birth using information on the month and year of birth and gestation length and limit the data to conception years 2007-2018. We aggregate outcomes into state-year-quarter cells defined by state of residence of the mother and year and quarter of conception.

3.1.2 *Treatment variables*

The effective dates of MMLs and RMLs are drawn from previous studies and ProCon [1, 38, 36, 37] (see Appendix Table 8). Appendix Figure 6 plots the timing of MML and RML implementation using these dates. MML implementation has occurred steadily since 1996, while RML implementation is a more recent phenomenon starting since 2012. All RML states were initially MML states. Previous research shows that medical marijuana dispensaries increase access to marijuana and are more strongly associated with marijuana use [21]. For this reason, we also consider the time when medical and recreational marijuana dispensaries became operational in a state.

[5]We considered the possibility of analyzing the proportion of births with low Apgar scores but opted not to do so after discovering odd patterns and discontinuities in Apgar scores over time for various states. While some of the discontinuities coincided with the state changing to the new birth certificate, this did not explain all data anomalies.

3.1.3 *Control variables*

We account for several control variables that may be correlated with perinatal health and marijuana liberalization policies to reduce potential confounding. All models control for state-year differences in the Affordable Care Act (ACA) Medicaid Expansions to account for changes in health insurance affecting healthcare utilization (i.e. prenatal care, SUD treatment) and for drug policies to account for other changes in the supply or demand of addictive substances. Effective dates of ACA Medicaid Expansions are drawn from the Henry J. Kaiser Family Foundation and previous studies [110, 111, 112]. Drug policies include the cigarette tax rate (dollars per pack), drawn from the Centers for Disease Control and Prevention's State Tobacco Activities Tracking and Evaluation System; and indicators of pain clinic laws and prescription drug monitoring program operations and mandates. Indicators were generated using effective dates drawn from the National Alliance for Model State Laws, the Prescription Drug Use Policy System, and previous studies [113]. We also control for additional sociodemographic variables. Analyses of HCUP-SID account for race, ethnicity, maternal age, expected payer (Medicaid), and newborn sex, at the individual discharge level. Analyses of NVSS account for average maternal age, race, ethnicity, parity, and newborn sex, at the state-year-quarter of conception level.

3.2 *Econometric approach*

Our identification strategy exploits variation in the staggered implementation of marijuana liberalization policies across states and over time using the effective dates in Appendix Table 8.

$$Y = \alpha + \gamma MML_{st} + \delta RML_{st} + X + S_s + T_t + \epsilon \tag{1}$$

Equation 1 is the baseline two-way fixed effects difference-in-differences (DID_{FE}) model that estimates the static effect of MMLs (γ) and RMLs (δ) on outcome Y.[6] MML_{st} is an indicator equal to one if a medical marijuana law is effective in state s and year-quarter t, and zero otherwise. RML_{st} is an indicator equal to one if a recreational marijuana law is effective in state s and year-quarter t, and zero otherwise. When the date of implementation does not fall in the first month of the quarter of implementation, we assign the policy to "turn on" in the following quarter. S_s are state fixed effects and T_t are year-quarter fixed effects. Threats to identification might remain if other determinants of Y change differentially over time in treated states. To minimize potential threats, a vector of control variables X that accounts for health insurance, drug policies, and demographic characteristics is incorporated into all specifications (see Section 3.1.3). Regressions using NVSS data are weighted with the number of births in a state-year. Standard errors are clustered at the state level using the cluster-robust variance matrix estimator [114].

When treatment effects are constant across states and time, DID_{FE} can estimate the average treatment effect on the treated (ATT) under the standard parallel trends assumption [54, 115]. However, DID_{FE} can generate biased estimates when treatment effects are heterogenous across states or time, even when the parallel trends assumption holds. This happens because DID_{FE} is a weighted sum of ATTs in each state and time, which compares the evolution of the outcome between consecutive time periods across pairs of states. In staggered implementation designs such as ours, the "control group" in some of those comparisons is treated in both periods and its treatment effect in the second period gets differenced out, generating negative

[6] The unit of observation is a state and year-quarter of conception in analyses of NVSS Natality Files and an individual discharge in analyses of HCUP-SID.

weights [54].[7] The negative weights can lead to misleading estimates when effects are heterogeneous [54, 115]. DID_{FE} is more likely to assign negative weights to periods with a large fraction of treated states and to states treated for many periods [54].

We begin our analyses by applying the diagnostic test $twowayfeweights$ described in [54] to examine whether DID_{FE} is robust to treatment effect heterogeneity in our context. Table 1 reports the percentage of all ATT estimates that have a negative weight and the sum of negative weights, for each analytical sample and for a variety of specifications and marijuana liberalization policies typically studied in the literature. We find that the percentage of negative weights attached to MML_{st} is substantial and increases from 30%-40% as we incorporate additional marijuana liberalization policies into the same specification in Columns (1), (3) and (4). While the percentage of negative weights attached to MML_{st} decreases to 18-25% when dropping always treated MML states in Column (5), this workaround adopted in some previous studies proved to be far from effective in our context. The percentage of negative weights attached to RML_{st} is zero or minimal in Columns (2) and (3), likely because RMLs are more recent and the share of treated states is low. However, when incorporating all marijuana liberalization policies into the same specification in Column (4), the percentage of negative weights attached to RMLs increases to 26-29% depending on the sample. Overall, Table 1 demonstrates that DID_{FE} estimates are riddled with negative weights, indicating that two-way fixed effects estimators are not robust to treatment effect heterogeneity and thus, possibly biased. Nevertheless, we report DID_{FE} estimates to provide a baseline comparison with other marijuana studies since nearly all have relied on two-way fixed effects DID estimators.

[7] Weights sum to one but may be negative.

$$Y = \alpha + \lambda_{1Pre} D1_{sj \in Pre} + \sum_{j=-2}^{-12} \lambda_{1j} D1_{sj} + \sum_{j=0}^{11} \lambda_{1j} D1_{sj} + \lambda_{1Post} D1_{sj \in Post} \\ + \lambda_2 P2_{st} + \theta X + S_s + T_t + \epsilon \quad (2)$$

We address limitations of DID_{FE} by relying on alternative DID estimators, namely, the dynamic event study estimator DID_{ES} and the multiperiod DID_M estimator described in [54]. DID_{ES} is a dynamic two-way fixed effects estimator that can estimate treatment effects when heterogeneity occurs over time but effects are constant across groups under the standard parallel trends assumption [116]. DID_{ES} is based on the event study approach in Equation 2, which controls for 12 leads and lags of the policy $P1$ (either MML or RML) and bins distant relative periods. We drop always treated states for $P1$ as suggested in previous studies [116] and Table 1. Lags and leads are captured in the dummy variables $D1_{sj}(j = t - k + 1)$, where k is $P1$'s effective date in state s, j is the period relative to $P1$'s effective date, and $P2$ is an indicator for the other policy (i.e. in an event study of $P1 = RML_{st}$, $P2 = MML_{st}$). $D1_{sj \in Pre}$ captures all relative periods such that $j < -13$ into a single indicator and $D1_{sj \in Post}$ captures all relative periods such that $j >= 12$ into a single indicator. The reference groups are $j = -1$ and $j = -13$, which are excluded to avoid multicollinearity. While DID_{ES} is more flexible than DID_{FE} and is robust to heterogeneity over time, it can be biased when treatment effects are heterogenous across states [116]. In our context, one might reasonably expect treatment effect heterogeneity across states given known state variation in MML and RML provisions, marijuana prevalence, and in other determinants of perinatal health.

The multiperiod DID_M estimator is robust to heterogeneity across states and over time and thus, our preferred estimator. DID_M generates treatment effects by comparing the evolution of the outcome between periods in switching and still untreated states [54]. DID_M can be used in applications where the panel of groups is unbalanced, but requires that for each pair of consecutive dates, there are groups whose treatment does not change. This condition is satisfied in our study since the sample includes data on never treated states. We relied on the Stata command *did_multiplegt* for estimating DID_M for each policy and specified 300 bootstrap samples for estimating state clustered standard errors. There may be a bias-variance trade-off since DID_M sometimes has larger variance [54]. When estimating the effect of MML_{st} we required that $RML_{st} = 0$ because DID_M does not naturally partial out the effect of variables nested in the primary DID variable of interest as would be the case with DID_{FE} and DID_{ES} estimates of MML_{st} that control for RML_{st}.

DID_{ES} and DID_M estimate dynamic treatment effects in staggered implementation designs and allow us to evaluate whether the parallel trends assumption appears reasonable. We plotted lags and leads of the policy to assess dynamic treatment effects and the parallel trends assumption. We generated overall treatment effect parameters during the first three years of exposure to the policy by averaging estimates from the first 12 quarters since policy implementation. DID_{ES} point estimates and standard errors were generated with the post estimation Stata command *lincom*, while DID_M point estimates and standard errors were generated with *did_multiplegt*. Each quarter received equal weight. Focusing on the first three years can help mitigate complications from the changing composition of treated states, which is more extreme for distant relative periods and may compromise the interpretation of dynamic effects as well as standard errors.

We extend our analysis to examine the heterogeneity and robustness of main findings in several ways. In Section 4.4, we consider treatment effects across subpopulations defined by maternal age (15-20, 21-44), race and ethnicity (Hispanic and non-Hispanic (NH) White, NH Black), and expected payer (Medicaid, private insurance, other payer). We also consider the time in which medical marijuana dispensaries MMD_{st} and recreational marijuana dispensaries MMD_{st} became operational in a state, which may increase ease of access to marijuana and generate larger effects than MMLs or RMLs alone by allowing for commercial sales of marijuana. In Section 4.5, we consider the robustness of findings by modifying the selection criteria, investigating potential compositional effects, and using alternate methods for statistical inference that further account for a small number of clusters.

4 Results

4.1 Time trends

Figure 1 plots raw trends in the proportion of maternal hospitalizations involving marijuana use disorder for MML states, RML states, and states with no marijuana liberalization policy (No MLP). While trends initially evolved similarly in MML, RML, and no-MLP states, outcomes in RML states began to diverge around 2013, soon after RML implementation in Washington and Colorado. Appendix Figures 7, 8, 9, and 10 plot raw trends for other maternal and newborn outcomes.

4.2 Maternal substance use disorders

Table 2 reports DID_{FE}, DID_{ES} and DID_M estimates of the effect of marijuana liberalization policies on the proportion of maternal hospitalizations involving substance use disorders. DID_{ES} and DID_M capture treatment effects in the first three years since policy implementation. We evaluate the parallel trends assumption for

DID_M with multiperiod estimates of leads and lags in Figure 2.

We find no association between MMLs and the proportion of maternal hospitalizations involving marijuana use disorder regardless of the estimator. There is a pattern of significant DID_{FE} estimates and smaller, insignificant DID_{ES} and DID_M estimates for remaining outcomes. DID_{FE} estimates suggest reductions in maternal hospitalizations involving opioids (γ=-0.001), stimulants (γ=-0.001), tobacco (γ=-0.004), any drugs (γ=-0.003), and any substances (γ=-0.005). This initially statistically significant association disappears for all outcomes except tobacco use disorder when using DID_{ES}, often due to reductions in coefficient magnitudes. Coefficient magnitudes are even smaller and insignificant when using DID_M.

RMLs are associated with a 23% ($\delta/Mean$ = 0.003/0.013) increase in the proportion of maternal hospitalizations involving marijuana use disorder when using the preferred DID_M estimator. DID_{FE} and DID_{ES} estimates imply similar albeit larger growth. Notably, DID_M estimates show a statistically significant reduction in the proportion of maternal hospitalizations with tobacco use disorder of 7% ($\delta/Mean$ = 0.004/0.060) and the estimate is of a similar magnitude in the DID_{FE} and DID_{ES} columns. RML implementation does not appear to affect opioid, stimulant, or alcohol use disorders, nor drug complications at birth. While these changes resulted in a 10% ($\delta/Mean$ = 0.003/0.031) increase in hospitalizations involving any drug use disorder, there was a net zero effect on hospitalizations involving any substance use disorder. Documented declines in tobacco use disorder along with the null effect in substance use disorder, which comprises drug use disorder plus alcohol and tobacco use disorder, suggest substitution between marijuana and tobacco.

For the remainder of the paper, we present results using our preferred DID_M estimator. Appendix Tables 13, 14, 22 and 23 report DID_{FE} and DID_{ES} estimates for the curious reader.

4.3 Newborn health

Table 3 reports DID_M estimates of the effect of marijuana liberalization policies on newborn health. We evaluate the parallel trends assumption for DID_M with multiperiod estimates of leads and lags in Figure 3.

There is no statistically significant effect of MMLs on the proportion of newborn hospitalizations with prenatal exposure to noxious substances, neonatal drug withdrawal syndrome, fetal alcohol syndrome, slow growth, respiratory conditions, feeding problems, congenital abnormalities, low gestational age, low birth weight, or very low birth weight. Likewise, RMLs appear to have no effect on these outcomes.

DID_M estimates of MML and RML imply that large, population-level increases in adverse newborn health outcomes are unlikely. For example, Appendix Table 23 shows that the 95% confidence interval on low gestational age is (-0.001, 0.002) for MMLs and (-0.002, 0.001) for RMLs, which would represent at most a 2.7% increase in the proportion of births classified as low gestational age for MMLs and at most a 1.3% increase for RMLs, respectively. Prenatal exposure to noxious substances is a notable exception because the 95% confidence interval is (-0.003, 0.001) for MMLs and (-0.003, 0.004) for RMLs, ruling out effects larger than 6% for MMLs and 24% for RMLs using the upper bound of the confidence interval. Despite the seemingly "large" proportional growth implied by the upper bound, in absolute numbers these upper bounds suggest that the number of newborns with prenatal exposure to noxious substances each year would increase by 3,800 if MMLs were implemented nationwide and by 15,200 if RMLs were implemented nationwide. On the whole, results in Table 3 suggest modest to no relationship between marijuana liberalization policies and the newborn health outcomes analyzed in this paper.

4.4 Treatment effect heterogeneity

In the previous two sections we documented modest effects of marijuana liberalization policies on perinatal health in the general population, which need not generalize to all subpopulations. Here, we consider treatment effect heterogeneity across subpopulations defined by sociodemographic characteristics. We also consider the role of dispensaries, which may increase ease of access to marijuana and generate larger effects than MML or RMLs alone.

Table 4 reports DID_M estimates for key maternal outcomes by age, race and ethnicity, and health insurance. We find that MMLs exhibit no statistically detectable effect on the proportion of maternal hospitalizations involving marijuana use disorder for any of the subgroups. RMLs, however, impact certain groups differentially. When data are stratified by age, we find that marijuana use disorder increases similarly among youth mothers and adult mothers in percentage point terms ($\delta = 0.003$), although the percentage change is smaller for youth mothers (11% vs. 25%) due to youth's higher baseline mean value. When data are stratified by race/ethnicity, we find that marijuana use disorder increases for White (29%) and Hispanic (38%) mothers and there is no statistically significant effect for Black (21%) mothers although the coefficient is positive. Lastly, when data are stratified by health insurance, we find that marijuana use disorder hospitalizations increase 33% ($\delta/Mean = 0.008/0.024$) for Medicaid beneficiaries. RMLs are associated with corresponding reductions in tobacco use disorder among mothers who are adult, White, on Medicaid, and on private health insurance. Table 5 reports DID_M estimates for key newborn outcomes by sex, race and ethnicity, and health insurance using HCUP-SID. There are no changes in the proportion of births with exposure to noxious substances, neonatal drug withdrawal syndrome, or fetal alcohol syndrome for the subgroups analyzed.

Appendix Table 3 reports estimates for low gestational age and low birth weight, by race and ethnicity. Estimates are also statistically insignificant across groups.

Table 6 reports DID_M estimates of the effect of medical marijuana dispensaries (MMD) and recreational marijuana dispensaries (RMD) on the proportion of maternal hospitalizations involving substance use disorders. DID_M estimates of leads and lags are in Figure 4. MMDs appear to have no effect on maternal outcomes. In contrast, RMDs increase the proportion of hospitalizations involving maternal marijuana use disorder and drug use disorder. Notably there is no corresponding decline in tobacco use disorder hospitalizations when using the date in which dispensaries become operational. Table 7 reports DID_M estimates of MMDs and RMDs on newborn health. DID_M estimates of leads and lags are in Figure 5. There is no statistically significant effect of either policy on newborn outcomes, although some of the lags of prenatal exposure to noxious substances are positive and statistically significant following RMD implementation.

4.5 Robustness checks

We test the robustness of main findings in three ways. First, we modify selection criteria in Appendix Section A.4. One might be concerned that changes in maternal marijuana use disorder reflect changes in hospital-seeking behavior from reduced stigma or fear of legal consequences of marijuana usage, as instead of changes in marijuana use. In Appendix Table 15, we re-define the perinatal period in HCUP-SID to only include delivery encounters. Deliveries are less discretionary and differ from the main maternal sample capturing encounters during pregnancy, delivery, or the postpartum period.[8] We find that estimates are robust to using less discretionary

[8]About 91% of maternal hospitalizations indicate a delivery.

hospital encounters. In Appendix Table 16 we restrict the NVSS sample to the subset of 34 states available in HCUP-SID. We find that estimates for low gestational age, low birth weight, and very low birth weight are still statistically insignificant in this subsample. In Appendix Table 17 we re-define selection criteria for RML states based on characteristics of the legal market. We find increases in the proportion of maternal hospitalizations involving marijuana use disorder and corresponding decreases in those involving tobacco use disorder following RML implementation in states with more lenient regulation around marijuana potency limits, with larger medical marijuana markets, and with long running medical marijuana programs.

Second, we investigate potential compositional effects in Appendix Section A.5, which have implications for the interpretation of findings. Previous research finds that MMLs may affect the demographic composition of births through increases in the number of women who become pregnant by inducing risky sexual behaviors along with greater substance use [17]. We evaluate whether this might be the case in our context by estimating DID_M models with maternal sociodemographic characteristics, stillbirths, abortive outcomes (i.e. spontaneous -miscarriage- or induced), and number of births as outcome variables. Overall, we find limited evidence of compositional effects in our context (see Appendix Tables 19 and 20). We do find increases in the proportion of mothers with Medicaid and reductions in those with private health insurance in MML states but not in RML states. This is likely driven by ACA Medicaid expansions, which we control for in addition to the Medicaid indicator.

Third, we consider various methods of statistical inference for clustered data in Appendix Section A.6. Inference for DID_{FE} and DID_{ES} estimates in Table 2 is based on the standard cluster-robust variance matrix estimator (CRVE), which is robust to intracluster correlation and heteroskedasticity of unknown form [114, 117, 118, 119]. The CRVE can work well if the number of total and treated clusters is sufficiently large and if the clusters are reasonably homogeneous in size and covariance structure [117]. One might be concerned that the number of total ($S_{Total} = 34$) and switching treated clusters ($S_{RML} = 9$ and $S_{MML} = 13$) in HCUP-SID is not sufficiently large, in which case standard methods of statistical inference can greatly over-reject the null.[9] A simulation study found that a Wald test based on the CRVE with critical value of 1.96 had rejection rates of .063, .058, .080, and .115 for S_{Total} equal to 50, 20, 10 and 6, respectively [114], while another found similar rejection rates of .068, .081, .118, and .208 for S_{Total} equal to 30, 20, 10 and 5, respectively [120]. While these rates suggest that over-rejection might be mild in our context, these studies use aggregate data and equally-sized clusters, neither of which applies to individual-level HCUP-SID [120, 118]. One way to improve statistical inference is to use the wild cluster bootstrap [117].[10] Appendix Tables 22 and 23 report 95% confidence intervals generated with the CRVE, the wild cluster bootstrap, and *did_multiplegt*. We find that confidence intervals for MML_{st} are somewhat similar regardless of the method, while those for RML_{st} are larger when using the wild cluster bootstrap but generally do not change conclusions from our findings.

As for DID_M, inference is based on a cluster bootstrap algorithm that resamples clusters with replacement from the original sample, and uses bootstrap estimates of the treatment effect to form the bootstrap estimate standard error. Previous simulation studies have not considered the sensitivity of DID_M rejection rates to a small number of unequally-sized clusters. We investigate this question as follows. For each RML_{st} (MML_{st}) policy, we randomly draw 9 (13) states out of the 34 states and allocate one of the RML (MML) effective dates. We then generate the

[9]The total number of treated MML states in HCUP-SID is 22, of which 13 "turned on" during our sample period.

[10]We implemented the wild cluster bootstrap using the Stata command *boottest*.

RML_{str} (MML_{str}) indicator corresponding to random treatment assignment r, and estimate DID_M using the maternal marijuana use disorder outcome and specifying 100 bootstrap samples for generating state clustered standard errors and t-statistics. We repeat this process 1,000 times and calculate the percentage of times the t-statistic is rejected assuming a critical value of 1.96 (5% rejection rate). If DID_M standard errors are valid, the t-statistics should be rejected about 5% of the time. For MML_{st} we find an under-rejection rate of 3.1%, while for RML_{st} we find an over-rejection rate of 6.5% (see Appendix Table 21 and Appendix Figure 11). When assuming a critical value of 1.645 (10% rejection rate), we find an under-rejection rate of 8.6% for MML_{st} and an over-rejection rate of 12.1% for RML_{st}. As such, we feel reasonably comfortable relying on standard errors generated with *did_multiplegt*.

5 Conclusion

Understanding the comparative effectiveness of marijuana liberalization policies across subpopulations can enhance their design as well as that of public health interventions to help mitigate any adverse outcomes. Although there is a burgeoning literature on the effects of marijuana liberalization on adults and teenagers, evidence is limited or lacking for key vulnerable subpopulations including pregnant women and their newborns. This study provides the most comprehensive evidence to date of the effect of MMLs and RMLs on perinatal health. Using administrative data and a multiperiod DID estimator, we generated four key findings.

First, we found that RMLs increased the proportion of maternal hospitalizations involving marijuana use disorder by 23% (0.3 percentage points) in the first three years of implementation. While large relative to baseline rates, this change is small in absolute terms. To place it in context, there are close to 3.8 million births each year in the United States. Back of the envelope calculations suggest that RMLs would lead to approximately 11,400 pregnancies involving marijuana use disorder each year if RMLs were implemented nationwide. The effects of RML implementation were proportionally largest among mothers who were 21 to 44 years old, White, Hispanic and Medicaid beneficiaries. Moreover, RML effects were partially driven by states with recreational marijuana dispensaries, an important distinction from RMLs themselves because dispensaries signify commercial availability of legal marijuana. Our findings are consistent with previous descriptive RML studies using single-state data and pre-post analyses documenting increases in measures of marijuana use during pregnancy, including THC in the newborn's meconium, positive urine drug tests, and self-reports [46, 47, 48, 49], as well as with studies documenting greater marijuana use in the general adult population [39, 40, 41, 42, 43]. Our study is the first to provide representative and quasi-experimental evidence of the impact of RMLs on perinatal populations using comparison groups and a large database.

Second, we found that RMLs reduced the proportion of maternal hospitalizations involving tobacco use disorder by 7% (-0.4 percentage points) and there were no changes in hospitalizations involving opioid, stimulant, nor alcohol use disorder, leading to net null effects in overall substance use disorder hospitalizations. Our findings align with an MML study that found reductions in adult cigarette smoking using survey data [26], but contrast with an RML study that found mixed effects on cigarette sales per capita using tax receipt data [121]. When stratifying the sample by sociodemographic subpopulations, we found that tobacco use disorder hospitalizations declined most among subpopulations displaying greatest growth in marijuana use disorder hospitalizations. Our findings could be suggestive of substitution between marijuana and tobacco. In RMD analyses, however, we found no corresponding reductions in tobacco use disorder hospitalizations, despite documented increases in marijuana use disorder hospitalizations. A possible explanation is that greater *legal* recreational marijuana availability through RMDs is only one of several pathways for increases in marijuana use and that these other pathways are driving the substitution effect with tobacco. Other pathways may include changes in the availability, potency, and relative price of *illegal* marijuana through changes in "gray" or "black" marijuana markets. For instance, previous research suggests that the price of illegal marijuana declined in states with and without RMDs [16]. Another pathway may include differences in the potency of legal marijuana products sold at RMDs relative to those available in RML states without RMDs, which may affect the probability of marijuana use disorder conditional on marijuana use. Lastly, the preexisting infrastructure of the medical marijuana market and the stringency of legal market regulation may be other influencing factors. Indeed, in robustness checks we found increases in marijuana use disorder hospitalizations following RML implementation in states with more lenient regulation around marijuana potency limits, with larger medical marijuana markets, and with long running medical marijuana programs. These increases were accompanied by corresponding decreases in tobacco use disorder hospitalizations. The null effect of RMDs on tobacco use disorder hospitalizations may also reflect the smaller number of post-RMD observations in our data. Further evaluation is needed to better understand the mechanisms by which marijuana liberalization affects maternal tobacco use.

Third, we found that MML implementation did not affect maternal hospitalizations involving marijuana use disorder nor other substances in any statistically significant manner. The lack of significant effects was consistent across maternal age groups, race, ethnicity, and health insurance, as well as in states with medical marijuana dispensaries. Anecdotal and qualitative evidence suggests that healthcare providers would not knowingly prescribe marijuana to pregnant women. However, several studies have documented greater marijuana use in the general adult population after MML implementation [18, 26, 27, 23, 28, 29, 30, 31, 17]. Our findings do not necessarily conflict with those findings because we focused on the population of pregnant women and our outcome reflected marijuana use disorder instead of light-to-moderate marijuana use. As such, our findings cannot rule out increases in marijuana use among pregnant women. Our findings do suggest that any intensive or extensive margin changes in maternal marijuana use were either not substantial enough to affect the presentation of marijuana use disorder or were effectively mitigated (i.e. SUD treatment, prenatal care). In two-way fixed effects models, we did find that MMLs were associated with reductions in the proportion of maternal opioid and tobacco use disorder and those findings were consistent with previous studies of MMLs also using two-way fixed effects estimators [33, 34, 35, 36, 37, 38, 26]. However, the magnitude and statistical significance of our MML coefficients disappear with the multiperiod DID estimator. Nevertheless, our findings do not rule out potential changes in light to moderate opioid, tobacco, or other substance use among pregnant women and need not generalize to the general adult population.

Fourth, we found null effects of MMLs and RMLs on newborn health. Epidemiological studies have shown that prenatal exposure to marijuana is associated with lower gestational age, birth weight and other adverse outcomes, although several studies have found that associations become insignificant when adjusting for tobacco use and other confounders [86, 87, 88, 58]. Our null findings do not refute nor support an argument that prenatal exposure to marijuana has negative effects on newborn health outcomes, but rather that state marijuana liberalization policies are not associated with net changes at the population-level that are statistically detectable or economically meaningful. Our MML findings coincide with a study that finds no significant effect of MML implementation on low gestational age and low birth weight

[50]. The null RML findings are somewhat consistent with single-state descriptive studies that found modest or no changes in newborn health [47, 48, 52]. A possible explanation for our null findings is substitution between marijuana and tobacco with offsetting toxic effects. While reductions in tobacco use during pregnancy due to RMLs may alleviate poor newborn outcomes, the relative increase in marijuana use may offset this. Another possible explanation is that increases in maternal marijuana use disorder are too small to induce population-level changes in newborn health.

From a policy perspective, this study highlights the complexity of efforts to liberalize marijuana for medical and recreational purposes. Policymakers must weigh the therapeutic benefits of medical marijuana, the utility and sociability gained from recreational marijuana, potential reductions in criminal justice disparities and illicit drug markets, as well as revenue gains from marijuana taxation, versus the potential public health risks of marijuana liberalization. If costs of marijuana liberalization outweigh benefits in select subpopulations such as pregnant women and newborns, then public health approaches that minimize marijuana access in these subpopulations could prevent or mitigate adverse effects without hindering access to marijuana among subpopulations for whom benefits outweigh costs. Alcohol legalization, where there are well-substantiated adverse effects of in utero exposure, as well as social normalization and broad access, may offer important lessons and policy directions. The development of policies requiring warning labels on alcoholic beverages or mandatory warning signs in locations where alcoholic beverages are sold are a few examples. Similarly, when controlled substances are approved for medical purposes, the Food and Drug Administration assigns "Pregnancy Categories" to indicate the potential of a drug to cause birth defects if used during pregnancy. Most states adopting marijuana liberalization policies are currently silent regarding marijuana use in pregnancy.

As states continue to liberalize marijuana, more research and a clear public health message is needed to educate expectant mothers and healthcare providers on potential risks of marijuana use, and to guide policymakers on the design of these policies. Another important policy consideration is financing and expanding SUD prevention and treatment services for mothers and newborns along with the implementation of marijuana liberalization policies [122]. Our results showed that RMLs mainly affected Medicaid-covered women. Medicaid is also the predominant payer for prenatal care, hospital births, and newborn health services, and disproportionately so for newborns exposed to substances [123]. CMS recently adopted initiatives to improve access and quality of care for mothers with opioid use disorder and their newborns and for alternative payment models that seek to increase the quality of care for children under 21 years of age through early identification and treatment of behavioral and physical needs [124]. These innovative models could broaden their scope to include marijuana. Although there are currently no medications available to treat marijuana use disorder as is the case for opioid use disorder, low intensity services such as Screening, Brief Intervention, and Referral to Treatment are known to reduce alcohol use and have been recommended by the Substance Abuse and Mental Health Services Administration and CMS for non-alcohol substance use. Such interventions are focused on reducing substance use to less harmful levels and may be helpful on the extensive margin for pregnant women where abstinence-based messaging is optimal.

Our study has several limitations. First, maternal outcomes measured in this paper reflect intensive substance use and thus, are unlikely representative of pregnant women who use substances less frequently. Nevertheless, our measures are more relevant given that marijuana use disorder is more correlated with adverse perinatal health outcomes than light marijuana use. Second, we consider effects on newborn health at or closely following birth and do not observe longer term events, such as behavioral or developmental outcomes. Third, since RMLs have only been adopted by a few states in recent years, our RML estimates may not generalize in the long term or for future RMLs. This is especially the case for RMDs, as much of its variation comes from a few states that were early adopters. Because these states also have looser regulations around dispensary operations or potency, they may not extend to later adopters or states with stricter regulations. Still, our HCUP-SID data capture 9 RML states. Fourth, increases in maternal marijuana use disorder could reflect increases in hospital-seeking behavior, healthcare provider awareness, or in reporting of marijuana use as instead of increases in underlying marijuana use. While we cannot rule out this possibility, our results are robust in a subsample of non-discretionary birth events and are correlated with greater marijuana availability. Additionally, the prevalence of marijuana use disorder among pregnant women in our HCUP-SID sample (1.56%) versus in the 2015-2018 NSDUH (1.3%) is comparable. Fifth, HCUP-SID is unbalanced. Sixth, the race/ethnicity variable in HCUP-SID is not properly collected for some states, especially during earlier sample years. As RML adoption occurred later in the study period, we believe this has little impact on our findings. Despite these limitations, we have conducted an exhaustive set of robustness checks and find little divergence in the estimates.

Taken together, this study presents novel evidence on the effects of marijuana liberalization policies on maternal substance use disorder and newborn health, and suggests that the impact of MMLs appears to be insignificant while that of RMLs appears to be modest in absolute terms. We caution that ACOG discourages the use of marijuana and other substances during pregnancy and that our results do not endorse marijuana liberalization as a tool in combatting the opioid crisis. Future research must better assess the tradeoffs of prenatal marijuana use on perinatal health outcomes in the long-run and the impact of RMLs in the short- and long-run as states continue to broaden access to recreational marijuana.

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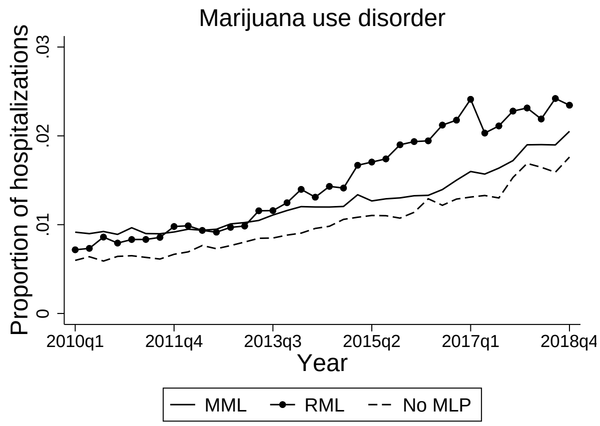

Figure 1: Trends in maternal marijuana use disorder

Notes: Maternal hospitalizations were drawn from the 2007-2018 HCUP-SID. Mutually exclusive marijuana liberalization groups were assigned based on policy implementation as of December 31, 2017. MML=Medical marijuana laws. RML=Recreational marijuana laws. No MLP=No marijuana liberalization policy.

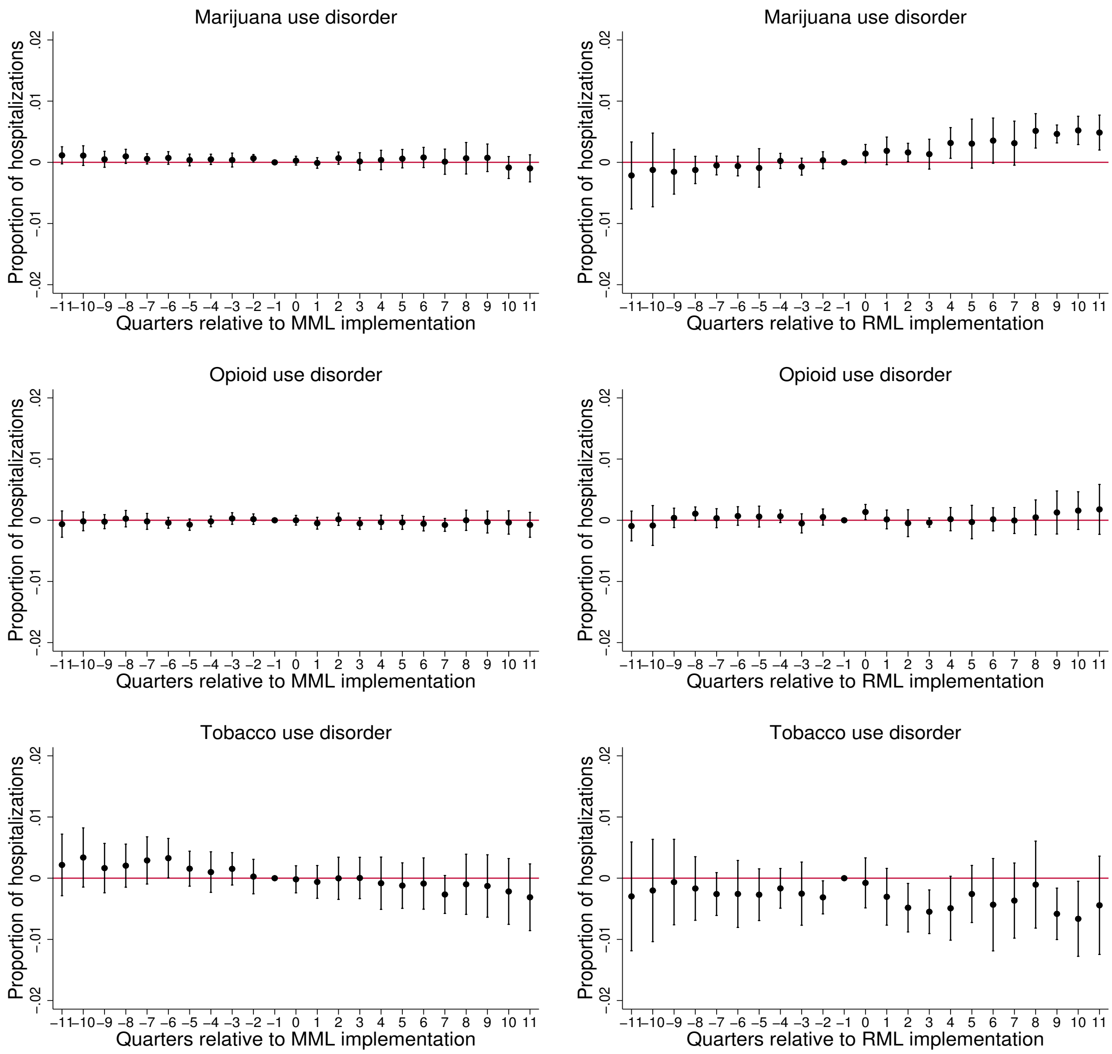

Figure 2: Marijuana liberalization policies and maternal substance use disorders

Notes: Maternal hospitalizations were drawn from the 2007-2018 HCUP-SID. DID_M coefficients and 95% confidence intervals were based on the Stata command *did_multiplegt* [54]. MML=Medical marijuana laws. RML=Recreational marijuana laws.

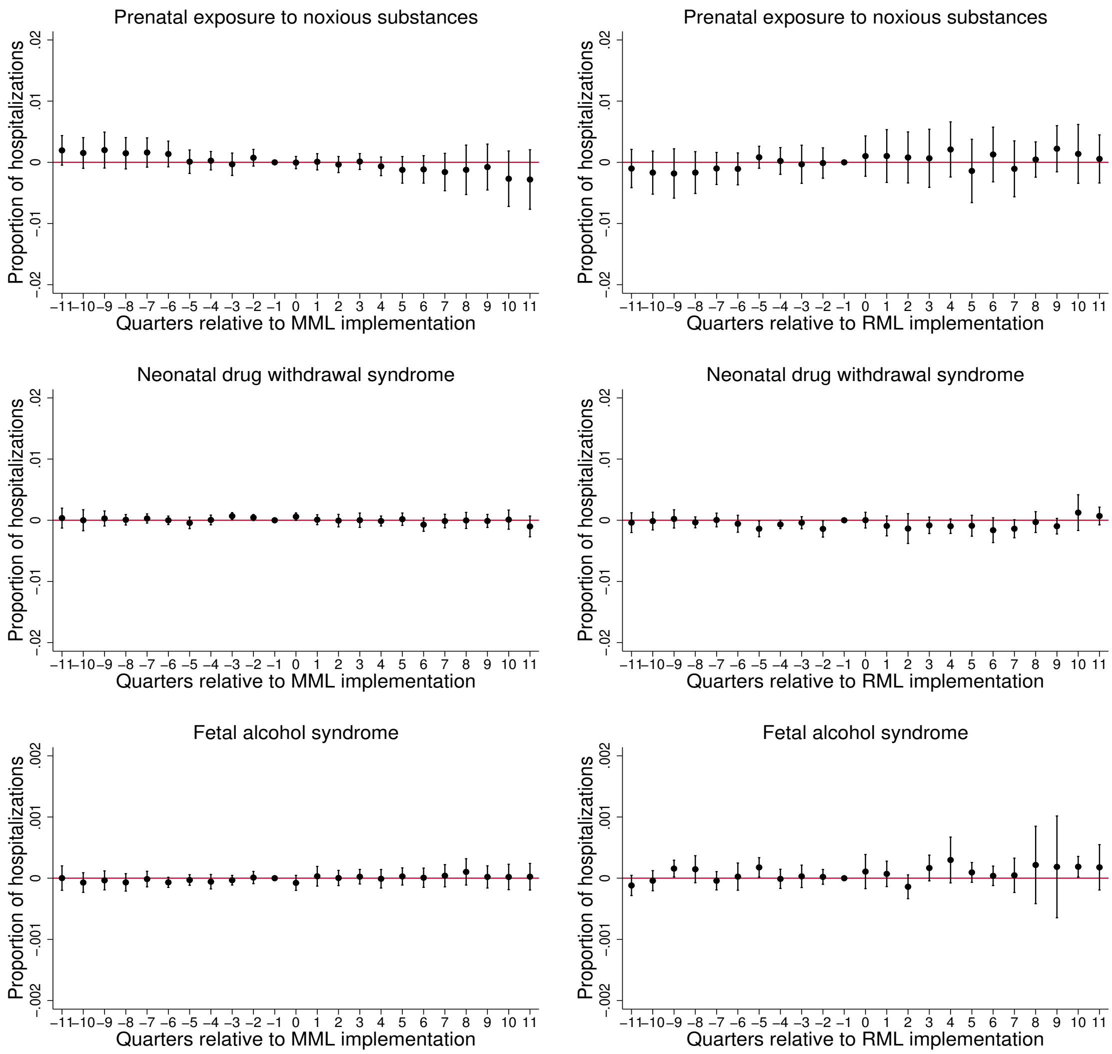

Figure 3: Marijuana liberalization policies and newborn health

Notes: Newborn hospitalizations were drawn from the 2007-2018 HCUP-SID. DID_M coefficients and 95% confidence intervals were based on the Stata command *did_multiplegt* [54]. MML=Medical marijuana laws. RML=Recreational marijuana laws.

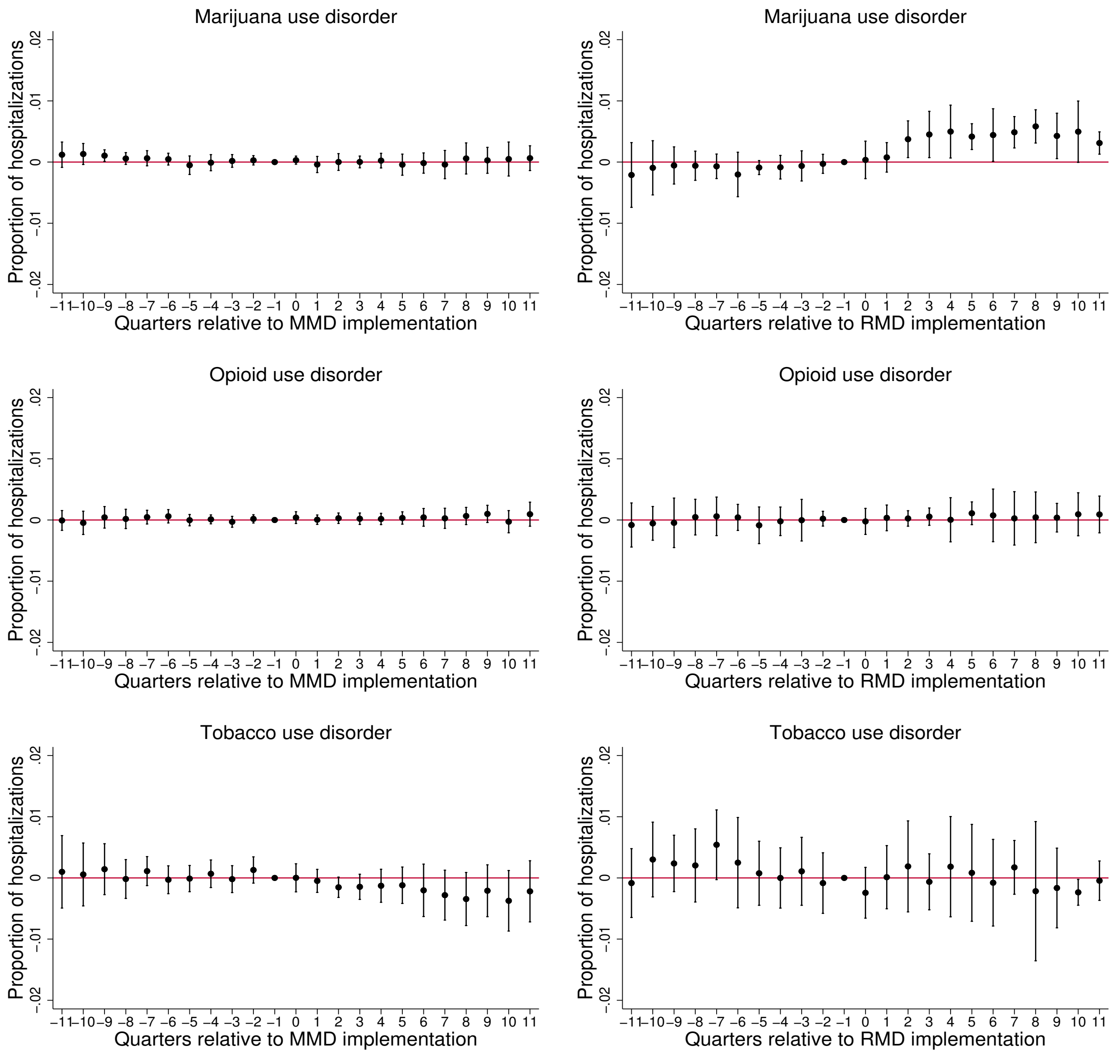

Figure 4: Marijuana liberalization policies and maternal substance use disorders, by dispensary status

Notes: Maternal hospitalizations were drawn from the 2007-2018 HCUP-SID. DID_M coefficients and 95% confidence intervals were based on the Stata command *did_multiplegt* [54]. MMD=Operational medical marijuana dispensary. RMD=Operational recreational marijuana dispensary.

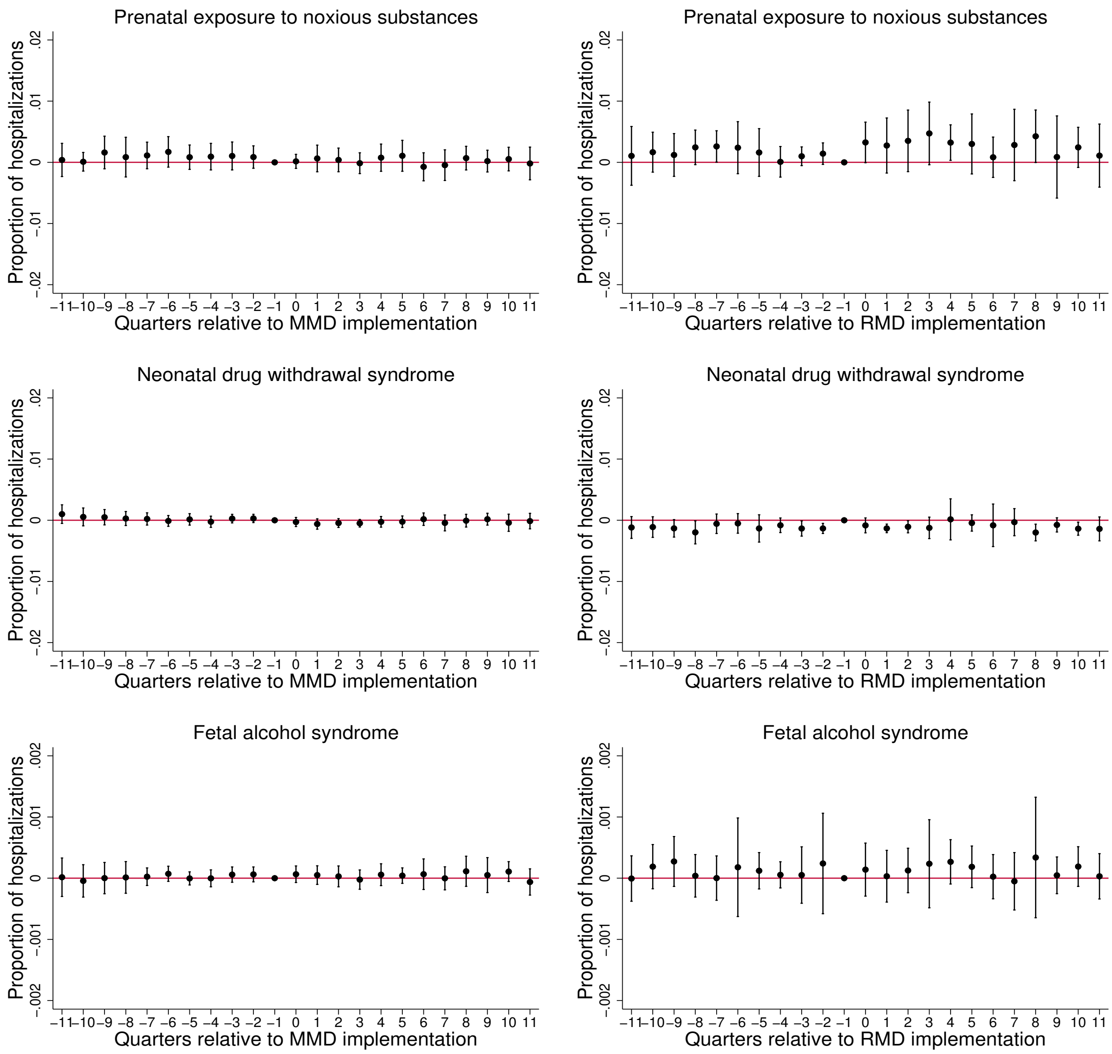

Figure 5: Marijuana liberalization policies and newborn health, by dispensary status

Notes: Newborn hospitalizations were drawn from the 2007-2018 HCUP-SID. DID_M coefficients and 95% confidence intervals were based on the Stata command *did_multiplegt* [54]. MMD=Operational medical marijuana dispensary. RMD=Operational recreational marijuana dispensary.

Table 1: Diagnostic tests

	(1)	(2)	(3)	(4)	(5)
	Full Sample				$MML \neq 1 \ \forall \ t$
Panel A: HCUP Sample of maternal hospitalizations					
MML	33%		36%	38.8%	24.6%
	[-0.30]		[-0.28]	[-0.32]	[-0.17]
MMD				19.1%	
				[-0.09]	
RML		0.84%	1.7%	27.7%	
		[-0.00004]	[-0.0003]	[-0.09]	
RMD				0%	
				[0.0]	
Panel B: HCUP Sample of newborn hospitalizations					
MML	34%		37.4%	39.2%	25.6%
	[-0.29]		[-0.265]	[-0.31]	[-0.16]
MMD				18.3%	
				[-0.08]	
RML		0%	0%	28.6%	
		[0.00]	[0.00]	[-0.07]	
RMD				0%	
				[0.00]	
Panel C: NVSS Sample of births					
MML	29%		30%	32%	18%
	[-0.37]		[-0.36]	[-0.40]	[-0.11]
MMD				14.8%	
				[-0.09]	
RML		0%	0%	26%	
		[0.00]	[-0.00]	[-0.05]	
RMD				0%	
				[0.00]	

Notes: This table presents the percentage of all ATT estimates that have a negative weight and the sum of negative weights attached to two-way fixed effects DID estimators for each of our three analytical samples. The sum of negative weights is in brackets. Diagnostic tests were performed with the *twowayfeweights* Stata command described in [54]. Regressions account for state fixed-effects, year-quarter fixed-effects, and control variables. In Columns (1) and (2), weights assumed each policy was estimated without controlling for the other policies. In Columns (3) and (4), weights assumed each policy was estimated while controlling for the other policies reported in the same column. Column (5) reproduced Column (1) but dropped always treated MML states ($MML = 1 \ \forall \ t$) from the sample. The majority of always treated MML states were also RML states. We observed a pre-period for all RML states, and thus, did not have always treated RML states. MML=Medical marijuana laws. MMD=Operational medical marijuana dispensary. RML=Recreational marijuana laws. RMD=Operational recreational marijuana dispensary.

Table 2: Marijuana liberalization policies and maternal substance use disorders

	(1)	(2)	(3)	(4)	(5)	(6)
	DID_{FE}	DID_{ES}	DID_M	DID_{FE}	DID_{ES}	DID_M
	Marijuana use disorder			Opioid use disorder		
MML	-0.001	-0.000	0.000	-0.001*	-0.001	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
RML	0.004**	0.004***	0.003***	0.001	-0.000	0.000
	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Mean	0.013	0.013	0.013	0.013	0.013	0.013
	Stimulant use disorder			Drug complications		
MML	-0.001**	-0.000	-0.000	-0.002	-0.001	-0.000
	(0.001)	(0.000)	(0.000)	(0.002)	(0.002)	(0.001)
RML	0.002	0.001	0.000	0.004	0.004	0.005
	(0.001)	(0.001)	(0.001)	(0.003)	(0.003)	(0.004)
Mean	0.007	0.007	0.007	0.017	0.017	0.017
	Alcohol use disorder			Tobacco use disorder		
MML	-0.000	-0.000	-0.000	-0.004**	-0.003*	-0.001
	(0.000)	(0.000)	(0.000)	(0.002)	(0.002)	(0.002)
RML	0.000	-0.000	-0.000	-0.004	-0.005*	-0.004**
	(0.000)	(0.000)	(0.000)	(0.004)	(0.003)	(0.002)
Mean	0.003	0.003	0.003	0.060	0.060	0.060
	Drug use disorder			Substance use disorder		
MML	-0.003**	-0.001	-0.000	-0.005**	-0.003	-0.001
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
RML	0.004	0.004*	0.003***	-0.001	-0.001	-0.001
	(0.003)	(0.002)	(0.001)	(0.005)	(0.003)	(0.002)
Mean	0.031	0.031	0.031	0.076	0.076	0.076

Notes: Effect of marijuana liberalization policies on the proportion of maternal hospitalizations involving a substance use disorder. We drew a 60% random sample from the 2007-2018 HCUP-SID for a total of N=15,951,326 observations at the individual discharge level. DID_{FE} coefficients were based on two-way fixed effects regressions described in Equation 1. DID_{ES} coefficients were based on event study regressions in the first 3 years post policy described in Equation 2. MML and RML estimates in Equation 2 were generated using different regressions, one for each policy, and dropped always treated states for the policy of interest. DID_M coefficients were based on the multiperiod estimator in the first 3 years post policy. The mean captured outcomes the year prior to RML implementation for RML states. MML=Medical marijuana laws. RML=Recreational marijuana laws. State clustered standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 3: Marijuana liberalization policies and newborn health

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M
	Exposure to noxious substances	Neonatal drug withdra.	Fetal alcohol syndrome	Slow growth	Respira. condition	Feeding problem	Congenital anomalies	Low gestational age	Low birth weight	Very low birth weight
MML	-0.001	-0.000	0.0000	0.001	-0.001	-0.002	0.004	0.001	0.001	0.0002
	(0.001)	(0.000)	(0.0001)	(0.001)	(0.001)	(0.002)	(0.003)	(0.001)	(0.001)	(0.0002)
RML	0.001	-0.001	0.0001	0.001	-0.001	-0.003	0.001	-0.001	0.001	0.0001
	(0.002)	(0.001)	(0.0001)	(0.001)	(0.001)	(0.003)	(0.004)	(0.001)	(0.001)	(0.0003)
Mean	0.017	0.009	0.0003	0.033	0.105	0.058	0.137	0.073	0.057	0.009

Notes: Effect of marijuana liberalization policies on newborn health outcomes. The proportion of newborn hospitalizations involving an adverse health outcome in Columns (1) to (7) were based on a 60% random sample from the 2007-2018 HCUP-SID for a total of N=16,263,309 observations at the individual discharge level. The proportion of births involving an adverse health outcome in Columns (8) to (10) were based on 2007-2019 NVSS Natality files for a total of N=2,448 at the state-year-quarter of conception level for conception years 2007-2018. DID_M coefficients were based on the multiperiod estimator in the first 3 years post policy. The mean captured outcomes the year prior to RML implementation for RML states. MML=Medical marijuana laws. RML=Recreational marijuana laws. State clustered standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 4: Marijuana liberalization policies and maternal substance use disorders, by subpopulations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M
	Age		Race/ Ethnicity			Health Insurance		
	15 - 20	21 - 44	White	Black	Hispanic	Medicaid	Private	Other
Panel A: Marijuana use disorder								
MML	0.001	0.000	0.001	0.000	0.000	0.000	0.000	-0.001
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.000)	(0.002)
RML	0.003*	0.003***	0.004***	0.005	0.003*	0.008***	0.001	-0.005
	(0.002)	(0.001)	(0.001)	(0.004)	(0.002)	(0.001)	(0.001)	(0.004)
Mean	0.027	0.012	0.014	0.024	0.008	0.024	0.005	0.023
Panel B: Tobacco use disorder								
MML	-0.000	-0.002	-0.000	-0.002	-0.001	-0.002	-0.001	-0.003
	(0.004)	(0.001)	(0.002)	(0.002)	(0.003)	(0.002)	(0.001)	(0.004)
RML	-0.004	-0.004***	-0.007***	-0.006	-0.003	-0.008**	-0.003*	-0.004
	(0.005)	(0.002)	(0.002)	(0.004)	(0.004)	(0.004)	(0.002)	(0.007)
Mean	0.077	0.058	0.076	0.054	0.023	0.107	0.024	0.086
Panel C: Opioid use disorder								
MML	-0.000	-0.000	0.000	-0.001	0.000	-0.000	-0.000	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.002)
RML	-0.000	0.001	0.000	-0.001	0.001	0.002	-0.000	0.007
	(0.001)	(0.001)	(0.001)	(0.004)	(0.002)	(0.002)	(0.000)	(0.005)
Mean	0.007	0.013	0.017	0.006	0.004	0.024	0.004	0.024

Notes: Effect of marijuana liberalization policies on the proportion of maternal hospitalizations involving substance use disorders, by maternal age, race/ethnicity, and health insurance. We drew a 60% random sample from the 2007-2018 HCUP-SID for a total of N=15,951,326 observations at the individual discharge level, of which females ages 15-20 represented 11% and those ages 21-44 represented 89%; NH White, NH Black, NH Other race, Hispanic, and missing represented 51%, 16%, 10%, 13% and 10%, respectively; and Medicaid, private insurance and other payer represented 44%, 49%, and 6%, respectively. DID_M coefficients were based on the multiperiod estimator in the first 3 years post policy. The mean captured outcomes the year prior to RML implementation for RML states. MML=Medical marijuana laws. RML=Recreational marijuana laws. State clustered standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 5: Marijuana liberalization policies and newborn health, by subpopulations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M
	Sex		Race/ Ethnicity			Health Insurance		
	Female	Male	White	Black	Hispanic	Medicaid	Private	Other
Panel A: Prenatal exposure to noxious substances								
MML	-0.001	-0.001	-0.001	-0.001	-0.000	-0.002	-0.000	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.000)	(0.002)
RML	-0.000	0.002	0.001	0.001	0.003	0.002	-0.000	0.003
	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)	(0.001)	(0.003)
Mean	0.017	0.017	0.020	0.022	0.010	0.029	0.007	0.022
Panel B: Neonatal drug withdrawal syndrome								
MML	-0.000	0.000	-0.000	0.000	0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
RML	-0.001	-0.000	-0.001	0.001	-0.000	-0.001	-0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Mean	0.009	0.009	0.013	0.004	0.003	0.018	0.003	0.008
Panel C: Fetal alcohol syndrome								
MML	-0.0000	0.0001	-0.0001	0.0001	-0.0000	-0.0000	0.0000	0.0002
	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0000)	(0.0001)
RML	0.0002	0.0001	0.0000	0.0001	0.0003	0.0002	0.0001	0.0004
	(0.0002)	(0.0001)	(0.0001)	(0.0004)	(0.0003)	(0.0002)	(0.0001)	(0.0005)
Mean	0.0003	0.0003	0.0004	0.0003	0.0002	0.0006	0.0001	0.0003

Notes: Effect of marijuana liberalization policies on newborn health outcomes, by newborn sex, race/ethnicity, and health insurance. We drew a 60% random sample from the 2007-2018 HCUP-SID for a total of N=16,263,309 observations at the individual discharge level, of which females and males represented 48% and 52%, respectively; NH White, NH Black, NH Other race, Hispanic, and missing represented 51%, 16%, 10%, 13% and 10%, respectively; and Medicaid, private insurance and other payer represented 47%, 46%, and 7%, respectively. DID_M coefficients were based on the multiperiod estimator in the first 3 years post policy. The mean captured outcomes the year prior to RML implementation for RML states. MML=Medical marijuana laws. RML=Recreational marijuana laws. State clustered standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 6: Marijuana liberalization policies and maternal substance use disorders, by dispensary status

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M
	Marijuana use disorder	Opioid use disorder	Stimulant use disorder	Alcohol use disorder	Tobacco use disorder	Drug Complications	Drug use disorder	Substance use disorder
MMD	0.000	0.000	0.000	0.000	-0.002	-0.001	0.000	-0.001
	(0.001)	(0.000)	(0.000)	(0.000)	(0.002)	(0.001)	(0.001)	(0.001)
RMD	0.004***	0.001	0.000	0.000	-0.000	0.007*	0.002	0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.004)	(0.002)	(0.002)
Mean	0.013	0.013	0.007	0.003	0.060	0.017	0.031	0.076

Notes: Effect of marijuana liberalization policies on the proportion of maternal hospitalizations involving substance use disorder, by dispensary status. We drew a 60% random sample from the 2007-2018 HCUP-SID for a total of N=15,951,326 observations at the individual discharge level. Dispensary dummies indicated the time a medical marijuana dispensary (MMD) or a recreational marijuana dispensary (RMD) -i.e. commercial sales- became operational. DID_M coefficients were based on the multiperiod estimator in the first 3 years post policy. The mean captured outcomes the year prior to RML implementation for RML states. State clustered standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 7: Marijuana liberalization policies and newborn health, by dispensary status

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M
	Exposure to noxious substances	Neonatal drug withdra.	Fetal alcohol syndrome	Slow growth	Respira. condition	Feeding problem	Congenital anomalies	Low gestational age	Low birth weight	Very low birth weight
MMD	0.000	-0.000	0.0000	0.000	0.001	0.000	-0.001	0.000	0.001	0.0002
	(0.001)	(0.000)	(0.0001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.0002)
RMD	0.003	-0.001	0.0001	-0.000	0.004	0.003	-0.003	0.001	0.000	0.0003
	(0.002)	(0.001)	(0.0001)	(0.002)	(0.002)	(0.003)	(0.006)	(0.001)	(0.001)	(0.0003)
Mean	0.017	0.009	0.0003	0.033	0.105	0.058	0.137	0.073	0.057	0.009

Notes: Effect of marijuana liberalization policies on newborn health outcomes. The proportion of newborn hospitalizations involving an adverse health outcome in Columns (1) to (7) were based on a 60% random sample from the 2007-2018 HCUP-SID for a total of N=16,263,309 observations at the individual discharge level. The proportion of births involving an adverse health outcome in Columns (8) to (10) were based on 2007-2019 NVSS Natality files for a total of N=2,448 at the state-year-quarter of conception level for conception years 2007-2018. Dispensary dummies indicated the time a medical marijuana dispensary (MMD) or a recreational marijuana dispensary (RMD) -i.e. commercial sales- became operational. DID_M coefficients were based on the multiperiod estimator in the first 3 years post policy. The mean captured outcomes the year prior to RML implementation for RML states. State clustered standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

A APPENDIX

Appendix Section A.1 provides additional information about our datasets, selection criteria, and measures to assist with the reproducibility of findings. Section A.2 graphs time trends as in Figure 1. Section A.3 includes estimates from two-way fixed-effects regressions. Section A.4 tests the robustness of findings to changes in selection criteria. Section A.5 evaluates whether our findings are driven by compositional effects. Lastly, Section A.6 considers alternative methods for statistical inference with a small number of clusters.

A.1 Data and Measures

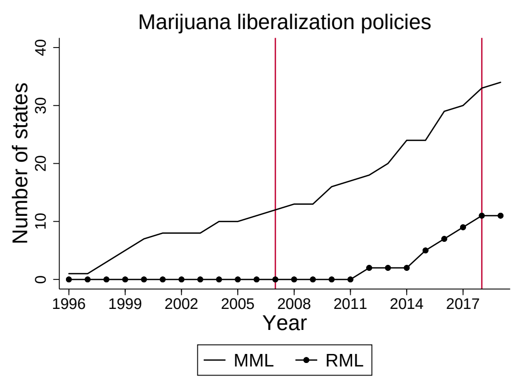

Figure 6: Time trends in marijuana liberalization policies as of 2019

Notes: Figure was constructed using effective dates in Table 8. The red lines capture variation during our sample period of 2007 to 2018. MML=Medical marijuana laws. RML=Recreational marijuana laws.

Table 8: Effective dates of marijuana liberalization policies

State	MML	MMD	RML	RMD
Alaska*	3/4/1999	10/29/2016	2/24/2015	10/29/2016
Arizona	11/29/2010	12/6/2012		
Arkansas	11/9/2016	5/11/2019		
California	11/6/1996	11/1/1996	11/9/2016	1/1/2018
Colorado	12/28/2000	7/1/2005	12/10/2012	1/1/2014
Connecticut	10/1/2012	9/22/2014		
Delaware	7/1/2011	6/26/2015		
District of Columbia	7/27/2010	7/29/2013	2/26/2015	
Florida	1/3/2017	12/19/18		
Hawaii	6/14/2000	8/8/2017		
Illinois	1/1/2014	11/9/2015	1/1/2020	
Louisiana	5/19/2016	8/6/2019		
Maine	12/23/1999	4/1/2011	1/30/2017	10/9/2020
Maryland*	6/1/2014	12/1/2017		
Massachusetts	1/1/2013	6/24/2015	12/15/2016	11/20/2018
Michigan	12/4/2008	12/1/2009	12/6/2018	12/1/2019
Minnesota	5/30/2014	7/1/2015		
Missouri	12/6/2018			
Montana	11/2/2004	4/1/2009		
Nevada	10/1/2001	7/31/2015	1/1/2017	7/1/2017
New Hampshire	7/23/2013	4/30/2016		
New Jersey	6/1/2010	12/6/2012		
New Mexico	7/1/2007	6/1/2009		
New York	7/5/2014	1/7/2016		
North Dakota	12/8/2016	3/1/2019		
Ohio	9/8/2016	1/16/2019		
Oklahoma	7/26/2018	10/26/2018		
Oregon	12/3/1998	7/1/2009	7/1/2015	10/1/2015
Pennsylvania	5/17/2016	1/17/2018		
Rhode Island	1/3/2006	4/19/2013		
Utah	12/3/2018			
Vermont	7/1/2004	6/1/2013	7/1/2018	
Washington	12/3/1998	10/1/2009	12/6/2012	7/8/2014
West Virginia	7/1/2019			

Notes: We obtained effective dates of MMLs, MMDs, RMLs, and RMDs directly from researchers [37]. We also examined ProCon[1], previous studies [38, 27, 125, 126], and the RAND dataset. Our MMD and RMD indicators capture the time when dispensaries became operational and may differ from some studies coding MMDs as starting when dispensaries were both operational and legally protected. In the few instances when a date was not consistent, we used consensus or searched news articles. Citations for each date are available upon request.
*Prior to 10/29/2016, AK did not have a system for distributing medical marijuana to patients. The passage of ballot measure 2 in 2014 created recreational dispensaries, but did not create separate medical dispensaries. Medical marijuana patients in AK obtain marijuana through recreational dispensaries.
*Although MD passed a law on 5/22/2003 (effective 10/2/2003) that provided legal protections to patients for possession/use of marijuana, no supply source was identified. Therefore, most studies do not recognize this first law, and do not code MD as having a medical marijuana law until the June 2014 law passed [38].
MML=Medical marijuana laws. MMD=Operational medical marijuana dispensary. RML=Recreational marijuana laws. RMD=Operational recreational marijuana dispensary.

Table 9: HCUP-SID availability and policy variation

State	Years	MML	MMD	RML	RMD
Alaska	2015-2018	1.00	0.54	0.93	0.54
Arizona	2007-2018	0.63	0.47	0.00	0.00
Arkansas	2007-2018	0.16	0.00	0.00	0.00
Colorado	2007-2018	1.00	1.00	0.49	0.40
Delaware	2007-2018	0.60	0.28	0.00	0.00
District of Columbia	2013-2018	1.00	0.92	0.62	0.00
Florida	2007-2018	0.17	0.00	0.00	0.00
Georgia	2010-2018	0.00	0.00	0.00	0.00
Iowa	2007-2018	0.00	0.00	0.00	0.00
Kansas	2011-2018	0.00	0.00	0.00	0.00
Kentucky	2007-2018	0.00	0.00	0.00	0.00
Louisiana	2007-2018	0.20	0.00	0.00	0.00
Maine	2010-2018	1.00	0.86	0.22	0.00
Maryland	2007-2018	0.36	0.12	0.00	0.00
Massachusetts	2007-2018	0.49	0.28	0.16	0.00
Michigan	2007-2018	0.82	0.73	0.00	0.00
Minnesota	2010-2018	0.51	0.39	0.00	0.00
Mississippi	2010-2018	0.00	0.00	0.00	0.00
Nebraska	2010-2018	0.00	0.00	0.00	0.00
Nevada	2007-2018	1.00	0.29	0.16	0.12
New Jersey	2007-2018	0.68	0.47	0.00	0.00
New Mexico	2007-2018	0.95	0.76	0.00	0.00
New York	2007-2017	0.30	0.17	0.00	0.00
North Carolina	2007-2018	0.00	0.00	0.00	0.00
Oregon	2010-2018	1.00	1.00	0.38	0.35
Pennsylvania	2007-2018	0.20	0.08	0.00	0.00
Rhode Island	2007-2018	1.00	0.45	0.00	0.00
South Carolina	2007-2018	0.00	0.00	0.00	0.00
South Dakota	2010-2018	0.00	0.00	0.00	0.00
Utah	2007-2017	0.00	0.00	0.00	0.00
Vermont	2007-2018	1.00	0.44	0.04	0.00
Washington	2007-2018	1.00	0.76	0.49	0.37
West Virginia	2010-2018	0.00	0.00	0.00	0.00
Wisconsin	2012-2018	0.00	0.00	0.00	0.00

Notes: HCUP-SID data years and policy variation in those years, defined as the proportion of observations for which the policy equals one. 2012 HCUP-SID Mississippi data were missing. Pennsylvania, Delaware, and Louisiana were obtained directly through each state's Department of Health. All other states were obtained through HCUP. MML=Medical marijuana laws. MMD=Operational medical marijuana dispensary. RML=Recreational marijuana laws. RMD=Operational recreational marijuana dispensary.

Table 10: Selection criteria for identifying newborn and maternal hospitalizations

	ICD-9	ICD-10
Panel A: Newborn hospitalizations		
Diagnostic codes	V30.X-V39.X Liveborn Infants According To Type Of Birth	Z38.X Liveborn infants according to place of birth and type of delivery
Demographics	Age < 1 Sex = male, female	
Panel B: Maternal hospitalizations		
Diagnostic codes	V22.X Normal pregnancy V23.X Supervision of high-risk pregnancy V24.X Postpartum care and examination V27.X Outcome of delivery V28.X Encounter for antenatal screening of mother 630.X-679.X Complications of Pregnancy, Childbirth, And The Puerperium 760.X-779.X Certain Conditions Originating in the perinatal period	Z32.X Encounter for pregnancy test and childbirth and childcare instruction Z33.X Pregnant state Z34.X Encounter for supervision of normal pregnancy Z36.X Encounter for antenatal screening of mother Z37.X Outcome of delivery Z39.X Encounter for maternal postpartum care and examination Z3A.X Weeks of gestation O.X Pregnancy, childbirth and the puerperium P.X Certain conditions originating in the perinatal period
Procedure codes	72.X-75.X Obstetrical Procedures	1.X Obstetrics
Demographics	Age = 15 to 44 Sex = female	

Notes: Demographic variables and International Classification of Diseases (ICD) codes used for identifying the analytical sample. In addition to these codes, we relied on HCUP generated variables to identify mothers and newborns. The sample of maternal hospitalizations captures encounters during pregnancy, delivery, or the puerperium. About 91% of maternal hospitalizations indicate a delivery and about 0.18% have a clear indicator for postpartum care. About 5% include this clear indicator or indicate complications predominantly related to the puerperium. Among this 5%, 74% also share a delivery code, suggesting some of the complications predominantly related to the puerperium are taking place in the same encounter as the delivery.

Table 11: International Classification of Diseases codes for maternal outcomes

Outcome	ICD-9	ICD-10
Marijuana use disorder	304.3 Cannabis dependence 305.2 Nondependent cannabis abuse	F12 Cannabis related disorders
Opioid use disorder	304.0 Opioid type dependence 304.7 Combinations of opioid type drug with any other drug dependence 305.5 Nondependent opioid abuse	F11 Opioid related disorders
Stimulant use disorder	304.4 Amphetamine and other psychostimulant dependence 305.7 Nondependent amphetamine or related acting sympathomimetic abuse 969.7 Poisoning by psychostimulants 970.81 Poisoning by cocaine	F15.XX Other stimulant related disorders T40.5 Poisoning by, adverse effect of and underdosing of cocaine T43.6 Poisoning by, adverse effect of and underdosing of psychostimulants
Tobacco use disorder	649.0 Tobacco use disorder complicating pregnancy, childbirth, or the puerperium 305.1 Tobacco use disorder 989.84 Toxic effect of tobacco	099.33 Smoking complicating pregnancy, childbirth, and the puerperium F17 Nicotine Dependence T65.2 Toxic effect of tobacco and nicotine
Alcohol use disorder	291 Alcohol-induced mental disorders 303 Alcohol dependence syndrome 305.0 Nondependent alcohol abuse	F10 Alcohol related disorders 099.31 Alcohol use complicating pregnancy
Drug complications	648.3 Drug dependence 655.5 Suspected damage to fetus from drugs affecting management of mother	O35.5 Maternal care for (suspected) damage to fetus by drugs O99.32 Drug use complicating pregnancy, childbirth, and the puerperium
Drug use disorder	304.1 Sedative, hypnotic or anxiolytic dependence 304.5 Hallucinogen dependence 305.3 Nondependent hallucinogen abuse 305.4 Nondependent sedative, hypnotic or anxiolytic abuse 304.6 Other specified drug dependence 304.8 Combinations of drug dependence excluding opioid type drug 304.9 Unspecified drug dependence Marijuana use disorder Opioid use disorder Stimulant use disorder	F13 Sedative, hypnotic, or anxiolytic related disorders F16 Hallucinogen related disorders F18 Inhalant related disorders F19 Other psychoactive substance related disorders Marijuana use disorder Opioid use disorder Stimulant use disorder
Substance use disorder	Drug use disorder Alcohol use disorder Tobacco use disorder	Drug use disorder Alcohol use disorder Tobacco use disorder

Notes: Table includes ICD-9 and ICD-10 diagnosis and procedure codes used to generate maternal outcomes in 2007-2018 HCUP-SID. All subcodes are included in truncated codes. We used `https://www.icd10data.com/Convert` and previous studies to harmonize ICD-9 and ICD-10 codes. About 5.9% of marijuana use disorder codes reflected marijuana use disorder in remission.

Table 12: International Classification of Diseases codes for newborn outcomes

Outcome	ICD-9	ICD-10
Noxious substances affecting fetus or newborn via placenta or breast milk	760.7 Noxious influences affecting fetus or newborn via placenta or breast milk 763.5 Maternal anesthesia and analgesia affecting fetus or newborn	P04 Newborn affected by noxious substances transmitted via placenta or breast milk Q86.0 Fetal alcohol syndrome (dysmorphic)
Neonatal drug withdrawal syndrome	779.5 Drug withdrawal syndrome in newborn	P96.1 Neonatal withdrawal symptoms from maternal use of drugs of addiction
Fetal alcohol syndrome	760.71 Alcohol affecting fetus or newborn via placenta or breast milk	P04.3 Newborn affected by maternal use of alcohol Q86.0 Fetal alcohol syndrome (dysmorphic)
Slow growth	764 Slow fetal growth and fetal malnutrition	P05 Disorders of newborn related to slow fetal growth and fetal malnutrition
Respiratory conditions	769 Respiratory distress syndrome in newborn 770 Other respiratory conditions of fetus and newborn	P22 Respiratory distress of newborn P23 Congenital pneumonia P24 Neonatal aspiration P25 Interstitial emphysema and related conditions originating in the perinatal period P26 Pulmonary hemorrhage originating in the perinatal period P27 Chronic respiratory disease originating in the perinatal period P28 Other respiratory conditions originating in the perinatal period P84 Other problems with newborn
Feeding problems	779.3 Feeding problems in newborn	P92 Feeding problems of newborn
Congenital Abnormalities	740-759 Congenital abnormalities	Q00-Q99 Congenital malformations, deformations and chromosomal abnormalities

Notes: Table includes ICD-9 and ICD-10 diagnosis and procedure codes used to generate infant outcomes in 2007-2018 HCUP-SID. All subcodes are included in truncated codes. We used `https://www.icd10data.com/Convert` and previous studies to harmonize ICD-9 and ICD-10 codes.

A.2 Time trends

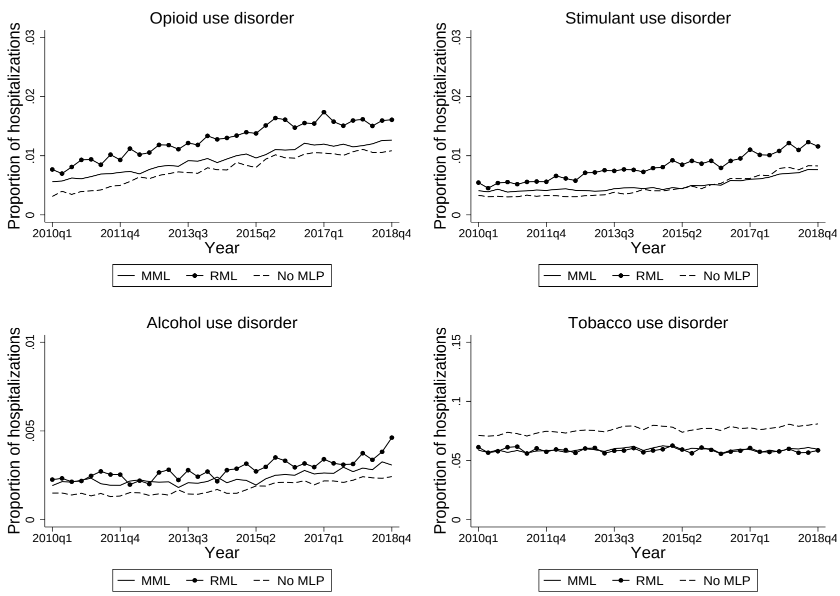

Figure 7: Trends in maternal outcomes

Notes: Maternal hospitalizations were drawn from the 2007-2018 HCUP-SID. Marijuana liberalization groups were mutually exclusive and assigned based on policy implementation as of December 31, 2017. MML=Medical marijuana laws. RML=Recreational marijuana laws. MLP=Marijuana liberalization policy.

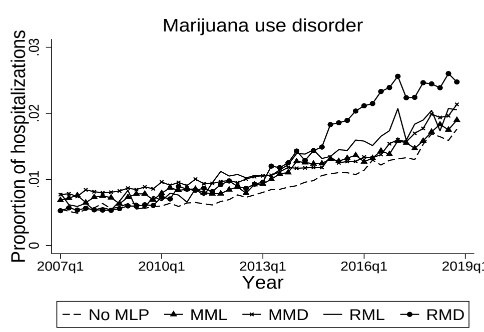

Figure 8: Trends in maternal marijuana use disorder, by dispensary status

Notes: Maternal hospitalizations were drawn from the 2007-2018 HCUP-SID. MML=Medical marijuana laws. MMD=Operational medical marijuana dispensary. RML=Recreational marijuana laws. RMD=Operational recreational marijuana dispensary.

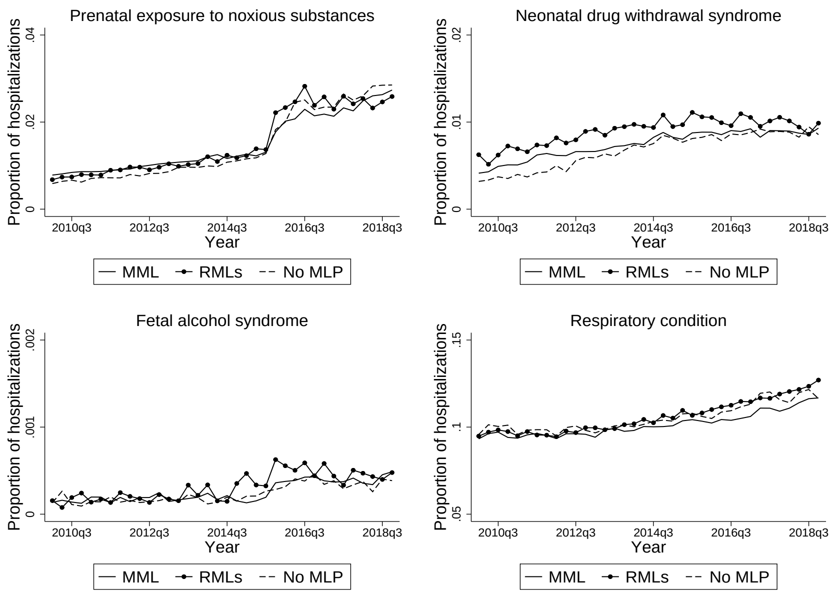

Figure 9: Time trends in newborn health

Notes: Newborn hospitalizations were drawn from the 2007-2018 HCUP-SID. Marijuana liberalization groups were mutually exclusive and assigned based on policy implementation as of December 31, 2017. MML=Medical marijuana laws. RML=Recreational marijuana laws. MLP=Marijuana liberalization policy.

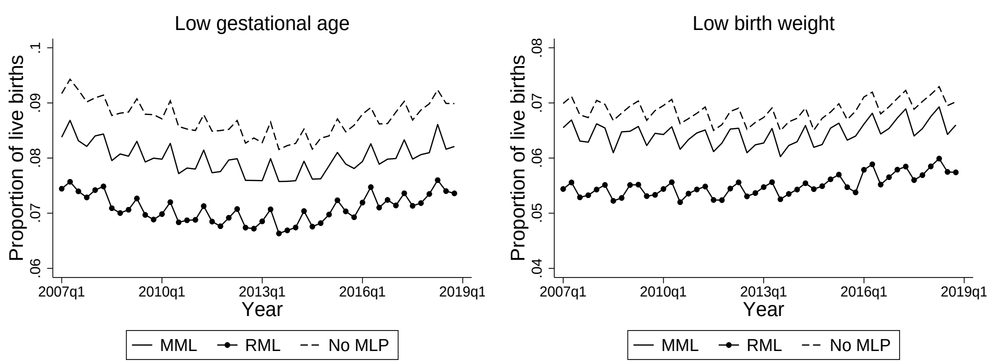

Figure 10: Time trends in newborn health

Notes: Newborn birth outcomes were drawn from the 2007-2019 NVSS Natality Files and reflect conception years 2007-2018. Marijuana liberalization groups were mutually exclusive and assigned based on policy implementation as of December 31, 2017. MML=Medical marijuana laws. RML=Recreational marijuana laws. MLP=Marijuana liberalization policy.

A.3 Two-way fixed effects

Table 13: Marijuana liberalization policies and maternal substance use disorders

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	DID_{FE}	DID_{FE}	DID_{FE}	DID_{FE}	DID_{FE}	DID_{FE}	DID_{FE}	DID_{FE}
	Marijuana use disorder	Opioid use disorder	Alcohol use disorder	Tobacco use disorder	Stimulant use disorder	Drug Compli.	Drug use disorder	Substance use disorder
MML	-0.000	-0.001*	-0.000	-0.003*	-0.001**	-0.001	-0.002*	-0.004*
	(0.001)	(0.001)	(0.000)	(0.002)	(0.000)	(0.002)	(0.001)	(0.002)
MMD	-0.001	0.001	0.000	-0.002	-0.000	-0.002	-0.001	-0.002
	(0.001)	(0.001)	(0.000)	(0.002)	(0.000)	(0.001)	(0.001)	(0.002)
RML	0.002	-0.000	0.000	-0.004	0.000	0.000	0.001	-0.002
	(0.001)	(0.001)	(0.000)	(0.003)	(0.001)	(0.002)	(0.003)	(0.004)
RMD	0.004***	0.002	-0.000	-0.000	0.002	0.006	0.005*	0.003
	(0.001)	(0.002)	(0.000)	(0.003)	(0.001)	(0.004)	(0.003)	(0.003)
Mean	0.013	0.013	0.003	0.060	0.007	0.017	0.031	0.076
States	34	34	34	34	34	34	34	34

Notes: Effect of marijuana liberalization policies on the proportion of maternal hospitalizations involving a substance use disorder. We drew a 60% random sample from the 2007-2018 HCUP-SID for a total of N=15,951,326 observations at the individual discharge level. DID_{FE} coefficients were based on two-way fixed effects regressions described in Equation 1. All policy indicators are included in the same regression. The mean captured outcomes the year prior to RML implementation for RML states. MML=Medical marijuana laws. MMD=Operational medical marijuana dispensary. RML=Recreational marijuana laws. RMD=Operational recreational marijuana dispensary. State clustered standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 14: Marijuana liberalization policies and newborn health outcomes

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	DID_{FE}	DID_{FE}	DID_{FE}	DID_{FE}	DID_{FE}	DID_{FE}	DID_{FE}	DID_{FE}	DID_{FE}	DID_{FE}
	Exposure to noxious substances	Fetal alcohol syndrome	Neonatal drug withdrawal	Slow growth	Respiratory condition	Feeding problems	Congenital anomalies	Low gestational age	Low birth weight	Very Low birth weight
MML	-0.002	0.000	-0.001	0.001	-0.002*	-0.002	0.006**	-0.000	-0.000*	-0.000
	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.000)	(0.000)
MMD	-0.002	-0.000	-0.001	-0.001	-0.001	-0.003	-0.004	-0.000	0.001***	0.000
	(0.001)	(0.000)	(0.001)	(0.001)	(0.002)	(0.002)	(0.003)	(0.001)	(0.000)	(0.000)
RML	0.001	0.000	-0.001	0.003**	0.002	0.007**	0.011	0.000	0.001	0.000
	(0.001)	(0.000)	(0.001)	(0.001)	(0.003)	(0.003)	(0.009)	(0.001)	(0.001)	(0.000)
RMD	-0.001	0.000	-0.000	-0.001	0.009**	-0.003	-0.005	-0.001*	0.001	0.000
	(0.002)	(0.000)	(0.001)	(0.002)	(0.004)	(0.005)	(0.009)	(0.001)	(0.000)	(0.000)
States	34	34	34	34	34	34	34	51	51	51
Mean	0.017	0.0003	0.009	0.033	0.105	0.058	0.137	0.073	0.057	0.009

Notes: Effect of marijuana liberalization policies on newborn health outcomes. The proportion of newborn hospitalizations involving an adverse health outcome in Columns (1) to (7) were based on a 60% random sample from the 2007-2018 HCUP-SID for a total of N=16,263,309 observations at the individual discharge level. The proportion of births involving an adverse health outcome in Columns (8) to (10) were based on 2007-2019 NVSS Natality files for a total of N=2,448 at the state-year-quarter of conception level for conception years 2007-2018. DID_{FE} coefficients were based on two-way fixed effects regressions described in Equation 1. All policy indicators are included in the same regression. The mean captured outcomes the year prior to RML implementation for RML states. MML=Medical marijuana laws. MMD=Operational medical marijuana dispensary. RML=Recreational marijuana laws. RMD=Operational recreational marijuana dispensary. State clustered standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

A.4 Changes to selection criteria and other analyses

Table 15: Maternal substance use disorders at delivery encounter

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M
	Marijuana use disorder	Opioid use disorder	Stimulant use disorder	Alcohol use disorder	Tobacco use disorder	Drug Comp.	Drug use disorder	Substance use disorder
MML	0.000	-0.000	-0.000	0.000	-0.001	0.000	-0.000	-0.000
	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.002)
RML	0.003***	-0.000	-0.000	-0.000	-0.004**	0.005	0.002*	-0.002
	(0.001)	(0.001)	(0.001)	(0.000)	(0.002)	(0.004)	(0.001)	(0.002)

Notes: Effect of marijuana liberalization policies on the proportion of hospital deliveries involving substance use disorder. We drew a 60% random sample from the 2007-2018 HCUP-SID for a total of N=15,951,326 observations at the individual discharge level. We kept hospital deliveries for a total of N=14,426,079 observations. DID_M coefficients were based on the multiperiod estimator in the first 3 years post policy. MML=Medical marijuana laws. RML=Recreational marijuana laws. State clustered standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 16: Newborn health outcomes in the NVSS subsample of 34 HCUP-SID states

	(1)	(2)	(3)
	DID_M	DID_M	DID_M
	Low gestational age	Low birth weight	Very low birth weight
MML	0.0009	0.0010	0.0003
	(0.0010)	(0.0008)	(0.0002)
RML	-0.0007	0.0001	-0.0005
	(0.0011)	(0.0008)	(0.0004)

Notes: Effect of marijuana liberalization policies on the proportion of live births with the indicated condition using 2007-2019 NVSS Natality data for conceptions years 2007-2018. The sample included the subset of 34 states in the HCUP-SID sample. DID_M heterogeneity robust coefficients were based on the multiperiod estimator in the first 3 years post policy. MML=Medical marijuana laws. RML=Recreational marijuana laws. State clustered standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.*** p<0.01, ** p<0.05, * p<0.1.

Table 17: Recreational marijuana laws, by state characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M
	Marijuana use disorder	Opioid use disorder	Stimulant use disorder	Alcohol use disorder	Tobacco use disorder	Drug Compli.	Drug use disorder	Substance use disorder
Panel A: RML implementation in states with lenient marijuana potency regulation								
RML	0.004***	0.001	0.001	-0.001	-0.005*	0.009	0.004***	-0.003
	(0.001)	(0.001)	(0.001)	(0.000)	(0.003)	(0.005)	(0.001)	(0.004)
Panel B: RML implementation in states with large medical marijuana markets								
RML	0.004***	0.001	0.001	-0.001	-0.006**	0.006	0.004***	-0.004
	(0.001)	(0.001)	(0.001)	(0.000)	(0.003)	(0.005)	(0.001)	(0.003)
Panel C: RML implementation in states with long running medical marijuana programs								
RML	0.004***	0.001	0.001	-0.000	-0.005**	0.007	0.004***	-0.002
	(0.001)	(0.001)	(0.001)	(0.000)	(0.002)	(0.006)	(0.001)	(0.003)

Notes: Effect of marijuana liberalization policies on the proportion of hospital deliveries involving substance use disorder. We drew a 60% random sample from the 2007-2018 HCUP-SID for a total of N=15,951,326 observations at the individual discharge level. DID_M coefficients were based on the multiperiod estimator in the first 3 years post policy. Each panel estimates the impact of recreational marijuana laws (RMLs) using the subset of RML states with the listed characteristic. Other RML states not meeting selection criteria are dropped. Non-RML states are the same in all specifications. Lenient RML states in Panel A (ME, NV, VT, OR, WA) were selected based on the THC dose allowed per transaction [127]. RML states with large medical marijuana markets in Panel B (CO, ME, OR, WA) were selected based on the estimated number of registered patients per capita in 2014-2016 [128, 129, 130]. RML states with long running MML programs in Panel C (AK, CO, ME, NV, OR, VT, WA) were selected if the state had already implemented an MML for at least 10 years at the time the RML was implemented as shown in Appendix Table 8. State clustered standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 18: Marijuana liberalization policies and newborn health, by subpopulations

	(1)	(2)	(3)	(4)	(5)	(6)
	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M
	White	Black	Hispanic	White	Black	Hispanic
	Low gestational age			Low birth weight		
MML	0.0008	0.0013	0.0004	0.0003	0.0002	0.0002
	(0.0008)	(0.0015)	(0.0019)	(0.0007)	(0.0018)	(0.0014)
RML	-0.0010	-0.0009	-0.0004	0.0004	-0.0030	0.0023
	(0.0009)	(0.0018)	(0.0023)	(0.0008)	(0.0049)	(0.0020)

Notes: Effect of marijuana liberalization policies on newborn health outcomes, by race/ethnicity, using 2007-2019 NVSS Natality data for conceptions years 2007-2018. DID_M coefficients were based on the multiperiod estimator in the first 3 years post policy. MML=Medical marijuana laws. RML=Recreational marijuana laws. State clustered standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

A.5 Compositional effects

Table 19: Compositional changes in maternal HCUP-SID sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M
	Fetal Deaths		Age		Race/ Ethnicity			Health Insurance		
	Abortion	Stillbirth	15-20	21-44	White	Black	Hisp.	Medicaid	Private	Other
MML	0.002	0.000	0.0002	-0.0002	0.014	0.003	0.002	0.015*	-0.016**	0.001
	(0.002)	(0.000)	(0.0016)	(0.0017)	(0.022)	(0.004)	(0.005)	(0.009)	(0.007)	(0.004)
RML	-0.001	0.000	-0.0013	0.0013	0.005	0.000	-0.010	0.011	-0.012	0.001
	(0.003)	(0.001)	(0.0016)	(0.0016)	(0.012)	(0.003)	(0.008)	(0.009)	(0.010)	(0.005)

Notes: Hospitalizations were drawn from the 2007-2018 HCUP-SID (N=15,951,326). DID_M coefficients were based on the multiperiod estimator in the first 3 years post policy. MML=Medical marijuana laws. RML=Recreational marijuana laws. State clustered standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 20: Compositional changes in NVSS Natality sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M	DID_M
	White	Black	Hispanic	Parity 1	Male	Married	Total Births
MML	-0.0001	-0.0004	0.0010	0.0019	0.0012	0.0001	-651.37
	(0.0018)	(0.0021)	(0.0026)	(0.0064)	(0.0010)	(0.0024)	(635.28)
RML	-0.0012	-0.0001	-0.0017	0.0001	0.0022	-0.0080	-622.20
	(0.0027)	(0.0022)	(0.0022)	(0.0044)	(0.0014)	(0.0074)	(1669.75)

Notes: Births in Columns (1)-(6) were drawn from 2007-2019 NVSS Natality files and capture the proportion of outcomes at the state-year-quarter of conception level for conception years 2007-2018 (N=2,448). State-year birth counts in Column (7) were drawn from public use 2007-2018 NVSS Natality files (N=612). DID_M coefficients were based on the multiperiod estimator in the first 3 years post policy. Column (7) model also controls for state-year counts of the population of females ages 15-44, in addition to all other controls. MML=Medical marijuana laws. RML=Recreational marijuana laws. State clustered standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

A.6 Statistical inference

Table 21: Rejection rates from 1,000 DID_M simulations

	(1) MML	(2) RML
Simulations	1000	1000
Total clusters	34	34
Total treated clusters	22	9
Switching treated clusters	13	9
Rejection rate = 10%, Critical value = 1.645	8.6%	12.1%
Rejection rate = 5%, Critical value = 1.96	3.1%	6.5%
Rejection rate = 1%, Critical value = 2.58	0.7%	1.9%

Notes: Rejection rates from 1,000 DID_M simulations.

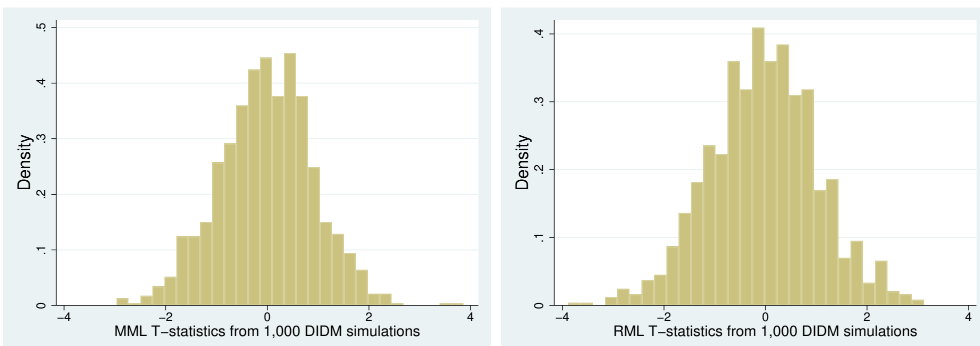

Figure 11: Histogram of T-statistics from 1,000 DID_M simulations

Table 22: 95% Confidence intervals for maternal estimates

	(1)	(2)	(3)	(4)	(5)	(6)
	DID_{FE}	DID_{ES}	DID_{M}	DID_{FE}	DID_{ES}	DID_{M}
	Marijuana use disorder			Opioid use disorder		
MML	-0.001	-0.000	0.000	-0.001	-0.001	-0.000
	[-0.002,0.000]	[-0.001,0.001]	{-0.001,0.001}	[-0.003,0.000]*	[-0.002,0.001]	{-0.001,0.001}
	(-0.002,0.001)	(-0.002,0.002)		(-0.003,0.000)	(-0.002,0.001)	
RML	0.004	0.004	0.003	0.001	-0.000	0.000
	[0.001,0.007]**	[0.001,0.006]***	{0.002,0.005}***	[-0.003,0.005]	[-0.003,0.003]	{-0.001,0.002}
	(-0.001,0.009)*	(0.000,0.008)**		(-0.004,0.006)	(-0.004,0.004)	
	Stimulant use disorder			Drug complications		
MML	-0.001	-0.000	-0.000	-0.002	-0.001	-0.000
	[-0.002,-0.000]**	[-0.001,0.000]	{-0.001,0.000}	[-0.005,0.001]	[-0.004,0.003]	{-0.003,0.002}
	(-0.003,-0.000)**	(-0.002,0.001)		(-0.005,0.002)	(-0.005,0.003)	
RML	0.002	0.001	0.000	0.004	0.004	0.005
	[-0.001,0.004]	[-0.001,0.003]	{-0.001,0.002}	[-0.003,0.011]	[-0.003,0.011]	{-0.003,0.013}
	(-0.001,0.005)	(-0.001,0.003)		(-0.005,0.017)	(-0.003,0.018)	
	Alcohol use disorder			Tobacco use disorder		
MML	-0.000	-0.000	-0.000	-0.004	-0.003	-0.001
	[-0.000,0.000]	[-0.000,0.000]	{-0.000,0.000}	[-0.008,-0.000]**	[-0.008,0.001]*	{-0.004,0.002}
	(-0.000,0.000)	(-0.000,0.000)		(-0.009,0.001)*	(-0.009,0.002)	
RML	0.000	-0.000	-0.000	-0.004	-0.005	-0.004
	[-0.000,0.000]	[-0.001,0.000]	{-0.001,0.001}	[-0.013,0.005]	[-0.010,0.001]*	{-0.008,-0.000}**
	(-0.001,0.001)	(-0.001,0.001)		(-0.017,0.007)	(-0.013,0.005)	
	Drug use disorder			Substance use disorder		
MML	-0.003	-0.001	-0.000	-0.005	-0.003	-0.001
	[-0.005,-0.000]**	[-0.003,0.002]	{-0.002,0.002}	[-0.009,-0.000]**	[-0.008,0.002]	{-0.004,0.003}
	(-0.005,0.000)*	(-0.004,0.002)		(-0.010,0.000)*	[-0.010,0.002]	
RML	0.004	0.004	0.003	-0.001	-0.001	-0.001
	[-0.002,0.010]	[-0.001,0.008]*	{0.001,0.005}***	[-0.010,0.009]	[-0.008,0.005]	{-0.006,0.003}
	(-0.004,0.011)	(-0.002,0.009)		(-0.014,0.011)	(-0.011,0.010)	

Notes: This table reports 95% confidence intervals (95%CI) of estimates in Table 2. 95%CIs in [brackets] were generated with the standard cluster-robust variance matrix estimator. 95%CIs in (parentheses) were generated with the wild cluster bootstrap. 95%CIs in {braces} were generated with a standard cluster bootstrap. We assumed clustering at the state-level in all cases. MML=Medical marijuana laws. RML=Recreational marijuana laws. *** p<0.01, ** p<0.05, * p<0.1.

Table 23: 95% Confidence intervals for newborn estimates

	(1)	(2)	(3)	(4)	(5)	(6)
	DID_{FE}	DID_{ES}	DID_{M}	DID_{FE}	DID_{ES}	DID_{M}
	Exposure to noxious substances			Fetal alcohol syndrome		
MML	-0.002	-0.002	-0.001	0.000	0.000	0.000
	[-0.005,0.000]*	[-0.005,0.001]	{-0.003,0.001}	[-0.000,0.000]	[-0.000,0.000]	{-0.000,0.000}
	(-0.005,0.001)	(-0.005,0.001)		(-0.000,0.000)	(-0.000,0.000)	
RML	0.000	0.001	0.001	0.000	0.000	0.000
	[-0.004,0.004]	[-0.003,0.005]	{-0.003,0.004}	[-0.000,0.000]	[-0.000,0.000]	{-0.000,0.000}
	(-0.004,0.007)	(-0.003,0.007)		(-0.000,0.000)	(-0.000,0.000)	
	Slow growth			Respiratory condition		
MML	0.001	0.001	0.001	-0.003	-0.003	-0.001
	[-0.001,0.002]	[-0.000,0.003]	{-0.001,0.003}	[-0.006,-0.000]**	[-0.005,0.001]	{-0.004,0.001}
	(-0.001,0.002)	(-0.001,0.003)		(-0.008,0.000)*	(-0.007,0.001)	
RML	0.002	0.001	0.001	0.007**	0.004	-0.001
	[-0.001,0.005]	[-0.000,0.003]	{-0.001,0.002}	[0.001,0.013]**	[0.000,0.008]**	{-0.004,0.002}
	(-0.002,0.005)	(-0.001,0.003)		(-0.004,0.013)	(-0.002,0.009)	
	Feeding problems			Congenital abnormality		
MML	-0.002	-0.003	-0.002	0.005	0.007	0.004
	[-0.007,0.002]	[-0.007,0.002]	{-0.006, 0.001}	[-0.001,0.011]*	[0.001,0.012]**	{-0.002,0.009}
	(-0.008,0.002)	(-0.008,0.002)		(-0.002,0.012)	(-0.000,0.013)*	
RML	0.005	0.001	-0.003	0.008	0.004	0.001
	[-0.002,0.011]	[-0.003,0.006]	{-0.008,0.003}	[-0.003,0.020]	[-0.002,0.010]	{-0.007,0.009}
	(-0.004,0.013)	(-0.004,0.008)		(-0.006,0.026)	(-0.007,0.012)	
	Neonatal drug withdrawal			Very low birth weight		
MML	-0.001	-0.000	-0.000	0.000	-0.000	0.000
	[-0.002,0.000]	[-0.002,0.001]	{-0.001,0.001}	[-0.000,0.000]	[-0.000,0.000]	{-0.000,0.000}
	(-0.002,0.000)	(-0.002,0.001)		(-0.000,0.000)	(-0.000,0.000)	
RML	-0.001	-0.001	-0.001	0.000	-0.000	0.000
	[-0.003,0.001]	[-0.003,0.001]	{-0.002,0.000}	[-0.000,0.000]	[-0.000,0.000]	{-0.001,0.001}
	(-0.004,0.002)	(-0.004,0.001)		(-0.000,0.000)	(-0.000,0.000)	
	Low gestational age			Low birth weight		
MML	-0.000	-0.000	0.001	-0.000	-0.000	0.001
	[-0.002,0.001]	[-0.001,0.001]	{-0.001,0.002}	[-0.001,0.000]	[-0.001,0.001]	{-0.001,0.002}
	(-0.002,0.001)	(-0.001,0.001)		(-0.001,0.000)	(-0.001,0.001)	
RML	-0.000	-0.001	-0.000	0.001	0.001	0.001
	[-0.001,0.001]	[-0.002,0.000]	{-0.002,0.001}	[-0.000,0.002]	[-0.000,0.001]	{-0.000,0.002}
	(-0.001,0.002)	(-0.002,0.001)		(-0.000,0.003)	(-0.001,0.001)	

Notes: This table reports 95% confidence intervals (95%CI) of estimates in Table 3. 95%CIs in [brackets] were generated with the standard cluster-robust variance matrix estimator. 95%CIs in (parentheses) were generated with the wild cluster bootstrap. 95%CIs in {braces} were generated with a standard cluster bootstrap. We assumed clustering at the state-level in all cases. MML=Medical marijuana laws. RML=Recreational marijuana laws. *** p<0.01, ** p<0.05, * p<0.1.