ABSTRACT

HIGH, BUT NOT HAPPY?
THE IMPACT OF CANNABIS CONSUMPTION ON MENTAL HEALTH

by Jacob Robert Pieniazek

This paper investigates the causal relationship between cannabis consumption and mental health using state-level longitudinal data in the United States from 2005-2018. We first estimate the impact of cannabis legalization on cannabis consumption and mental health among the states that have legalized cannabis using recent developments in the difference-in-differences literature to account for treatment heterogeneity across cohorts and time under staggered treatment adoption. We then estimate the direct effect of cannabis consumption on mental health using an instrumented difference-in-differences (DDIV) approach exploiting state-level variation in the legal status of cannabis. We link the legalization of cannabis to an average increase of 1.59 percentage points (7.3 percent) and 0.92 percentage points (5.0 percent) in the proportion of the population with symptoms of a mental health disorder for adults aged 18-25 and aged 26+, respectively. Our DDIV estimates suggest that, among the states that have legalized cannabis, roughly 2 out of 10 adults that engage in frequent cannabis consumption developed symptoms of a mental health disorder.

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1. INTRODUCTION

Cannabis is one of the most widely consumed and abused substances. In the United States from 2008 to 2018, cannabis consumption within the past month for adults above the age of 18 has increased from 6.33% to 11.17%, with roughly a common 5 percentage point (pp) increase for both adults aged 18-25 and adults above the age of 26+ (SAMHSA, 2005-2018).[1] The increase in cannabis usage is in direct parallel with increasing legal access of cannabis products across the United States including decriminalization, medicalization, and full legalization (Williams, 2016). During the same 2008-to-2018-time frame, adults aged 18-25 having any mental illness within the past year has increased roughly 10pp from 18.25% to 27.85%, while adults above the age of 26 have seen a more minimal 1pp increase from 17.86% to 18.60% (SAMHSA, 2005-2018). The present literature has increasingly highlighted evident associations between cannabis consumption and mental health illness, particularly among adolescents and young adults (Lowe *et al.*, 2019). However, the direction of causality is not as clear. Pinpointing plausibly exogenous variation in cannabis consumption has made isolating this relationship non-trivial. This paper seeks to further evaluate the ambiguous relationship between cannabis consumption and mental health illness. More specifically, we seek to identify the causal impact of cannabis legalization on cannabis consumption and mental health illness and to then isolate the direct impact of cannabis consumption on mental health illness among the states that have undergone legalization.

The recent transforming legal landscape has fostered a clear and distinct ambivalence among the public with respect to the benefits and consequences of cannabis use. However, much of the legislative changes towards medicalization and legalization have been "minimally informed by science" albeit the lack of research has been attributed to the severe legal restrictions in conducting quality research with cannabis in the United States (Compton, 2016, p. 7; D'Souza and Ranganathan, 2015)[2]. In terms of policy implications, it is of marked importance to establish the causal relationship between cannabis use and mental health illness to aid in the cost and benefit discussions over legal status. The Organization for Economic Cooperation and Development estimates that poor mental health results in economic costs of roughly 4.2% of GDP, resulting heavily from direct costs and more than a third from indirect costs such as lower employment and lost productivity (OECD, 2021). On the other hand, the costs associated with cannabis prohibition are pervasive. In modeling the cost and benefits of different cannabis policies, Rogeberg (2018) argues that strict regulation of cannabis is preferable to prohibition or laissez-faire policy. As pro-cannabis advocacy groups continue to gain momentum in influencing the legal landscape, it is of vital importance to have a robust analysis of the consequences associated with cannabis consumption in order to influence well-informed legislative changes—be it decriminalization,

[1] For adults aged 18 to 25, the increase is from 17.42% to 22.54%. For adults age of 26+, the increase is from 4.42% to 9.39%.
[2] Additionally, much federally supported research has been more oriented towards negative effects rather than the positive effects of cannabis use (Compton, 2016).

medicalization, or legalization with regulatory or laissez-faire policy. And as of this writing, New Jersey has been the most recent state to allow legal cannabis sales on April 21, 2022.

In this study, we utilize a balanced longitudinal data set from 2005-2018 across all 50 states in the United States and the District of Columbia (DC) on mental health illness and cannabis consumption outcomes from the Substance Abuse and Mental Health Services Administration (SAMHSA). Using a recent method in the dynamic difference-in-differences (DiD) literature developed by Callaway and Sant'Anna (CS; 2021), we estimate the causal impact of cannabis legalization on cannabis consumption and mental health. The new DiD methods are necessary to address concerns of bias that arise from heterogenous treatment effects across cohorts and time under staggered treatment adoption in the canonical two-way fixed effects (TWFE) model. We further employ these methods to provide evidence in favor of the assumptions necessary to estimate the direct impact of cannabis consumption on mental health illness utilizing an instrumented difference-in-differences (DDIV) framework exploiting the variation in legal status of cannabis. We contribute to the literature by exploiting full legalization of cannabis with policy variation across 10 states and DC to address endogeneity and pinpoint the causal relationship between cannabis consumption and mental health illness. To the best of our knowledge, we are the first to extend the new DiD methods in establishing identification assumptions in a DDIV setting.

Among the states that have legalized cannabis, we estimate that legalization increased the proportion of the population that has used cannabis within the past month by an average of 3.7pp (18.9 percent) and 3.1pp (50.8 percent) for adults aged 18-25 and 26+, respectively.[3] With respect to mental health illness among adults aged 18-25, we find that legalization resulted in a 1.59pp (7.3 percent), 0.49pp (9.1 percent), and 0.78pp (7.8 percent) average increase in the prevalence of any mental health, serious mental health, and major depressive disorders, respectively. For adults above the age of 26, the estimate is a 0.92pp (5.0 percent) increase in any mental health disorder and we find no evidence for serious mental health or major depressive disorders. Using 2021 population estimates for California and Colorado, our estimates suggest that approximately 213,000 and 32,000 additional adults above the age of 18 developed any mental health illness following legalization, respectively. Furthermore, we find evidence of non-diminishing dynamic effects of cannabis legalization on cannabis use and mental health illness. This raises possible concerns that this may be a dynamically growing relationship of concern.

Our DDIV estimates quantify the average impact of cannabis consumption on mental health among the states that have undergone legalization. On average, for adults aged 18-25 and aged 26 up, our estimates suggest that a 1pp increase in the proportion of the population that has used cannabis within the past month resulted in a 0.325pp and 0.192pp increase in the proportion of the population with any mental health illness, respectively. This amounts to roughly 2-3 out of every 10 adults that engage in monthly cannabis consumption

[3] All percentages are with respect to sample means reported in table 1.

at the intensive and extensive margins following legalization. For serious mental health and major depressive disorders among adults aged 18-25, the estimates are 0.129pp and 0.203pp, respectively. We find no evidence that cannabis consumption increases serious mental health or major depressive disorders among adults above the age of 26. We provide some of the first robust evidence to suggest cannabis consumption results in negative mental health outcomes at an epidemiologic scale.

The remainder of this paper tracks as follows. Section 2 discusses the relevant literature from a medical perspective and an economic and epidemiologic perspective. Section 3 examines the data used in the empirical analysis. Section 4 presents the econometric specification and provides an in-depth treatment of our identification strategy. Section 5 presents the empirical estimation results. Section 6 targets vulnerabilities in our specification via robustness checks. Lastly, section 7 summarizes our findings and concludes.

2. RELEVANT LITERATURE

2.1 Medical Evidence

Cannabis, which refers to the species of *Cannabis Sativa*, *Cannabis Indica*, and *Cannabis Ruderalis*, is a remarkably complex substance. The cannabis plant material that is consumed contains upwards of 400 different chemical constituents, with approximately 80 *cannabinoids* (Compton, 2016). The chemical composition of cannabis among different strains is extremely intricate and varies to a significant degree. Thus, it is difficult to isolate individual effects of the different constituents (Compton, 2016; D'Souza & Ranganathan, 2015). Nevertheless, the primary *cannabinoids* that receive attention are Δ^9-tetrahydrocannabinol (THC), known for its powerful psychoactive effects, and, the non-psychoactive constituent, cannabidiol (CBD; Borgelt *et al.*, 2013; Compton, 2016).

Cannabinoids derive their physiological impact from their complex interaction with the human's endogenous cannabinoid system—the endocannabinoid system (ECS; Compton, 2016). The ECS plays important roles in a vast array of physical and mental processes—including "the regulation of appetite, memory, and other domains of cognition, mood, pain, sleep, inflammation, and other physical and mental functions" (Compton, 2016, p. 3). Furthermore, the ECS is remarkably important in brain development, which raises specific concerns with respect to cannabis use in adolescents and young adults (Maccarrone *et al.*, 2014). The body naturally produces cannabinoids within the ECS with short durations of action; however, cannabinoids obtained exogenously—specifically with the use of cannabis—maintain longer activation of the ECS (Compton, 2016). The physiological and subsequent psychological impact of cannabis consumption is marked and complex. The medical literature is expanding in its understanding of the ECS and the role of cannabis use in altering its function—both positively and negatively. Nevertheless, there is a clear physiological and psychological relationship between cannabis use and the ECS.

Cannabis is well-known for its acute intoxication effects of consumption.[4] The presumption that the intoxicating and reinforcing effects of cannabis are somehow distinctly unique from other substances is flawed: "The concept that marijuana is distinct from other illicit drugs is not supported by science; there are well-demonstrated overlaps of the marijuana neural system with the neural systems of other drugs of abuse" (Atkinson, 2016, pp. 13). Whether one can develop a dependence and addiction to cannabis has been scientifically and medically determined (Atkinson, 2016; Budney *et al.*, 2007). The 5th edition of the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5) includes cannabis use disorder, cannabis withdrawal, and acute cannabis-induced disorders (American Psychiatric Association, 2013). It has been estimated that roughly 7-10% of regular cannabis users will develop a cannabis dependence (Kalant, 2004). Thus, with cannabis legalization we can expect mental health disorders to increase on the grounds of increased cannabis usage and subsequent addiction and acute disorders alone.[5] As noted, "The effects of a drug (legal or illegal) on individual health are determined not only by its pharmacologic properties but also by its availability and social acceptability. In this respect, legal drugs (alcohol or tobacco) offer a sobering perspective, accounting for the greatest burden of disease associated with drugs not because they are more dangerous than illegal drugs but because their legal status allows for more widespread exposure" (Volkow *et al.*, 2014, p. 6).

The justification for *medical* cannabis legalization has been on the grounds of notable medical benefits of cannabis. Although this paper focuses on full recreational cannabis legalization, a brief discussion of these highlighted medical benefits is necessary—most notably with respect to the purported mental health benefits. Much of the studied medical indications for cannabis use—with varying degrees of efficacy—have been with respect to appetite enhancement in HIV/AIDS, pain, spasticity and multiple sclerosis, nausea, seizures, glaucoma, Hepatitis C, Crohn's disease, amyotrophic lateral sclerosis (ALS), and Parkinson's disease (Thant *et al.*, 2016). Research into the psychiatric indications for cannabis use have been less promising. Notably, cannabis can induce psychotic symptoms in healthy individuals, as well as those at risk for psychotic disorders (Thant *et al.*, 2016). There has been a growing disconnect between self-reported benefits and scientific studies for cannabis use in psychiatric indications (Kancherla *et al.*, 2021). Ultimately, there has been conflicting evidence for cannabis use for anxiety and PTSD, while there has been strong evidence the cannabis use worsens depression, bipolar disorder, and psychotic disorders (Kancherla *et al.*, 2021; Thant *et al.*, 2016). However, note that much of the above medical research has focused on individuals with preexisting mental health conditions. Thus, determining if cannabis is *causally* responsible for mental health illness has not been medically established (with the exception of triggering acute psychotic symptoms as mentioned above). Nevertheless, the evidence within the medical community has suggested a more harmful rather than beneficial relationship between

[4] Non-intoxicating consumption of the other additional constituents of cannabis, such as CBD, is not of focus in this paper.
[5] Note, however, that the mental health measures utilized in this paper exclude any substance abuse disorders.

cannabis use and mental health. It is important to again reiterate that there have been substantial barriers to researching the effects of cannabis use among the medical community due to federal limitations.

2.2 Economic & Epidemiologic Evidence

The medical literature has established a clear physiological expectation of a relationship between cannabis use and mental health, particularly by way of addiction and acute effects. Evidence has been growing to suggest the mental health effects can persist beyond acute effects, particularly for psychotic disorders (Moore *et al.*, 2007). A limited number of epidemiologic and economic researchers have attempted to quantify the causal impact of cannabis use on mental health outcomes. However, controlling for confounding effects and simultaneity poses to be quite difficult due to the many social determinants that influence both cannabis use and mental health (Hall, 2014; Luther *et al.*, 2016). In a longitudinal study, Green and Ritter (2000) find the association between cannabis consumption and depression to be mediated heavily by educational attainment, employment status, marital status, other drug use, alcohol use, and tobacco use. The identification for the causal impact of cannabis on mental health has been at odds due to a lack of plausibly exogenous variation in cannabis consumption. Nevertheless, a growing body of research has identified clear relationships between the two.

A large set of the present epidemiologic and economic literature highlights either a positive or a minimal relationship between cannabis use and certain mental illnesses (Buckner *et al.*, 2010; Crippa *et al.*, 2009; Hall, 2014; Kalant, 2004; Konefal *et al.*, 2019; Lowe *et al.*, 2019; van Ours & Williams, 2012). While other research has found more mixed relationships (Hanna, 2017; van Ours & Williams, 2015). Additionally, Guttmannova *et al.* (2017) found a positive relationship between cannabis use and cannabis use disorder, alcohol use disorder, and nicotine dependence—all of which are classified as mental illnesses via DSM-5 (American Psychiatric Association, 2013). In a comprehensive review of the present literature Lowe *et al.* (2019) finds evidence of harmful associations between cannabis consumption and schizophrenia, major depressive disorder, bipolar disorder, post-traumatic stress disorder, and generalized anxiety disorder. Utilizing a discrete factor approach to account for endogeneity, van Ours and Williams (2011; 2012) finds a positive, albeit small, causal relationship between cannabis use and mental health illness, particularly for high frequency users which suggests a dose-dependent relationship.

Cannabis legalization in the United States over the past decade has provided a novel source of variation to exploit in isolating the relationship between cannabis consumption and mental health. Cannabis legalization has been clearly linked to an increase in cannabis usage among adults (Smart and Pacula, 2019). Our paper contributes and seeks to pinpoint the causal increase in cannabis consumption following legalization for future researchers. The legalization of cannabis has been exploited in the economic literature to look at cannabis-related traffic fatalities (Hansen *et al.*, 2020) and opioid mortality (Chan *et al.*, 2020). However, Gouron *et al.*

(2020) synthesized the present literature on the impacts of cannabis legalization on mental health and concluded that there is extremely limited research evaluating this topic. Anderson *et al.* (2014), using a two-way fixed effects DiD specification, found that *medical* marijuana laws were associated with a decrease in middle-aged adult male suicide rates. This result was later refuted by Grucza *et al.* (2015). Further, Kalbfuss *et al.* (2018) utilize survey data on self-reported mental health and the staggered implementation of *medical* cannabis laws and conclude a slight reduction in the number of poor mental health days. This effect is mainly concentrated among those who face physical health issues, such as pain. Nevertheless, the recent developments in the DiD literature suggest the results of the aforementioned papers warrant reexamination. To the best of our knowledge, we are the first exploit full recreational cannabis legalization and further implement new robust DiD methodologies in pinpointing the causal impact of cannabis consumption on mental health.

Legalization and the development of recreational markets for cannabis raises a particular concern with respect to increasing the frequency of cannabis consumption and the consumption of cannabis with remarkably higher potency. In the United States, individuals in states with legalized cannabis were significantly more likely to consume cannabis daily or weekly and consume higher potency cannabis products such as concentrates, oils, and edibles (Goodman *et al.*, 2020). Furthermore, from 2008 to 2017 the mean content of the main psychoactive constituent, THC, in cannabis products has increased from 8.9% to 17.1% (Chandra *et al.*, 2019). This is likely a result of both legalization and improvements in cultivation practices over the decade. Indeed, cannabis strains are increasingly becoming engineered to become more potent and are being advertised based on potency in the recreational market (Compton, 2016).

Continuing this point, a positive relationship has been highlighted between mental health and high frequency cannabis use and highly potent product use, although the direction of causality is not agreed upon (Rup *et al.*, 2021). A report by the Canadian Centre on Substance Use and Addiction found that regular cannabis use is at a minimum two times as prevalent among individuals with mental health disorders (Konefal *et al.*, 2019). Additional researchers have found a similar relationship between mental health and cannabis use frequency (Crippa *et al.*, 2009; van Ours and Williams, 2011). On the other hand, other have found that cannabis use is associated with greater mental health problems irrespective of the frequency of usage (Buckner *et al.*, 2010). As the legal landscape for cannabis changes in the United States, it is important to keep in mind the subsequent effects that wide-spread commodification may have on the potency of products and the propensity for higher frequency usage.

This paper expands the current literature on the relationship of cannabis legalization on cannabis consumption and mental health. We do this by exploiting the staggered implementation of cannabis legalization across states in the United States using a new robust DiD methodology developed by CS (2021) to account for heterogenous treatment effects across cohorts and time. We then further exploit cannabis legalization in constructing an instrumented difference-in-differences (DDIV) estimate to estimate the direct impact of cannabis consumption on mental health levels. We thus contribute a wholistic picture of the dynamic interactions between cannabis consumption and mental health illness across the United States.

3. SUMMARY EVIDENCE & DATA

This section discusses the nature of the data and considers summary evidence. To estimate the desired relationships between cannabis legalization, cannabis consumption, and mental health illness, data were collected on state-level mental health and cannabis consumption outcomes, as well as legal status and demographic covariates. A balanced longitudinal panel data set was constructed for all 50 states and the District of Columbia across the United States from 2005-2018.

3.1 SAMHSA National Survey on Drug Use and Health State Estimates

The Substance Abuse and Mental Health Services Administration (SAMHSA) collects survey data on the present state of substance abuse and mental health in its annual National Survey on Drug Use and Health (NSDUH) collected in the last and first half of year-pairs. The NSDUH is utilized as the primary statistical resource for the use of illicit drugs, alcohol, and tobacco among the U.S. civilian population with measures on mental health outcomes. From 2005-2018, the survey averaged a 70.22% weighted interview response rate with an average of 48,383 respondents each year for adults above the age of 18 (SAMHSA, 2019).[6] SAMHSA computes state-level estimates using a weighted-survey hierarchical bayes estimation methodology for a given year-pair (i.e., 2005-2006, 2006-2007, etc.; SAMHSA, 2019). In our data set, we categorized each pair with the first year (i.e., 2005-2006 is classified as 2005). This will cause no major interpretive challenges except extra care must be given to the year cannabis legalization occurs for a state, which we discuss in further detail in section 3.2. There are no major methodological changes during the period of this study that raise red flags.

The primary variables of interest obtained from the state-level estimates data set are the measures of mental illness and cannabis use (SAMHSA, 2005-2018). The mental illness measures include the proportion of the population in each state with any mental illness in the past year, a serious mental illness in the past year, and a major depressive episode in the past year based on self-reported symptoms. Any mental illness is defined "as having any mental, behavioral, or emotional disorder in the past year that met DSM-IV criteria" *not* including developmental disorders and substance use disorders (SAHMSA, 2017, p.36). Serious mental illness is defined as a mental illness that "substantially interfered with or limited one or more major life activities" (SAMHSA, 2017, p.36). Major depressive episode is defined as "a period of 2 weeks or longer in the past 12 months when

[6] Final estimates are "adjusted to reflect the probability of selection, unit nonresponse, poststratification to known census population estimates, item imputation, and other aspects of the estimation process" (SAMHSA, 2019, p.A-4).

Table 1—Descriptive Statistics

Variable	Definition	Age Group	Statistics					
			Mean	Std. Dev.	Minimum	Median	Maximum	Observations
Cannabis Use in Past Year	Proportion of the population that has used cannabis in the past year	18+	0.1286	0.0415	0.0589	0.1190	0.2856	714
		18-25	0.3183	0.0681	0.1681	0.3067	0.5320	714
		26+	0.0965	0.0394	0.0370	0.0866	0.2548	714
Cannabis Use in Past Month	Proportion of the population that has used cannabis in the past month	18+	0.0805	0.0317	0.0304	0.0718	0.2030	714
		18-25	0.1956	0.0549	0.0774	0.1838	0.3899	714
		26+	0.0610	0.0293	0.0190	0.0527	0.1807	714
Avg. Annual Rate of First Use	Average annual rate of first use of cannabis	18+	0.0134	0.0047	0.0070	0.0123	0.0354	714
		18-25	0.0786	0.0201	0.0296	0.0757	0.1597	714
		26+	0.0031	0.0025	0.0007	0.0021	0.0170	714
Any Mental Illness	Proportion of the population with any mental health illness	18+	0.1904	0.0184	0.1466	0.1898	0.2686	561
		18-25	0.2182	0.0396	0.1532	0.2067	0.3428	561
		26+	0.1859	0.0183	0.1429	0.1850	0.2529	561
Serious Mental Illness	Proportion of the population with a serious health illness	18+	0.0441	0.0067	0.0305	0.0435	0.0637	561
		18-25	0.0538	0.0184	0.0278	0.0473	0.1135	561
		26+	0.0425	0.0063	0.0279	0.0421	0.0604	561
Major Depression	Proportion of the population with a major depressive episode	18+	0.0705	0.0080	0.0465	0.0699	0.0997	714
		18-25	0.1001	0.0240	0.0653	0.0920	0.1761	714
		26+	0.0656	0.0075	0.0427	0.0654	0.0905	714

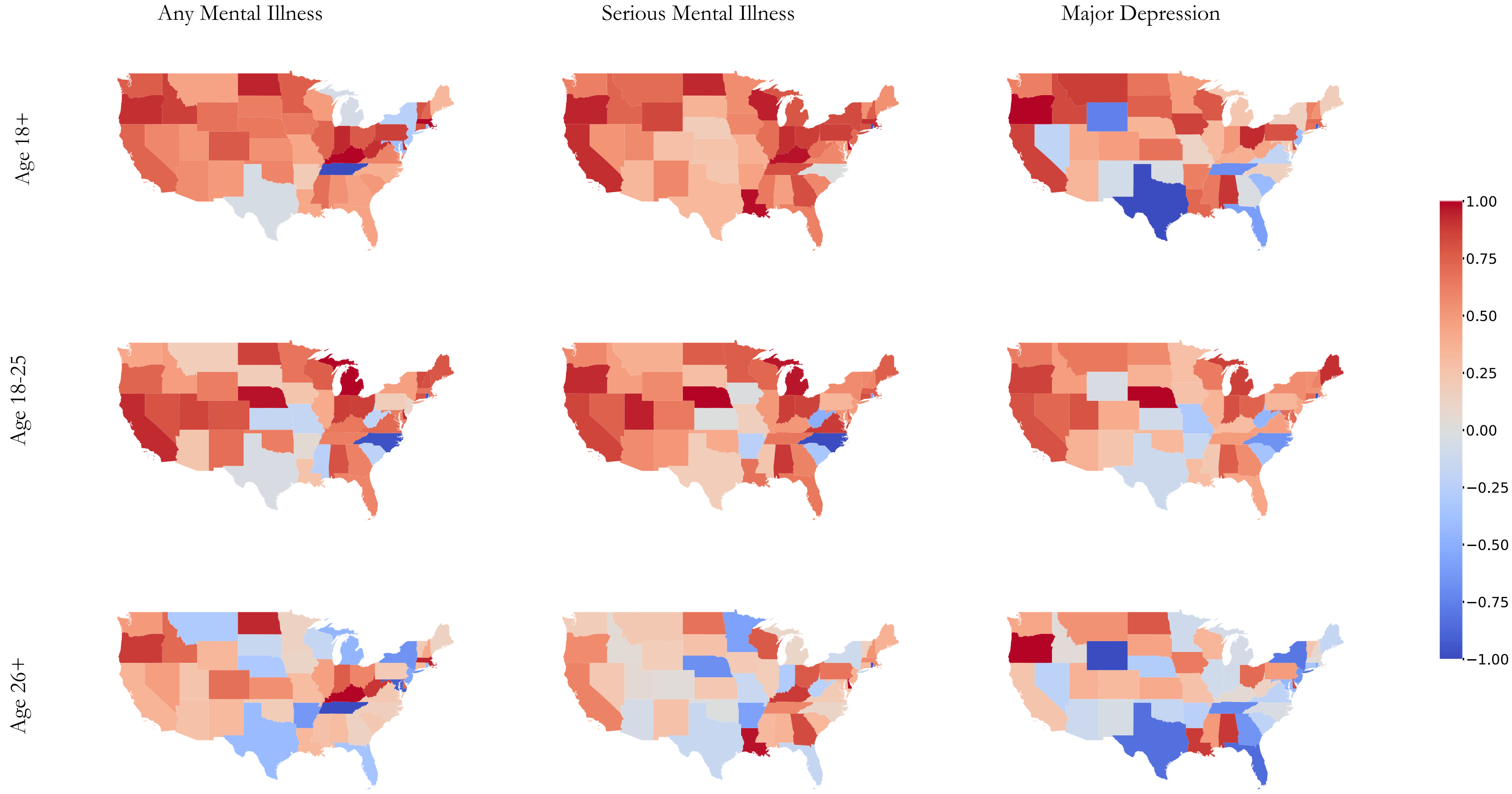
Note: ***Data for cannabis measures and major depression available from 2005-2018. Data for any mental health and serious mental health available from 2008-2018.***

they experienced a depressed mood or loss of interest or pleasure in daily activities, and they had at least some additional symptoms, such as problems with sleep, eating, energy, concentration, and self-worth" (SAMHSA, 2017, p. 33). The mental health measures are not mutually exclusive such overlap will occur across all three mental health measures (i.e., any mental health includes serious mental health & major depressive disorders).

The cannabis consumption measures include the proportion of the population in each state that has consumed cannabis in the past year, consumed cannabis in the past month, and a measure of the average annual rate of first use of cannabis (incidence rate). The average annual rate of first use of cannabis is not a direct measure of cannabis consumption. Thus, the interpretability is slightly more limited when assessing the impact on mental health. However, this measure is particularly informative for studying the impacts of legalization on the dynamics of cannabis consumption for the epidemiologic community and thus we provide estimates. Data were collected on tobacco product use within the past month, alcohol use in the past month, illicit drug use other than marijuana in the past month.[7] All variables from SAMHSA discussed thus far are collected from

[7] The data on illicit drug use is not comparable before and after 2015 due to change in survey methodology.

Figure 1—Correlation Between Cannabis Use & Mental Health Across Contiguous United States



Note: ***Pearson correlation coefficient computed for Cannabis use in the past month and respective mental health category in each column and age group in each row. Data available from 2008-2018 for any mental health and serious mental health. Data available from 2005-2018 for major depression data.***

2005-2018 and categorized by the following age groups: 18+, 18-25, and 26+. This allows us to analyze within-state variation in cannabis consumption and mental illness outcomes by subcategorized age groups.

Descriptive statistics of the key variables of interest are highlighted in Table 1. Note that adult aged 18-25 have generally higher cannabis consumption and mental health levels than adults aged 26+. This result is consistent with our expectations in that younger adults would be more likely to engage in cannabis consumption and have been an age group with significant increases in mental illness levels. Figure 1 presents a state-level heatmap of the raw correlation between cannabis use in the past month and any mental health illness, serious mental health illness, and major depression, respectively. Each category is further broken down to compare the different correlations among different age groups. There appears to be a generally strong positive association between mental health and cannabis consumption, particularly for young adults. However, there appears to be a weakening correlation between the two for adults above the age of 26+. This could, in part, be due to lower variation of both cannabis consumption and mental health for older adults.

3.2 Legal Status & Demographic Covariates

Data were collected on the legal status of cannabis and a set of demographic controls for each state. The legal status data was manually coded based on legislation and passed ballot measures and contains three mutually exclusive indicator variables: criminal offense, decriminalization, and legalization. The variable for criminal offense is equal to one when a state has cannabis penalties that are unadjusted from the federal law. Decriminalization has had significant degrees of policy variation with uncertain beliefs among the public's perception of their ability to consume cannabis with limited risk of legal penalty. Thus, to keep things unambiguous, we categorize decriminalization as when a state has in place *any* legislation reducing the penalty of cannabis possession, typically under a certain threshold, with respect to federal law to capture states that are, perhaps, more progressive in their cannabis policies. Legalization is defined as the full removal of the legal prohibition of cannabis. Table A1 highlights the legal status of cannabis for each state over the time period of this study.

In our main specifications, we utilize cannabis legalization as the sole measure for two main reasons: 1) Legalization provides a significantly higher degree in variation of cannabis consumption and thus it is a stronger instrument alone, allowing us to avoid potential biases of including a second weaker instrument and 2) The issues associated with staggered implementation become excessively confounding with the inclusion of both legalization and decriminalization. Nevertheless, we exploit both legalization and decriminalization to estimate an overidentified 2SLS model in a robustness check, which allows us to test the sensitivity of our main results and further test the exogeneity of legal status. A further treatment of this issue will be discussed in section 6. The timing of legalization is of particular importance in interpretation of the results. We chose to code the year in which the ballot measure was passed, which occurred around November of that year. Because the SAMHSA data is calculated for year-pairs, we will be capturing a smaller "half" effect of the legalization in the first coded year. This is done to capture the early effects of the months leading up to the ballot measure and subsequent enactment to capture any anticipatory effect resulting from expectations and, perhaps, relaxed legal enforcement. Empirical results are consistent with our hypothesis.

Data for demographic covariates were obtained via the Center for Economic and Policy Research's (CEPR) Outgoing Rotational Group (ORG) files of the Current Population Survey (CPS) from 2005-2018 on individuals' age, marital status, education level, labor force status, race, gender, whether one was born in a foreign country, and household income (CEPR, 2005-2018). These variables were characterized into respective categories (i.e., unemployed, employed, not in labor force) and the proportion of the population that fell into each group were calculated for each state and year to normalize the data with respect to the SAMHSA data. Lastly, data on adult obesity rates were obtained from the State of Childhood Obesity (State of Childhood Obesity, 2005-2018). The listed demographic covariates, along with tobacco use and alcohol use mentioned prior, are potential confounders that were either hypothesized or relevant in the literature (Green and Ritter, 2000; Rothert *et al.*, 2020; Spetz *et al.*, 2019). Through the inclusion of these additional covariates, we seek to evaluate the robustness of our estimates.

4. ECONOMETRIC STRATEGY

This section discusses our empirical strategy. We first present the instrumented difference-in-differences (DDIV) specification to outline the overarching relationships of interest. We then present the new DiD methodology developed by Callaway and Sant'Anna (CS; 2021) to study the effects of cannabis legalization on cannabis consumption and mental health. We give an in-depth treatment into establishing the identifying assumptions necessary for proper estimation in the following sections.

4.1 Instrumented Difference-in-Differences

The economic and epidemiologic literature has struggled to isolate the causal impact of cannabis consumption on mental health illness due to a lack of plausibly exogenous variation in cannabis consumption. The simultaneous and confounding nature between cannabis use and mental health illness has made it particularly difficult to isolate this relationship. Recent variation in the legal status of cannabis across states has provided a useful natural experiment to be exploited. We estimate a within-group instrumented difference-in-differences (DDIV) specification via two-stage least squares (2SLS) estimation. The first stage, reduced form, and second stage equations are characterized, respectively, by:

$$Cannabis_{st} = \mathbb{1}(Legalized_{st})\beta^{FS} + X_{st}\Phi + \omega_s + \delta_t + \epsilon_{st} \quad (1)$$

$$MentalHealth_{st} = \mathbb{1}(Legalized_{st})\beta^{RF} + X_{st}\Omega + \omega_s + \delta_t + \nu_{st} \quad (2)$$

$$MentalHealth_{st} = \widehat{Cannabis}_{st}\beta^{DDIV} + X_{st}\Psi + \omega_s + \delta_t + \eta_{st} \quad (3)$$

where s and t index state and year, respectively. The primary variables of interest are measures of cannabis consumption ($Cannabis_{st}$), measures of mental health ($MentalHealth_{st}$), and, the instrument, an indicator variable equal to 1 if the state has legalized cannabis $\mathbb{1}(Legalized_{st})$. $\widehat{Cannabis}_{st}$ represents the predicted values from the first stage equation, eq. (1). The additional components are the state fixed effects (ω_s), the year fixed effects (δ_t), the composite error terms (ϵ_{st}, ν_{st}, η_{st}), and a vector of demographic controls (X_{st}). The demographic controls include state measures of tobacco use, alcohol use, obesity rate, age, marital status, education level, labor force status, race, gender, foreign birth status, and household income. We include the demographic control, as well as measures for other illicit drug use and border effects, in robustness checks. We cluster all robust standard errors at the state level.

The key estimates of β^{FS} and β^{RF} measure the impact of cannabis legalization on cannabis consumption and mental health, respectively. The DDIV estimate β^{DDIV} measures the direct impact of cannabis consumption on mental health. We anticipate that TWFE estimation of eq. (3) alone will produce biased estimates of β^{DDIV} due to omitted confounders and simultaneous determination of cannabis consumption and mental health illness. However, under specific assumptions, we can utilize two-stage least squares estimation to identify the DDIV estimator, β^{DDIV}, to isolate the causal impact of cannabis consumption on mental health.

In order to properly estimate and interpret our key estimates, we must first address concerns of biased estimation in the first stage and reduced form equations—eq. (1) and eq. (2), respectively. Given we have variation in timing of cannabis legalization, recent developments in the DiD literature have shown that static TWFE estimation of eq. (1) and eq. (2) results in population coefficients prone to significant bias under heterogenous treatment effects across time and cohorts (Baker *et al.*, 2022; Callaway and Sant'Anna, 2021; de Chaisemartin and D'Haultfœuille, 2020; Goodman-Bacon, 2021; Sun and Abraham, 2021).[9] Roth *et al.* (2022) highlight that in order to construct unbiased estimates under static TWFE estimation, we must make the following identifying assumptions: (1) *No anticipation,* (2) *Parallel trends*, and (3) *Homogenous treatment effects across years and cohorts*. Where a cohort is defined as the set of states that legalize cannabis in a common year with the comparison group as the set of states who do not legalize cannabis. Under these assumptions, we can construct

[9] We refer the reader to Roth *et al.* (2022) for a synthesis on the present developments in the difference-in-differences literature.

unbiased estimates of the impact of cannabis legalization on cannabis consumption, β^{FS}, and mental health, β^{RF}.

Assumption (1) implies that there is no treatment effect in the years leading up to cannabis legalization for each yearly cohort of treated states. We address this by carefully choosing the year of legalization for our data to capture any possible anticipatory effects—see section 3.2. To address assumptions (2) and (3), we utilize new methods developed by CS to provide evidence in support of assumption (2)—parallel counterfactual trends between each cohort and the comparison group—and in support of *relaxing* assumption (3)—homogenous treatment effects across time and cohorts. An in-depth treatment of assumptions (2) and (3) are addressed in the following section.

In addition to the assumptions stated above, the following traditional 2SLS assumptions must be made as well in order to properly estimate β^{DDIV}: (4) *Monotonicity*, (5) *Relevance*, and (6) *Exclusion*. Assumptions (4) and (5) hold when $\mathbb{E}[Cannabis_{st^*}|\mathbb{1}(Legalized_{st}) = 1] \geq \mathbb{E}[Cannabis_{st^*}|\mathbb{1}(Legalized_{st}) = 0]$, for all $t^* \geq t$ and $cov(Cannabis_{st}, \mathbb{1}(Legalized_{st})) \neq 0$, respectively. That is, the legalization of cannabis only *increases* cannabis consumption in each state and this effect is significant, which are both trivially true and verifiable in the estimation of eq. (1). Assumption (6) holds when $cov(\mathbb{1}(Legalized_{st}), \eta_{st}) = 0$, which implies that cannabis legalization impacts mental health only through cannabis consumption. Hudson *et al.* (2017) highlight that the parallel trends assumption is necessary for proper estimation of β^{DDIV}; however, this allows for certain violations of the traditional IV independence assumptions such that cannabis legalization can be correlated with time-invariant state characteristics that impact cannabis consumption and mental health. Thus, satisfying assumption (2) above provides evidence necessary to support the necessary exogeneity of legal status in the first stage and reduced form. If assumptions (1)-(6) are satisfied, the DDIV estimate measures a weighted average causal response of mental health levels to a change in cannabis consumption levels among the states that underwent cannabis legalization (Angrist and Pischke, 2009; Hudson *et al.*, 2017). Angrist and Pischke (2009) refer to this estimate as the average causal response, denoted ACR.

4.2 Event Study Framework & Group-Time ATT's

Under the prior conventional framework, we could establish and provide support for parallel trends in both the first stage (eq. 1) and reduced form (eq. 2) equations utilizing the following event study specification:

$$Y_{st} = \sum_{\substack{i=-7 \\ i\neq -1}}^{6} \kappa_i * \mathbb{1}(t - LegalYear_s = i) + X_{st}\Gamma + \omega_s + \delta_t + \xi_{st} \tag{4}$$

where s and t index state and year, respectively. In this case, Y_{st} represents either mental health or cannabis consumption measures and $LegalYear_s$ is the year during which state s legalizes cannabis. As above, the additional components are the state fixed effects (ω_s), the year fixed effects (δ_t), the composite error term (ξ_{st}), and a vector of demographic controls (X_{st}). The binary indicator $\mathbb{1}(t - LegalYear_s = i)$ is equal to 1 when a state s is i years away from legalization. The coefficient estimates κ_i are interpreted as the differential trends between treated versus never-treated states at each period i and can be compiled together into an event study visualizing these trends over the relative event time period. The parallel trends assumption can be visually tested by observing these estimates prior to cannabis legalization, such that $i < 0$, and if the coefficient estimates κ_i are not statistically different from zero, we take this as evidence in favor of assuming parallel counterfactual trends. That is, the states that legalized cannabis would have continued a similar trajectory as the comparison states for cannabis consumption and mental health levels given cannabis legalization did not occur.

As mentioned above, recent developments in the DiD literature have highlighted that under multiple treatment periods and heterogenous treatment effects across cohorts and time, both a static and dynamic TWFE approach is prone to significant bias (Baker *et al.*, 2022; Callaway and Sant'Anna, 2021; de Chaisemartin and D'Haultfœuille, 2020; Goodman-Bacon, 2021; Sun and Abraham, 2021). This bias grows particularly pervasive as the dependency of later treated units on earlier treated units increases (i.e., a large proportion of the sample is treated and/or treatments occur early in the sample timeframe). Therefore, we implement an estimation approach developed by CS that is robust to heterogenous treatment effects across cohorts and time. This approach seeks to identify what CS refer to as the group-time average treatment effect on the treated—denoted $ATT(g,t)$—which measures the average treatment effect on the treated for group g in year t where group is synonymous to cohort. Under the assumptions of no anticipation and *unconditional* parallel trends, CS show that the $ATT(g,t)$ can be computed as a simple difference in sample means:[10]

$$ATT(g,t) = \mathbb{E}[Y_t - Y_{g-1} | G_g = 1] - \mathbb{E}[Y_t - Y_{g-1} | C = 1] \tag{5}$$

where G_g and C are indicator variables equal to 1 if a unit belongs to group g or the control group of never-treated units C, respectively. In our case, the outcomes Y_t correspond to cannabis consumption and mental health outcomes in year t, the groups g correspond to cohorts of states that legalized cannabis in a common year, and the control/comparison set C corresponds to the states the do not legalize cannabis over the timeframe.

[10] Callaway and Sant'Anna (2021) additionally allow for estimation conditional on covariates utilizing doubly robust estimation. We find conditioning on covariates does not change our results.

Note eq. (5) makes comparisons only between a specific cohort and the never-treated comparison states for each time period, thus this approach is robust to heterogenous treatment effects across cohorts and time. It becomes apparent that this estimation process results in numerous estimates that are difficult to extrapolate when viewed in isolation. Therefore, we report multiple aggregation approaches recommended by CS including a dynamic aggregation approach, a group-specific aggregation approach, and an overall simple group-size weighted average.

With respect to the dynamic aggregation approach, we compute a group-size weighted average of all the $ATT(g,t)$ in each time period relative to the legalization period and a base period, where $t = 0$ denotes the legalization period. For $t^* \geq t$, the base period is $t - 1$ which results in coefficients that can be interpreted synonymously to κ_i in eq. (4) for the post-treatment period. For $t' < t$, the relative base period is the immediately preceding period (i.e., time period t' is relative to base period $t' - 1$). The coefficients in the pre-treatment periods lend themselves to a slightly different interpretation than eq. (4) albeit an intuitive one. Each pre-treatment period estimate takes on what CS refer to as a "pseudo-ATT" interpretation. That is, if the treatment were to take place in period t' what would the group-size weighted average $ATT(g,t)$ have been relative to period $t' - 1$. As recommended by CS, we use these estimates to construct an event study plot to visually test for parallel trends and no anticipation and to study the dynamics of the treatment effect over time. Coefficient estimates not significantly distinguishable from zero in the pre-treatment period provide evidence in favor of these assumptions.[11] We then compute and report an overall single point estimate by taking the average of these estimates for $t^* \geq t$. This allows us to get a sense of the average dynamic treatment effect across all time periods post-treatment.

For the group-specific aggregation approach, we compute the average $ATT(g,t)$ across the entire length of treatment exposure for each group g. We then compile these into a single point estimate by taking the average across all group-specific estimates. This allows us to get a sense of the average treatment effect across all of the groups, regardless of treatment exposure length. We expect to observe mental health having a gradually increasing and thus the group-specific aggregation approach to be less than the dynamic estimates. Lastly, we compute a simple single point estimate of a group-size weighted average across all individual $ATT(g,t)$ estimates. This approach provides an overall picture of the treatment effect, with heavier weighting on those with longer exposure to treatment. We report each single-point estimate for each aggregation approach—denoted AGGTT.

We use the CS methodology to study the dynamic causal impact of cannabis legalization on cannabis consumption and mental health. We further utilize this methodology to provide evidence in support of assumptions (1)-(3) in section 4.1. Using the CS method to construct an event study plot, we are able to provide support for parallel trends *unconditional on any covariates* and no anticipation. Furthermore, we show that the

[11] Persistent estimates greater than zero is akin to an upwards pre-trend, and vice-versa.

AGGTT estimates are reasonably close to the TWFE estimates of the first stage, β^{FS}, and reduced form, β^{RF}, relationship in eq. (1) and eq. (2), respectively. This allows us to relax assumption (3) of homogenous treatment effects across time and cohorts and make a reasonable interpretation of the DDIV estimate, β^{DDIV}, in eq. (3). This result is consistent with the theory of what drives the bias in the canonical TWFE specification under staggered treatment adoption (i.e., when the dependency of later treated units on earlier treated units is high). Note that our sample has a relatively small number of treated units (11/51) and the bulk of the treatment happens towards the latter half of the sample period. We provide the TWFE event study plots of eq. (4) in the Appendix.

5. EMPIRICAL RESULTS

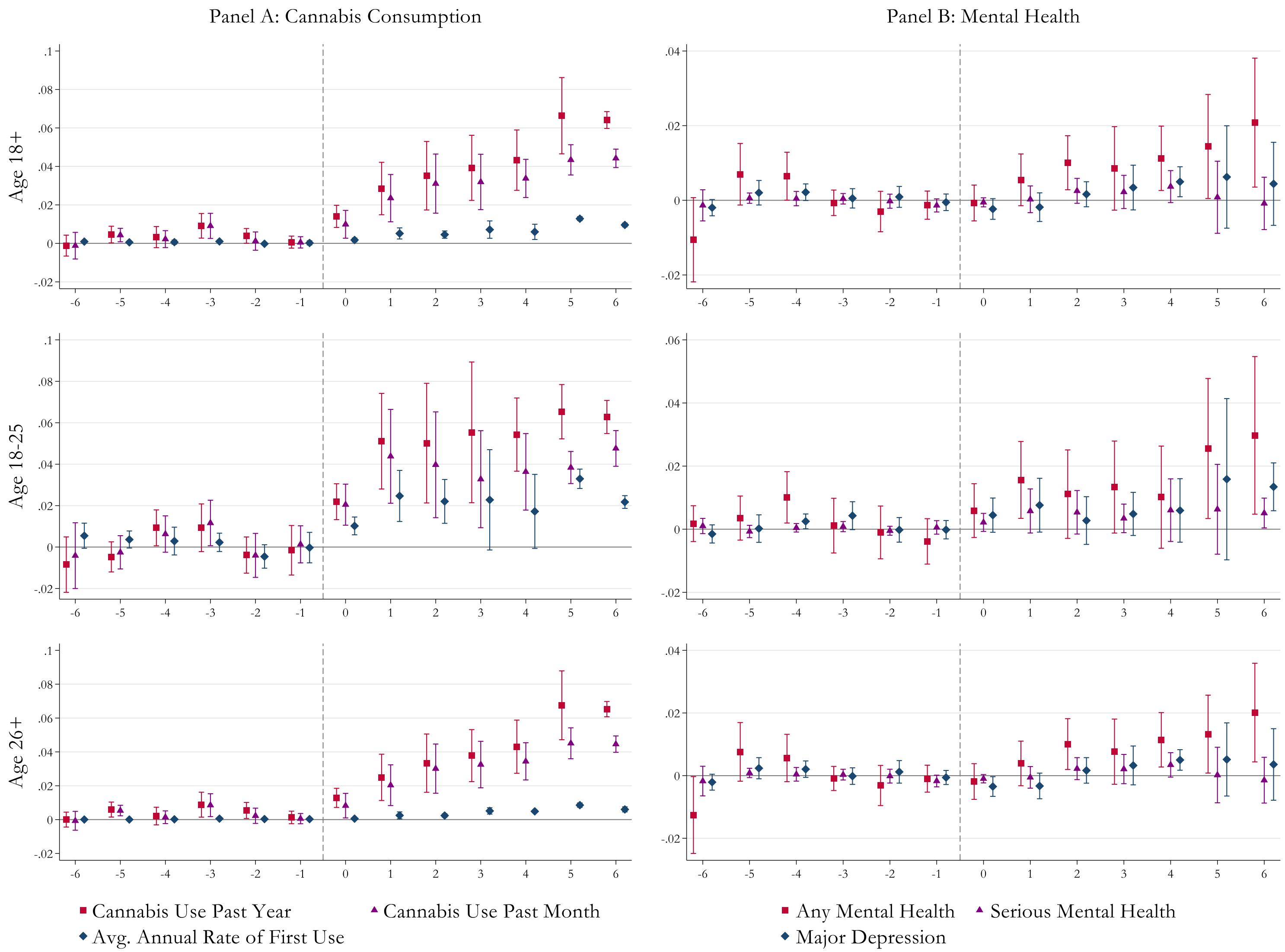
In this section, we first present our results of the estimated impact of cannabis legalization on cannabis consumption and mental health. We estimate this relationship using the Callaway and Sant'Anna (CS; 2020) method outlined in the previous section and using the traditional TWFE method highlighted in eq. (1) and eq. (2). We then estimate the direct impact of cannabis consumption on mental health utilizing our DDIV framework highlighted in the previous section. Our key variables of interest are outlined in Table 1.

5.1 The Impact of Cannabis Legalization on Cannabis Consumption & Mental Health

Figure 2 presents the constructed event study utilizing the CS methodology to study the dynamic impact of cannabis legalization on cannabis consumption and mental health. The x-axis denotes the event time relative to cannabis legalization for each cohort normalized at time 0. As discussed, time 0 captures the months leading up to the ballot measure thus capturing anticipatory effects.[12] We anticipate this effect to be smaller than subsequent years, which is observed. Panel A plots the estimates for cannabis consumption measures for each respective age group in each row. For adults aged 18-25, we observe no pre-trend in cannabis consumption.[13] However, we observe slight pre-trends in cannabis consumption for adults aged 26+ and the aggregated group for adults 18+ albeit these estimates are, in general, statistically close to zero. Nevertheless, an upwards pre-trend would lead to positive selection bias such that our estimates *overstate* the impact of cannabis legalization on cannabis consumption. We keep this in mind for potential bias in our estimates for the impact of cannabis legalization on cannabis consumption for adults aged 18+ and aged 26+; however, we anticipate the bias to be generally small given the drastic shift in cannabis consumption levels post-legalization Similarly, Panel B plots the estimates for mental health outcomes. For all age groups, we observe no pre-trend in in mental health levels, suggesting cannabis legalization is exogenous to mental health illness levels.

[12] See section 3.2 for a discussion behind this decision.
[13] See section 4.2 for a discussion of the reference periods utilized in the pre-treatment period of the event study.

Figure 2—The Dynamic Impact of Cannabis Legalization on Cannabis Consumption & Mental Health



Note: ***The figures above show the estimates constructed utilizing the Callaway and Sant'Anna (2020) method outlined in Section 4. Panels A and B plot the estimates for cannabis consumption and mental health, respectively, for a respective age group in each row. The vertical bars represent 95% C.I. constructed using robust SEs clustered at the state level. The x-axis denotes relative time since ballot measure was passed at t = 0. Pre-event estimates use immediately preceding period as reference.***

In Panel A of Figure 2, we can clearly see a drastic increase in cannabis consumption levels for all measures among states that legalized cannabis across age groups. Note the minimal increase in average annual rate of first use for adults aged 26+. We expect this result given the average annual rate of first use is generally very low among adults aged 26+ due to a significant proportion of adults have likely already tried cannabis at some point in their past. A result of much more interest is the drastic increase in average annual rate of first use among adults aged 18-25. We observe a greater proportion of young adults engaging in cannabis consumption for the first time and consuming cannabis more frequently as highlight by monthly consumption. The gradually increasing dynamics of cannabis consumption suggests that cannabis consumption is increasingly becoming more prevalent among these states, likely from cultural normalization and peer effects. These results, generally, come as no surprise following the legalization of recreational cannabis. However, the two notable takeaways are: 1) The increase in young adults consuming cannabis is of concern given the medical literature suggests young adults are of greatest concern for cannabis-induced mental health consequences & 2) The gradually increasing dynamics of cannabis consumption are of interest for hypothesizing the long-term implications for mental illness given the complexity of mental illness development.

In Panel B of Figure 2, we can see that the prevalence of adults with symptoms of *any* mental health illness follows a lagged trajectory remarkably similar to cannabis consumption across all age groups among states that have legalized cannabis. These two results together provide evidence of increasing dynamic interactions between cannabis consumption and mental health illness. We observe an initial shock for adults aged 18-25 suggesting a more acute impact as well, but not for adults aged 26+. Additionally, we observe increases in serious mental health illness and major depression among adults aged 18-25, but not for adults aged 26+. This is consistent with the medical literature such that adolescents and young adults are increasingly susceptible to the negative mental health consequences of cannabis consumption.

The results of Panels A and B in Figure 2 are aggregated and summarized in Tables 2 & 3, respectively. Tables 2 & 3 present the results of the TWFE estimation of eq. (1) & (2), respectively, and the three different aggregation approaches (AGGTTs) of the CS method outlined in section 4.2 for each respective mental health measure in the columns. Panels A, B, and C correspond to adults aged 18+, 18-25, and 26+, respectively. The adults aged 18+ category provides an aggregate estimate for all adults. However, we narrow our focus on estimates between adults aged 18-25 and 26+ to account for age heterogeneity. Given the evidence of dynamically increasing effects, our preferred estimate of interest is the dynamic aggregate estimate, which computes the average AGGTT across all post-treatment estimates. The group aggregate estimate will understate the true effect under increasing dynamic effects by weighting too heavily those states that we only observe for a short period post legalization. Each of these estimates takes on a quasi-ATT interpretation of the average effect of legalization on cannabis consumption and mental health among states that underwent legalization.

Table 2—The Estimated Impact of Cannabis Legalization on Cannabis Consumption

Dep. Var.	Cannabis Use in Past Year				Cannabis Use in Past Month				Avg. Annual Rate of First Use			
	ATT	SE	95% C.I.		ATT	SE	95% C.I.		ATT	SE	95% C.I.	
A: Age 18+:												
TWFE	0.0441***	0.005	0.0344	0.0538	0.0332***	0.0038	0.0256	0.0407	0.0058***	0.0008	0.0042	0.0074
AGGTT												
Simple	0.0326***	0.0057	0.0215	0.0437	0.0257***	0.0046	0.0167	0.035	0.0051***	0.0008	0.0035	0.0067
Dynamic	0.0415***	0.0046	0.0325	0.0506	0.0311***	0.0035	0.0242	0.0380	0.0067***	0.0007	0.0054	0.0081
Group	0.0273***	0.0059	0.0157	0.0389	0.0207***	0.0052	0.0106	0.031	0.0044***	0.0008	0.0029	0.0060
B: Age 18-25:												
TWFE	0.0448***	0.0084	0.0280	0.0616	0.0422***	0.0067	0.0288	0.056	0.0199***	0.0032	0.0134	0.0263
AGGTT												
Simple	0.0455***	0.0080	0.0299	0.0611	0.0348***	0.0069	0.0213	0.048	0.0196***	0.0035	0.0127	0.0265
Dynamic	0.0516***	0.0074	0.0372	0.0660	0.0370***	0.0055	0.0261	0.048	0.0217***	0.0033	0.0151	0.0282
Group	0.0415***	0.0084	0.0250	0.0580	0.0326***	0.0079	0.0172	0.048	0.0197***	0.0033	0.0131	0.0262
C: Age 26+:												
TWFE	0.0446***	0.0049	0.0348	0.0544	0.0323***	0.004	0.0247	0.0398	0.0036***	0.0005	0.0027	0.0046
AGGTT												
Simple	0.0311***	0.0059	0.0194	0.0427	0.0246***	0.0049	0.0151	0.034	0.0030***	0.0004	0.0022	0.0039
Dynamic	0.0407***	0.0045	0.0320	0.0494	0.0308***	0.0036	0.0237	0.038	0.0043***	0.0004	0.0036	0.0050
Group	0.0255***	0.0059	0.0140	0.0370	0.0192***	0.0051	0.0092	0.029	0.0025***	0.0005	0.0015	0.0035

Note: ***Dependent variable: Proportion of adults with respective cannabis use measure in each column for each age group in respective panel (A, B, C). Heteroskedastic robust SEs allow for arbitrary correlation of residuals within each state. Demographic covariates are not included. Each AGGTT aggregation estimate computed as discussed in section 4.2. TWFE presents two-way fixed effect estimation of eq. (3). State and Year FE included in TWFE estimation. Each estimate is over the full time period from 2005-2018 (N=714). *, **, and *** represent significance at the 10, 5, and 1% levels, respectively.***

Table 3—The Estimated Impact of Cannabis Legalization on Mental Health

Dep. Var.	Any Mental Illness				Serious Mental Illness				Major Depression			
	ATT	SE	95% C.I.		ATT	SE	95% C.I.		ATT	SE	95% C.I.	
A: Age 18+												
TWFE	0.0060**	0.0018	0.0023	0.0097	0.0007	0.0008	-0.0009	0.0023	0.0022**	0.0010	0.0024	0.0041
AGGTT												
Simple	0.0070***	0.0026	0.0020	0.0120	0.0011	0.0015	-0.0017	0.0040	0.0008	0.0020	-0.0031	0.0047
Dynamic	0.0100***	0.0036	0.0029	0.0170	0.0012	0.0020	-0.0027	0.0050	0.0024	0.0029	-0.0034	0.0081
Group	0.0073***	0.0021	0.0031	0.0114	0.0016	0.0010	-0.0004	0.0035	0.0007	0.0015	-0.0022	0.0036
B: Age 18-25												
TWFE	0.0119***	0.0037	0.0045	0.0192	0.0047**	0.0022	0.0002	0.0092	0.0086***	0.0016	0.0053	0.0118
AGGTT												
Simple	0.0124***	0.0043	0.0039	0.0209	0.0045**	0.0021	0.0003	0.0087	0.0059***	0.0021	0.0018	0.0101
Dynamic	0.0159***	0.0054	0.0053	0.0265	0.0049**	0.0024	0.0002	0.0096	0.0078**	0.0031	0.0018	0.0139
Group	0.0089*	0.0049	-0.0007	0.0184	0.0037	0.0023	-0.0009	0.0082	0.0042*	0.0024	-0.0005	0.0089
C: Age 26+												
TWFE	0.0052**	0.0020	0.0012	0.0092	0.0002	0.0008	-0.0014	0.0018	0.0013	0.0010	-0.0008	0.0034
AGGTT												
Simple	0.0062**	0.0025	0.0014	0.0110	0.0007	0.0015	-0.0022	0.0036	0.0001	0.0021	-0.0040	0.0043
Dynamic	0.0092***	0.0034	0.0027	0.0158	0.0007	0.0019	-0.0031	0.0045	0.0017	0.0029	-0.0040	0.0074
Group	0.0071***	0.0021	0.0031	0.0112	0.0013	0.0010	-0.0060	0.0032	0.0003	0.0015	-0.0027	0.0033

Note: ***Dependent variable: Proportion of adults with respective mental health measure in each column for each age group in respective panel (A, B, C). Key variable of interest is cannabis legalization in a state. Heteroskedastic robust SEs allow for arbitrary correlation of residuals within each state. Demographic covariates are not included. For AGGTT, each aggregation estimate computed as discussed in section 4.2. TWFE presents two-way fixed effect estimation of eq. (3). State and Year FE included in TWFE estimation. Any mental health and serious mental health estimates from 2008-2018 (N = 561) and major depression estimates from 2005-2018 (N = 714). *, **, and *** represent significance at the 10, 5, and 1% levels, respectively.***

Table 2 presents the estimated impact of cannabis legalization on cannabis consumption. Among states that have legalized cannabis, our estimates suggest that cannabis legalization resulted in a 3.70pp and 3.08pp average increase in the proportion of the population that has consumed cannabis within the past month for adults aged 18-25 and 26+, respectively. This corresponds to an 18.9 and 50.8 percent increase from the sample mean. The estimates for cannabis consumption in the past year are 5.16pp (16.2 percent) and 4.07pp (42.3 percent), respectively. Additionally, we estimate that cannabis legalization increased the average annual rate of first use (incidence rate) by 2.17pp (27.6 percent) and 0.43pp (139 percent) for adults aged 18-25 and 26+, respectively. However, the estimates for adults aged 18+ and 26+ will likely *overstate* the true impact of legalization on cannabis consumption due to the evidence of upwards pre-trends. All estimates from Table 2 are statistically significant at the 1 percent level. These estimates are robust irrespective of aggregation method.

Table 3 presents the estimated impact of cannabis legalization on mental health illness. Among states that have legalized cannabis, we estimate that cannabis legalization resulted in a 1.59pp (7.3 percent) and 0.92pp (5.0 percent) average increase in the proportion of the population that has symptoms of any mental health illness for adults aged 18-25 and 26+, respectively. These estimates are statistically significant at the 1 percent level. For adults aged 18-25, we estimate that serious mental health illness and major depression increased by 0.49pp (9.1 percent) and 0.78pp (7.8 percent). These results are significant at the 5 percent level. We can thus deduce that approximately half of the increase in any mental health among adults aged 18-25 is driven by depressive disorders. We find no evidence that cannabis legalization increased serious mental health or major depression among adults aged 26+.

We believe the AGGTT estimates to be the most accurate estimates to gauge the causal impact of cannabis legalization on cannabis consumption and mental health. However, the new developments in the DiD literature have not yet explicitly been extended into IV settings. Fortunately, in our case, the TWFE estimates are sufficiently close to the AGGTT estimates in Tables 3 & 4. This result is consistent with the mechanisms that drive bias with heterogenous treatment effects across cohorts and time (i.e., later treated units rely heavily on earlier treated units for comparison). In our case, legalization occurs for a relatively small proportion of the states and heavily towards the latter half of the sample period. Given the results provided, we feel comfortable moving forward in estimating the direct impact of cannabis consumption on mental health using our DDIV framework (i.e., exploiting legalization as an instrument using 2SLS under a TWFE framework).

5.2 The Direct Impact of Cannabis Consumption on Mental Health

The different measures of cannabis consumption estimated in the previous section are individually informative into the dynamics of how cannabis legalization alters cannabis consumption among the public. However, cannabis consumption within the past month provides a more robust measure of regular cannabis consumption. Therefore, all estimates of the impact of cannabis consumption on mental health are constructed utilizing this measure of monthly cannabis consumption. Estimates including the other measures of cannabis consumption are provided in Table A2 in the appendix.

Table 4 provides the estimates of the DDIV specification outlined in section 4.1 for each respective measure of mental health noted in the columns. For each mental health measure, we first estimate a simple pooled OLS estimation of eq. (3), a TWFE estimation of eq. (3), and, finally, the DDIV estimation of eq. (3) less the set of demographic covariates.[14] We provide the first stage F-statistic for each DDIV estimate.[15] The DDIV estimate lends itself to the average causal response (ACR) interpretation (Angrist and Pischke, 2009; Hudson *et al.*, 2017). That is, the weighted average response of mental health levels to a change in cannabis consumption levels among states that have legalized cannabis.[16] The potential bias arising from pre-trends in our first-stage relationship, highlighted in the previous section, will result in our DDIV estimate *understating* the true relationship between cannabis consumption and mental health for the age categories 18+ and 26+.[17] We continue with our analysis acknowledging this possible conservative interpretation of the true impact.

For adults aged 18-25 and 26+, our estimates suggest that a 1pp increase in the proportion of the population that has consumed cannabis within the past month resulted in a 0.325pp and 0.192pp increase in the proportion of the population with any mental health illness, respectively. The economic significance is substantial—these results imply that roughly 3 out of 10 adults aged 18-25 and 2 out of 10 adults aged 26+ develop symptoms of any mental health illness after engaging in monthly cannabis consumption at both the intensive and extensive margin following legalization within a state. These results are significant at the 1% and 5% level, respectively. For adults aged 18-25, we additionally estimate that a 1pp point increase in cannabis consumption results in a 0.129pp and 0.203pp increase in serious mental illness and major depression, respectively. This further suggests that 1 out of 10 adults aged 18-25 develop a serious mental health illness that significantly interferes with major life activities, as defined by SAMHSA (SAMHSA, 2017). We find no evidence of this effect on serious mental illness or major depression for adults aged 26+. These results, nevertheless, raise significant red flags to the negative implications of cannabis consumption on mental health, particularly among young adults.

[14] Because we find evidence of unconditional parallel trends in section 5.1, we include the set of demographic covariates and additional controls in robustness checks in section 6.2.

[15] These F-statistics range between 24 and 78, which exceeds traditional standards (Staiger and Stock, 1998). However, recent literature has suggested this may not be sufficient. We address this in section 6.

[16] Weighted by states whose cannabis consumption levels are most impacted by legalization.

[17] The IV Wald Estimator and 2SLS are algebraically equivalent in a just-identified model such that $\beta^{DDIV} = {\beta^{RF}}/{\beta^{FS}}$. Thus, positive selection bias in β^{FS} will deflate the true β^{DDIV}.

Table 4—The Estimated Impact of Cannabis Consumption on Mental Health

	Any Mental Illness			Serious Mental Illness			Major Depression		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	OLS	TWFE	DDIV	OLS	TWFE	DDIV	OLS	TWFE	DDIV
A: Age 18+									
Cannabis Use in Past Month	0.197*** [0.045]	0.165*** [0.053]	0.216*** [0.067]	0.068*** [0.013]	0.041** [0.016]	0.026 [0.030]	0.094*** [0.016]	0.091*** [0.022]	0.066** [0.030]
First Stage F-Statistic	-	-	59	-	-	59	-	-	78
B: Age 18-25									
Cannabis Use in Past Month	0.303*** [0.050]	0.138*** [0.038]	0.325*** [0.123]	0.117*** [0.018]	0.026 [0.016]	0.129* [0.071]	0.196*** [0.026]	0.090*** [0.017]	0.203*** [0.049]
First Stage F-Statistic	-	-	24	-	-	24	-	-	40
C: Age 26+									
Cannabis Use in Past Month	0.137*** [0.049]	0.163*** [0.058]	0.192** [0.075]	0.041*** [0.014]	0.039** [0.017]	0.007 [0.030]	0.041** [0.017]	0.081*** [0.023]	0.041 [0.032]
First Stage F-Statistic	-	-	60	-	-	60	-	-	74
State & Year FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Instruments	-	-	Legalization	-	-	Legalization	-	-	Legalization
Observations	561	561	561	561	561	561	714	714	714

Note: ***Dependent variable: Proportion of adults with mental health measure in respective column for each age group in respective panel (A, B, C). Heteroskedastic robust SEs allow for arbitrary correlation of residuals within each state. Each estimate is an individual regression estimate, noted by column, for respective age group, cannabis use measure and mental health measure. Demographic covariates not included in any estimate. OLS presents pooled ordinary least squares estimates of eq. (3). TWFE presents two-way fixed effects estimates of eq. (3). DDIV presents instrumented difference-in-differences estimates outlined in section 4. DDIV includes cannabis legalization as the sole instrument. *, **, and *** represent significance at the 10, 5, and 1% levels, respectively.***

6. ROBUSTNESS

In this section, we address the robustness of our model specification. We target potential vulnerabilities of our model via 3 avenues. First, we consider a placebo test assigning cannabis legalization status to alternative states to test that there were not unobserved factors driving cannabis consumption and/or mental health levels among other states around a similar time. Second, the literature has highlighted that the first-stage F-statistic can be a deceiving measure of the true attenuation of bias in 2SLS inference, thus we address possible concerns of a weak IV (Keane and Neal, 2021). Lastly, we consider the inclusion of a set of demographic covariates, the use of other illicit drugs, and border effects to evaluate the sensitivity of our results to additional covariates.

6.1 Placebo Test

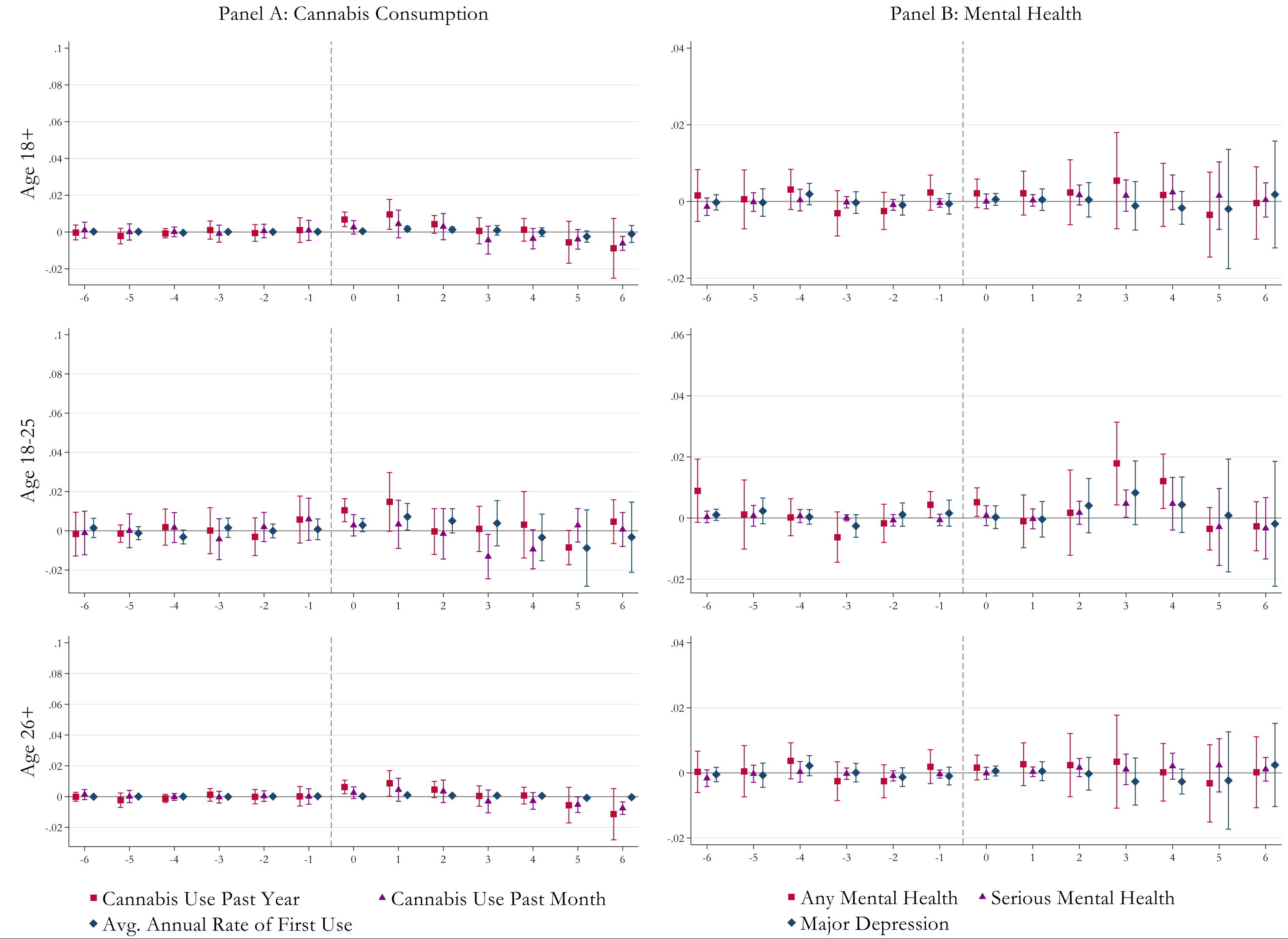
We consider the possibility that there were differential trends in cannabis consumption and mental health among other states during the same time frame that the "true" states in this study legalized cannabis. This is particularly important in conceptualizing the counterfactual as a robust measure for the path that the "true" states would have continued given legalization did not occur. To avoid any ambiguity in the selection of placebo states, we utilize a simple K-nearest neighbors (KNN) algorithm to classify each "true" state to a unique "placebo" state that is most similar based on an aggregated, z-score normalized vector of demographic variables measuring distributions on age, education, race, gender, foreign born status, income, marital status, labor market status, and total population. We conducted this process by assigning each "true" state a "placebo" state without replacement. Table A2 highlights each states respective placebo state. We then drop the "true" states from the sample and re-estimate the CS model outlined in section 4.2.

Figure 3 presents the results of the placebo test utilizing the CS method as similarly done in section 4.2, now with each cohort corresponding to the equivalent cohort of respective "placebo" states and the comparison set corresponding to states that do not legalize less the new "placebo" states. Visually, we observe near perfect parallel trends prior to and after the event period for cannabis consumption across all age groups. Although less statistically precise, we observe strong evidence of parallel trends across time and age groups for mental health as well. We thus feel confident in using the other states as the counterfactual in our main model. These results persisted across different strategies in choosing "placebo" states, including geographic proximity and randomization. See Figures A2-A4 for the distribution of placebo estimates under randomization.

6.2 IV Robustness

It is well established in the literature that 2SLS estimation can perform worse than OLS estimation when instruments are weak. Stock and Yogo (2005) note, as a general rule of thumb, that a first stage F-statistic greater than 10 is sufficient to alleviate concerns of weak IV bias. However, recent literature has highlighted

Figure 3—Placebo Test with K-Nearest Neighbors Selected States



Note: ***These figures show the estimates constructed utilizing the Callaway and Sant'Anna (2020) method outlined in Section 4. <u>These plots use placebo states outlined in Table A2.</u> The vertical bars represent 95% C.I. constructed using robust SEs clustered at the state level. The x-axis denotes relative time since ballot measure was passed at t = 0. Pre-event estimates use immediately preceding period as reference.***

that this threshold must be significantly higher to alleviate other issues that arise in 2SLS such that, even with sufficiently strong instruments by Stock and Yogo (2005) standards, 2SLS "will have spuriously inflated power to find false positive effects, and little power to detect true negative effects" (Keane and Neal, 2021, p. 2). Following suggestions by Keane and Neal (2021), we address these concerns by reporting the Anderson and Rubin (AR; 1949) test for inference of our DDIV estimates and provide results from the unbiased estimator of Andrews and Armstrong (2017) as an alternative estimator to our 2SLS estimator of the DDIV specification.[18] Furthermore, we include decriminalization as an additional instrument to estimate an over-identified DDIV specification using 2SLS and Limited Information Maximum Likelihood (LIML). We do this for two main reasons: 1) To test the robustness of our estimates in the just-identified specification and 2) To test further the exogeneity of our instrument set using the overidentification test. Together these tests provide strong robustness checks against bias from weak IVs and, in our case, a relatively limited sample size and further provide evidence in favor of legalization as an exogenous instrument.

Table 5 provides the average causal response (ACR) estimates for the just-identified specifications, using our main DDIV specification and the Unbiased IV estimator, and the over-identified specifications, using 2SLS and LIML. Each estimate utilizes cannabis use in the past month as the key variable of interest and the dependent variable as the respective mental health outcome noted in the columns. We report the traditional clustered robust standard errors (SE), the first-stage F-statistic (F-stat), the Anderson- Rubin test (AR Test) p-value, and the over-identification test (Over-ID Test) p-value for each appropriate estimator. The AR test is utilized to conduct inference on the DDIV estimates—which tests the null hypothesis that the ACR estimate is equal to 0. The Over-ID test allows us to test the plausibility that exogeneity holds for the instruments. Failing to reject this test provides evidence in favor of the instrument set being exogenous.

We observe that across the different just-identified and over-identified estimators utilized, the ACR estimates remain remarkably robust. Furthermore, the AR test inference on the DDIV estimates does not differ significantly from the standard t-test inference. The results of the Over-ID Test overwhelmingly provide support in the exogeneity of legal status as an instrument. Note that the inclusion of decriminalization as an additional instrument the first stage F-statistic decreases, thus theory predicts that the over-identified 2SLS estimates will be more biased towards the OLS bias. Referring to column (2), (5), and (8) of Table 4, we can see that this is generally what is observed. All of these results together increase our confidence in the DDIV estimates of our main specification.

[18] The just-identified 2SLS case is median-biased when instruments are weak and/or the sample size is small with no first moment. Andrews and Armstrong (2017) show that by exploiting the sign of the first-stage coefficient one can construct a mean-unbiased IV estimator. This estimator is more robust than 2SLS under small samples and/or weak IVs. We refer the reader to Andrews and Armstrong (2017) for an in-depth treatment of this estimator.

Table 5—The Estimated Impact of Cannabis Consumption on Mental Health (IV Robustness)

	Any Mental Illness					Serious Mental Illness					Major Depression				
	ACR	SE	F-Stat	AR Test	Over-ID Test	ACR	SE	F-Stat	AR Test	Over-ID Test	ACR	SE	F-Stat	AR Test	Over-ID Test
A: Age 18+															
Just-Identified															
DDIV	0.216***	0.066	59	0.011	-	0.026	0.029	59	0.377	-	0.066**	0.009	78	0.051	-
Unbiased IV	0.214***	0.066	59	-	-	0.024	0.029	59	-	-	0.065**	0.008	78	-	-
Over-Identified															
2SLS	0.192***	0.067	31	-	0.205	0.027	0.030	31	-	0.893	0.068**	0.028	38	-	0.813
LIML	0.192***	0.067	31	-	0.205	0.027	0.030	31	-	0.893	0.068**	0.028	38	-	0.813
B: Age 18-25															
Just Identified															
DDIV	0.325***	0.120	24	0.021	-	0.129*	0.070	24	0.069	-	0.203***	0.048	40	0.004	-
Unbiased IV	0.311***	0.120	24	-	-	0.121*	0.070	24	-	-	0.198***	0.048	40	-	-
Over-Identified															
2SLS	0.327***	0.122	12	-	0.905	0.125*	0.070	12	-	0.563	0.197***	0.048	14	-	0.461
LIML	0.327***	0.122	12	-	0.905	0.126*	0.070	12	-	0.563	0.198***	0.049	14	-	0.461
C: Age 26+															
Just-Identified															
DDIV	0.192***	0.074	60	0.024	-	0.007	0.029	60	0.812	-	0.041	0.031	74	0.212	-
Unbiased IV	0.190***	0.074	60	-	-	0.005	0.029	60	-	-	0.041	0.031	74	-	-
Over-Identified															
2SLS	0.158**	0.074	30	-	0.125	0.010	0.029	30	-	0.786	0.045	0.029	35	-	0.741
LIML	0.158**	0.074	30	-	0.125	0.010	0.029	30	-	0.786	0.045	0.029	35	-	0.741

Note: ***Dependent variable: Proportion of adults with respective mental health measure in each column for each age group in respective panel (A, B, C). Key variable of interest is proportion of the population that has used cannabis in the past month. Heteroskedastic robust SEs allow for arbitrary correlation of residuals within each state. State and year fixed effects included in all estimates. ACR denotes the average causal response as defined in section 4. First-stage F-statistic reported in F-Stat column, Anderson-Rubin test p-value reported in AR Test column, and overidentification test p-value reported in Over-ID Test column. Legalization used as sole instrument in just-identified estimates. Legalization and decriminalization used as instruments in over-identified estimates. DDIV presents instrumented difference-in-differences estimates outlined in section 4. Unbiased IV presents estimates from the Andrews and Armstrong (2017) estimator discussed in section 6. 2SLS and LIML present over-identified estimates using two-stage least squares and limited information maximum likelihood, respectively. Any mental health and serious mental health estimates from 2008-2018 (N = 561) and major depression estimates from 2005-2018 (N = 714). *, **, and *** represent significance at the 10, 5, and 1% levels, respectively.***

Table 6—The Estimated Impact of Cannabis Consumption on Mental Health (Additional Covariates)

		Any Mental Illness			Serious Mental Illness			Major Depression		
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		TWFE	Unbiased IV	DDIV	TWFE	Unbiased IV	DDIV	TWFE	Unbiased IV	DDIV
	Age									
		A: Controlling for Demographic Covariates								
Cannabis Use in Past Month	18+	0.159***	0.208**	0.212**	0.033**	0.007	0.007	0.086***	0.052	0.053
		[0.048]	[0.087]	[0.090]	[0.016]	[0.035]	[0.036]	[0.023]	[0.032]	[0.033]
	18-25	0.078*	0.254**	0.273**	0.013	0.144**	0.151**	0.053**	0.175***	0.182***
		[0.051]	[0.129]	[0.135]	[0.016]	[0.067]	[0.070]	[0.021]	[0.054]	[0.056]
	26+	0.171***	0.197**	0.200*	0.031**	-0.019	-0.019	0.088***	0.033	0.033
		[0.053]	[0.099]	[0.104]	[0.017]	[0.038]	[0.039]	[0.023]	[0.035]	[0.036]
		B: Controlling for Demographic Covariates & Illicit Drug Use Other Than Cannabis								
Cannabis Use in Past Month	18+	0.149***	0.204**	0.209**	0.029*	0.005	0.005	0.081***	0.051	0.052
		[0.051]	[0.087]	[0.091]	[0.017]	[0.036]	[0.037]	[0.023]	[0.033]	[0.034]
	18-25	0.064	0.253**	0.273**	0.015	0.143**	0.151**	0.051**	0.173***	0.180***
		[0.042]	[0.129]	[0.135]	[0.017]	[0.067]	[0.070]	[0.022]	[0.052]	[0.055]
	26+	0.167***	0.180*	0.182*	0.030*	-0.022	-0.023	0.086***	0.026	0.025
		[0.054]	[0.100]	[0.104]	[0.017]	[0.038]	[0.040]	[0.024]	[0.034]	[0.035]
		C: Controlling for Demographic Covariates & Border Effects								
Cannabis Use in Past Month	18+	0.155***	0.193**	0.198*	0.028*	-0.015	-0.015	0.083***	0.035	0.035
		[0.050]	[0.097]	[0.102]	[0.016]	[0.036]	[0.037]	[0.023]	[0.033]	[0.035]
	18-25	0.071	0.242*	0.263*	0.012	0.155**	0.163**	0.048**	0.169***	0.176***
		[0.045]	[0.129]	[0.148]	[0.016]	[0.072]	[0.075]	[0.022]	[0.058]	[0.060]
	26+	0.166***	0.177	0.179	0.025	-0.049	-0.050	0.084***	0.012	0.010
		[0.055]	[0.100]	[0.116]	[0.017]	[0.038]	[0.040]	[0.024]	[0.037]	[0.038]

Note: ***Dependent variable: Proportion of adults with mental health measure in respective column and age in respective row. Each estimate is an individual specification, noted by column, estimate for respective age group, cannabis use measure and mental health measure. Heteroskedastic robust SEs allow for arbitrary correlation of residuals within each state. State and year fixed effects included in all estimates. Omitted demographic reference group is U.S. born, white, male, some college education, age 35-44, married, employed, earn between fifty-thousand and seventy-five thousand dollars per year, not obese, and has not used tobacco products or alcohol within the last month. Any mental health and serious mental health estimates from 2008-2018 (N = 561) and major depression estimates from 2005-2018 (N = 714). *, **, and *** represent significance at the 10, 5, and 1% levels, respectively.***

6.3 Additional Covariates

Up until this point, we have conducted our analysis without the inclusion of additional covariates. We did so contingent upon the strong evidence for unconditional parallel trends presented in section 5—apart from cannabis consumption for adults aged 26+. Nevertheless, we consider the robustness of our DDIV results given the inclusion of a large set of demographic controls outlined in section 3 including measures for age, marital status, education, labor force status, race, gender, household income, obesity, tobacco use, alcohol use, and U.S. born rates across each state. Our state fixed effects likely controlled for much of these demographics; however, the inclusion can nevertheless allow for some time-varying variation in demographics across states. We then consider adding a control for other illicit drug usage as it has been found to be a strong confounder and heavily associated with cannabis consumption in the literature (Green and Ritter, 2000; Hall, 2014; Luther *et al.*, 2016). Lastly, we consider controlling for possible border effects between states that legalized and their neighboring states such that possible spillover or migratory effects may occur.

Table 6 considers each of the aforementioned set of controls. For each mental health measure in the respective columns, we estimate the TWFE specification of eq. (3), the unbiased IV estimator of Andrews and Armstrong (2017) introduced in the former section, and our main DDIV model outlined in section 4 for each respective age. Panel A controls for the set of demographic controls and we observe no qualitative difference in our estimates with a loss of some statistical precision. Panel B controls for illicit drug use other than cannabis with near identical outcomes. Lastly, Panel C includes an indicator variable equal to 1 for a state that borders a state that legalized cannabis during that specific legalization time period. We observe a slight reduction in the estimates with a loss in statistical precision. In general, the DDIV estimates are robust to the inclusion of a vast array of controls. We thus feel confident in the robustness of our DDIV estimates.

7. DISCUSSION & CONCLUSION

There has been a prominent ambivalence among that public on the costs and benefits of cannabis consumption. The trade-offs between prohibition and liberalization are at the forefront of policy debates. Cannabis prohibition can impose pervasive costs associated with an illegal market and subsequent enforcement; on the other hand, an unregulated cannabis market can impose significant social and health costs. Having a well-informed basis on the costs and benefits is crucial for implementing socially optimal policies. We provide some of the first evidence of the negative mental health consequences of cannabis consumption at the population level.

By exploiting variation in the legal status of cannabis across states in the United States, we are able to study the impact of cannabis legalization on cannabis consumption and mental health outcomes. We then further exploit legal status as an instrument to pinpoint the direct impact of cannabis consumption on mental health. Our estimates suggest that cannabis legalization resulted in an average increase of 1.59 percentage points (7.3 percent) and 0.92 percentage points (5.0 percent) in the proportion of the population with symptoms of any mental health disorder for adults aged 18-25 and aged 26+, respectively. Among the states that have legalized cannabis, we estimate that roughly 2 out of 10 adults that engaged in monthly cannabis consumption following legalization developed symptoms of any mental health disorder. Young adults aged 18-25 appear to be more susceptible to developing severe mental illnesses and major depressive disorders.

This paper has raised a red flag on the current trajectory of mental health outcomes among the states that have legalized cannabis. However, further research is needed to help understand the specific mental health illnesses that are arising and the mechanisms by which cannabis consumption increases mental health illness. For instance, the literature has highlighted an increasing potency of cannabis products among recreational markets and an association between high potency product use and mental illness (Chandra *et al.*, 2019; Rup *et al.*, 2021). Moreover, there also appears to be a link between high frequency use and mental illness (Crippa *et al.*, 2009; Konefal *et al.*, 2019; Rup *et al.*, 2021; van Ours and Williams, 2011). Understanding these relationships can help pave a pathway for policymakers to optimally regulate cannabis markets. Furthermore, heterogeneity analysis of the underlying recreational markets can help to provide insights into regulatory mechanisms that can help limit the negative mental health consequences of cannabis consumption.

Cannabis consumption has expanded rapidly in the United States over the past decade and shows no signs of slowing. This paper does do not encourage prohibition of cannabis, nor do we encourage laissez-faire cannabis policies. Rather, as additional states pursue more liberal cannabis policies, it is important that policymakers are aware of the negative social implications and how to effectively design policies and regulatory markets to counter them. Further research into the dose-dependent relationship of cannabis consumption on physical and mental health is needed. At the very minimum, we encourage states to provide education and awareness to consumers on the potential negative health implications of consuming cannabis—particularly with respect to individuals most vulnerable to mental illness.

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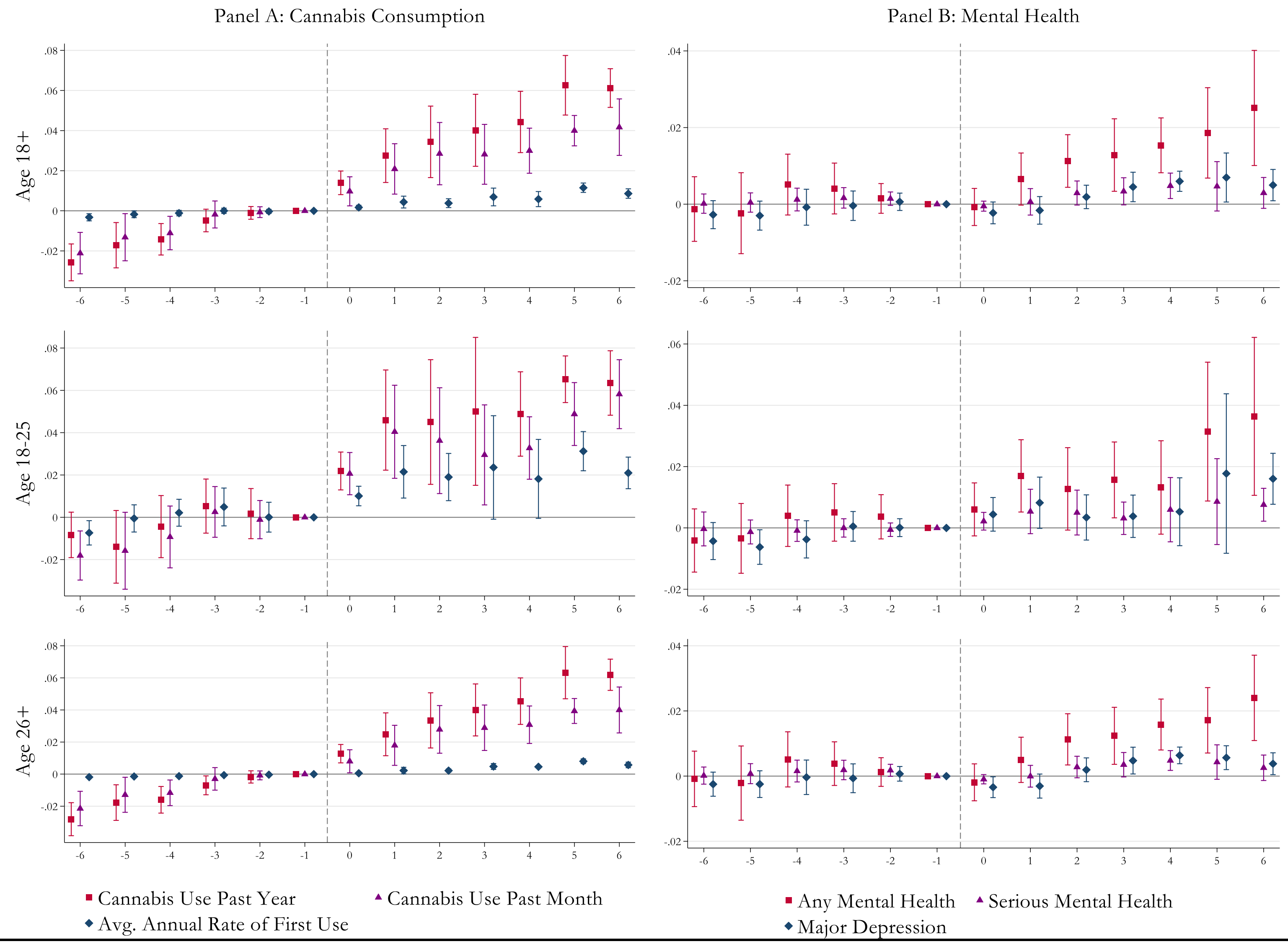
APPENDIX

Table A1—Legal Status of Cannabis by State Over 2005-2018 Time Frame

	(1) Criminal Offense	(2) Decriminalized	(3) Legalized
Alabama	2005-2018	-	-
Alaska	2005-2013	-	2014-2018
Arizona	2005-2018	-	-
Arkansas	2005-2018	-	-
California	-	2005-2015	2016-2018
Colorado	-	2005-2011	2012-2018
Connecticut	2005-2010	2011-2018	-
Delaware	2005-2014	2015-2018	-
District of Columba	2005-2013	-	2014-2018
Florida	2005-2018	-	-
Georgia	2005-2018	-	-
Hawaii	2005-2018	-	-
Idaho	2005-2018	-	-
Illinois	2005-2015	2016-2018	-
Indiana	2005-2018	-	-
Iowa	2005-2018	-	-
Kansas	2005-2018	-	-
Kentucky	2005-2018	-	-
Louisiana	2005-2018	-	-
Maine	-	2005-2015	2016-2018
Maryland	2005-2013	2014-2018	-
Massachusetts	2005-2007	2008-2015	2016-2018
Michigan	2005-2017	-	2018
Minnesota	-	2005-2018	-
Mississippi	-	2005-2018	-
Missouri	2005-2013	2014-2018	-
Montana	2005-2018	-	-
Nebraska	-	2005-2018	-
Nevada	-	2005-2015	2016-2018
New Hampshire	2005-2016	2017-2018	-
New Jersey	2005-2018	-	-
New Mexico	2005-2018	-	-
New York	-	2005-2018	-
North Carolina	-	2005-2018	-
North Dakota	2005-2018	-	-
Ohio	-	2005-2018	-
Oklahoma	2005-2018	-	-
Oregon	-	2005-2013	2014-2018
Pennsylvania	2005-2018	-	-
Rhode Island	2005-2011	2012-2018	-
South Carolina	2005-2018	-	-
South Dakota	2005-2018	-	-
Tennessee	2005-2018	-	-
Texas	2005-2018	-	-
Utah	2005-2018	-	-
Vermont	2005-2012	2013-2017	2018
Virginia	2005-2018	-	-
Washington	2005-2011	-	2012-2018
West Virginia	2005-2018	-	-
Wisconsin	2005-2018	-	-
Wyoming	2005-2018	-	-

Note: ***Each legal status category is mutually exclusive. Decriminalization defined as having any legislation in place that reduces the penalty with respect to federal law. Legalization is defined as having recreational or full legalization of cannabis.***

Figure A1— The Dynamic Impact of Cannabis Legalization on Cannabis Consumption & Mental Health (TWFE)



Note: ***These figures show the estimates constructed utilizing two-way fixed effects estimation of eq. (4). Panels A and B plot the estimates for cannabis consumption and mental health for a respective age group in each row, respectively. The vertical bars represent 95% C.I. constructed using robust SEs clustered at the state level. The x-axis denotes relative time since ballot measure was passed at t = 0. All estimates relative to period t = -1.***

Table A2—The Estimated Impact of Cannabis Consumption on Mental Health

	Any Mental Illness			Serious Mental Illness			Major Depression		
	(1) OLS	(2) TWFE	(3) DDIV	(4) OLS	(5) TWFE	(6) DDIV	(7) OLS	(8) TWFE	(9) DDIV
A: Age 18+									
Cannabis Use in Past Year	0.155***	0.161***	0.163**	0.051***	0.035***	0.019	0.071***	0.086***	0.050**
	[0.034]	[0.038]	[0.050]	[0.012]	[0.012]	[0.022]	[0.013]	[0.018]	[0.022]
Cannabis Use in Past Month	0.197***	0.165***	0.216***	0.068***	0.041**	0.026	0.094***	0.091***	0.066**
	[0.045]	[0.053]	[0.067]	[0.013]	[0.016]	[0.036]	[0.016]	[0.022]	[0.030]
Avg. Annual Rate of First Use	1.293***	0.947***	1.150***	0.428***	0.154**	0.136	0.627***	0.439***	0.374**
	[0.261]	[0.198]	[0.361]	[0.134]	[0.070]	[0.153]	[0.118]	[0.107]	[0.172]
B: Age 18-25									
Cannabis Use in Past Year	0.231***	0.086**	0.295**	0.086***	0.023	0.117*	0.149***	0.085***	0.191***
	[0.042]	[0.036]	[0.121]	[0.015]	[0.016]	[0.067]	[0.020]	[0.017]	[0.055]
Cannabis Use in Past Month	0.303***	0.138***	0.325***	0.117***	0.026	0.129*	0.196***	0.090***	0.203***
	[0.050]	[0.038]	[0.123]	[0.018]	[0.016]	[0.071]	[0.026]	[0.017]	[0.049]
Avg. Annual Rate of First Use	0.792***	0.226***	0.655***	0.312***	0.112***	0.260**	0.536***	0.236***	0.430***
	[0.145]	[0.079]	[0.233]	[0.052]	[0.036]	[0.128]	[0.069]	[0.039]	[0.108]
C: Age 26+									
Cannabis Use in Past Year	0.108***	0.151***	0.139**	0.029**	0.031**	0.005	0.030**	0.069***	0.030
	[0.036]	[0.038]	[0.055]	[0.011]	[0.012]	[0.022]	[0.013]	[0.018]	[0.023]
Cannabis Use in Past Month	0.137***	0.163***	0.192**	0.041***	0.039**	0.007	0.041**	0.081***	0.041
	[0.049]	[0.058]	[0.075]	[0.014]	[0.017]	[0.030]	[0.017]	[0.023]	[0.032]
Avg. Annual Rate of First Use	1.268***	1.299***	1.527**	0.406***	0.220*	0.054	0.285**	0.537**	0.363
	[0.348]	[0.433]	[0.638]	[0.117]	[0.130]	[0.232]	[0.138]	[0.222]	[0.281]
State & Year FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Instruments	-	-	Legalization	-	-	Legalization	-	-	Yes
Observations	561	561	561	561	561	561	714	714	714

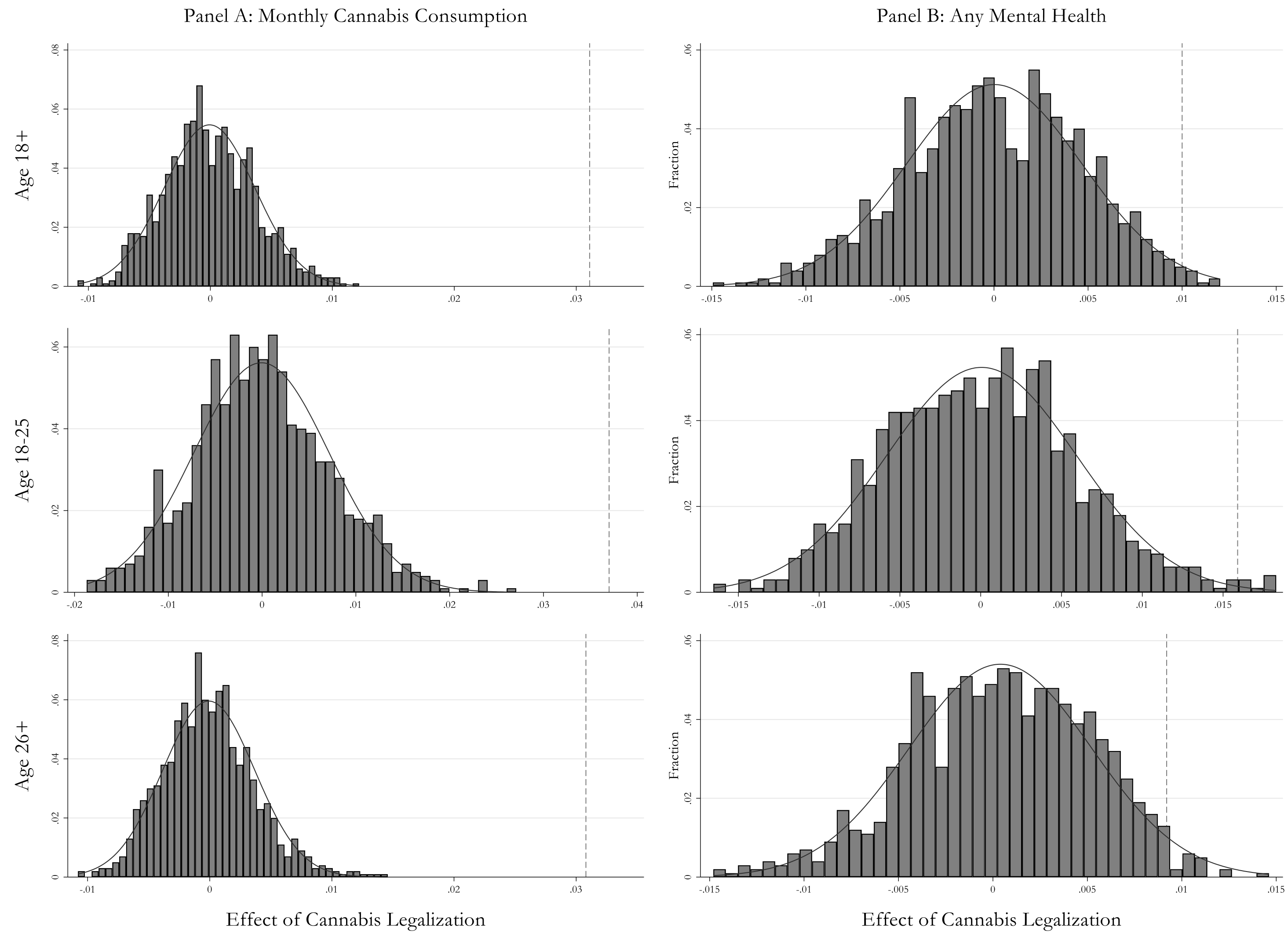
Note: Dependent variable: Proportion of adults with mental health measure in respective column for each age group in respective panel (A, B, C). Heteroskedastic robust SEs allow for arbitrary correlation of residuals within each state. Each estimate is an individual regression estimate, noted by column, for respective age group, cannabis use measure and mental health measure. Demographic covariates not included in any estimate. OLS presents pooled ordinary least squares estimates of eq. (3). TWFE presents two-way fixed effects estimates of eq. (3). DDIV presents instrumented difference-in-differences estimates outlined in section 4. DDIV includes cannabis legalization as the sole instrument. *, **, and * represent significance at the 10, 5, and 1% levels, respectively.**

Table A3—Placebo States

(1) True State	(2) Year Cohort	(3) Placebo State
Colorado	2012	Virginia
Washington	2012	Wisconsin
Alaska	2014	Minnesota
Oregon	2014	Kansas
District of Columbia	2014	Maryland
California	2016	Texas
Maine	2016	Indiana
Massachusetts	2016	Connecticut
Nevada	2016	Arizona
Michigan	2018	Ohio
Vermont	2018	New Hampshire

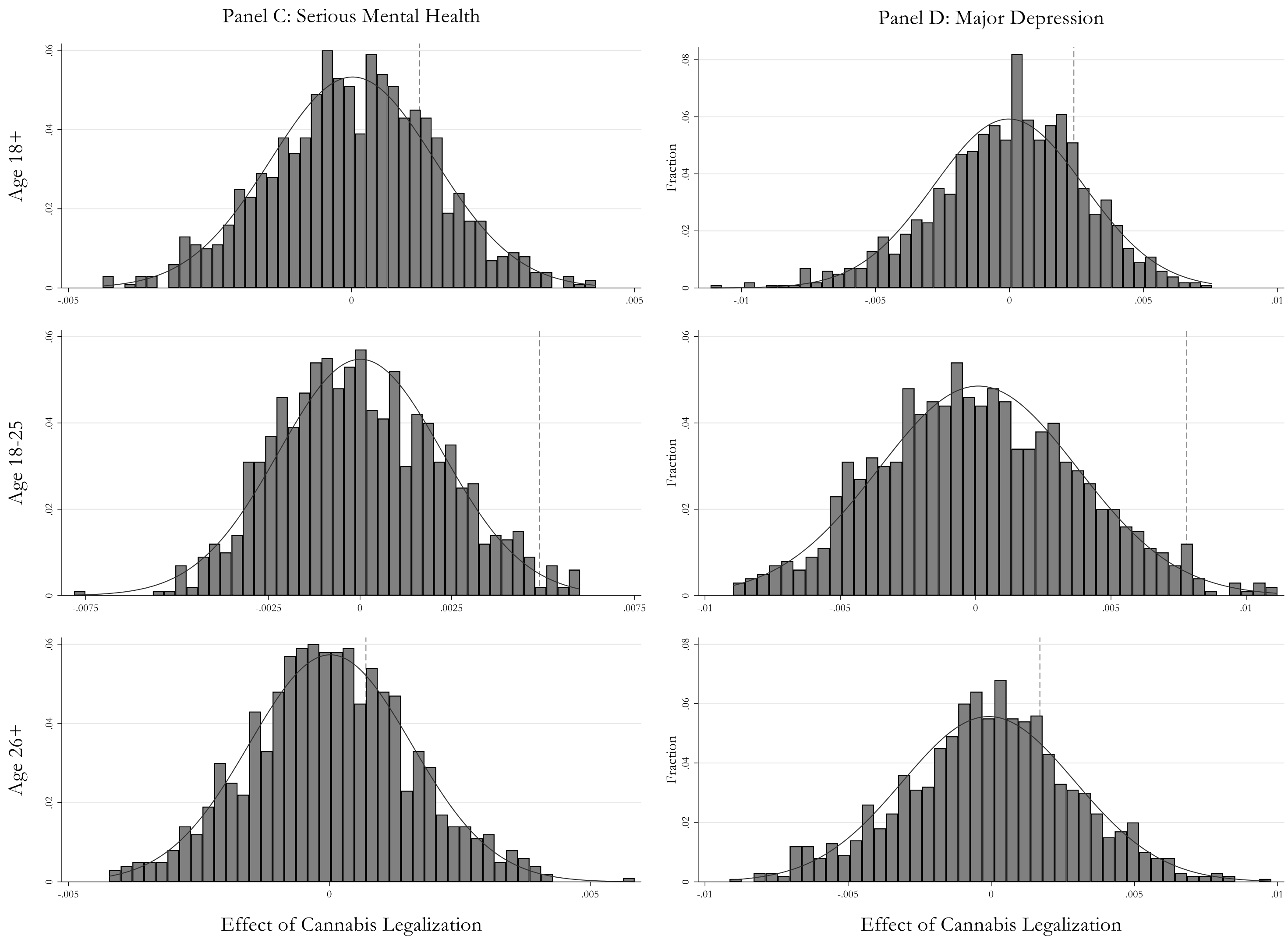
Note: ***Each true state is classified as the corresponding placebo state using an aggregated k-nearest neighbors algorithm classifying each true state based on a set of z-score normalized demographics and population.***

Figure A2—Distribution of Placebo Test Estimates with Randomly Assigned States



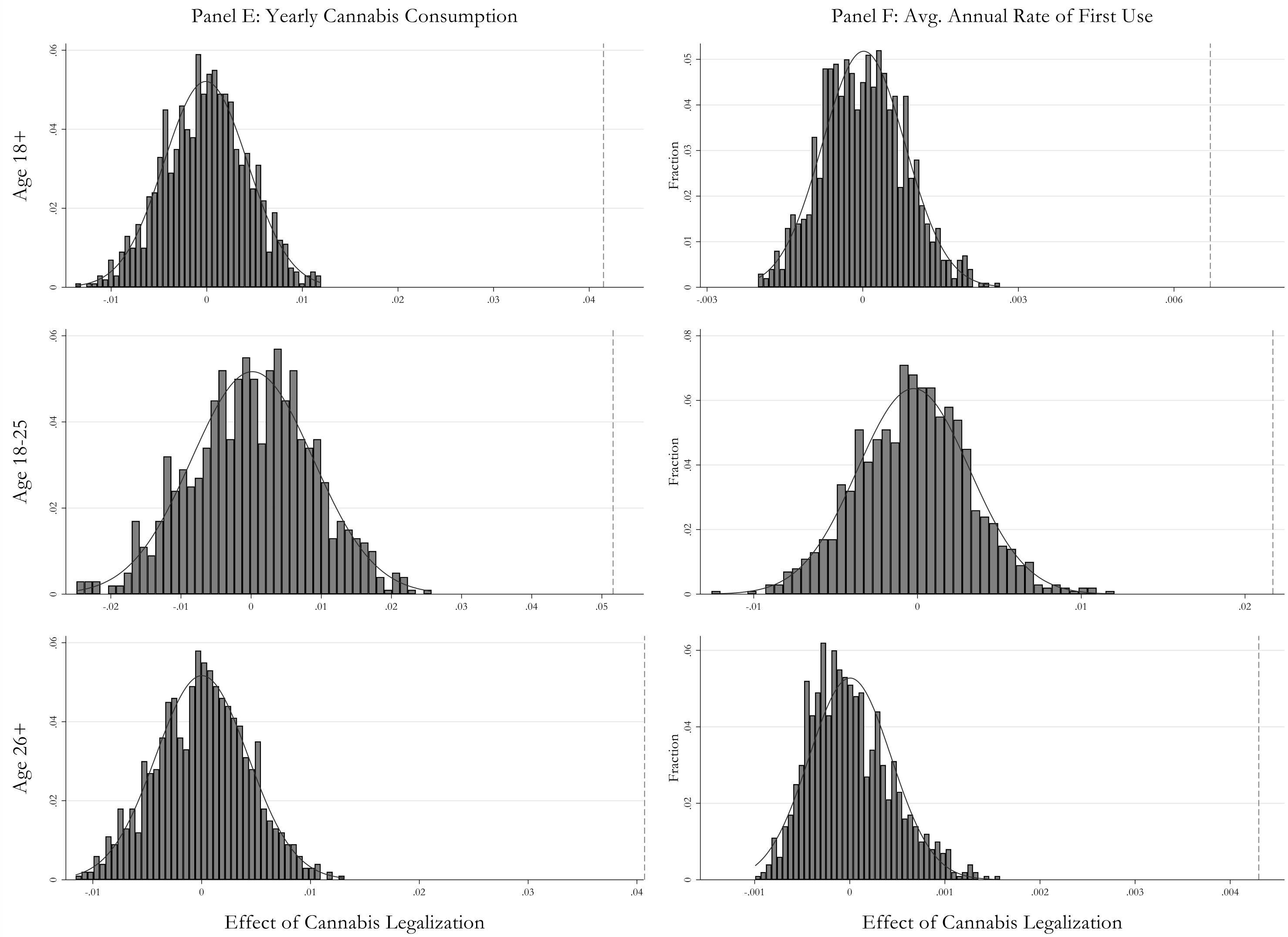
Note: ***These figures show the distribution of the dynamic aggregation estimates constructed utilizing the Callaway and Sant'Anna (2020) method outlined in Section 4 for 1000 placebo tests with randomly assigned states. The vertical line represents the dynamic aggregation estimates from our true specification.***

Figure A3—Distribution of Placebo Test Estimates with Randomly Assigned States Cont.



Note: ***These figures show the distribution of the dynamic aggregation estimates constructed utilizing the Callaway and Sant'Anna (2020) method outlined in Section 4 for 1000 placebo tests with randomly assigned states. The vertical line represents the dynamic aggregation estimates from our true specification.***

Figure A4—Distribution of Placebo Test Estimates with Randomly Assigned States Cont.



Note: ***These figures show the distribution of the dynamic aggregation estimates constructed utilizing the Callaway and Sant'Anna (2020) method outlined in Section 4 for 1000 placebo tests with randomly assigned states. The vertical line represents the dynamic aggregation estimates from our true specification.***