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ARTICLE

Medical marijuana laws and mental health in the United States

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Abstract
The consequences of legal access to medical marijuana for individuals' well-being are controversially assessed. We contribute to the discussion by evaluating the impact of the introduction of medical marijuana laws across US states on self-reported mental health considering different motives for cannabis consumption. Our analysis is based on BRFSS survey data from close to eight million respondents between 1993 and 2018 that we combine with information from the NSDUH to estimate individual consumption propensities. We find that eased access to marijuana through medical marijuana laws reduce the reported number of days with poor mental health for individuals with a high propensity to consume marijuana for medical purposes and for those individuals who likely suffer from frequent pain.

Keywords: medical marijuana laws; marijuana regulation; mental health; chronic pain

JEL classification: H75; I12; I18; I31; K42

1. Introduction

The legal status of marijuana has become successively less restrictive in many countries in recent years. In the United States, a majority of the states eased access to marijuana via decriminalisation, medical programmes or recreational allowances. Nevertheless, the new laws remain contentious. Major controversies revolve around the long-term consequences of marijuana consumption. These concern the therapeutic value of marijuana, but also potential negative externalities and internalities due to addiction. The medical marijuana movement is thus concurrently understood as an attempt to bring back marijuana as medicine for patients with different conditions such as chronic pain, spasticity, nausea or loss of appetite, and as a Trojan horse for the legalisation of cannabis (Kilmer and MacCoun, 2017). Whether the medical benefits outweigh the potentially negative consequences due to recreational abuse is thereby still debated.

We contribute to this discussion with an evaluation of the effect of US medical marijuana laws (MMLs) on mental health, measured by self-reported number of days with poor mental health per month. Our metric attempts to capture changes in individual well-being due to the policy implementation in a comprehensive way, allowing us to consider that the introduction of an MML might affect people via various channels.[1] Importantly, our analysis allows us to assess whether MMLs benefit those groups for which the laws are designed, such as people with certain medical conditions and the experience of frequent pain. The policy evaluation for the overall population

[1]A similar approach was applied by Gruber and Mullainathan (2005) and Odermatt and Stutzer (2015) to evaluate tobacco control policies based on reported subjective well-being.

additionally captures any potentially negative effects through, for example, diversion. To identify the effects of the policy on mental well-being, we exploit the staggered introduction of MMLs in the United States until the end of 2018. The basis for our analysis is repeated cross-sectional data from the Behavioral Risk Factor Surveillance System (BRFSS) starting from 1993. The data comprise a total of around 7.9 million observations. Moreover, for the analysis of group-specific effects, we rely on an imputation strategy making use of the National Survey on Drug Use and Health (NSDUH). It provides information on individuals' marijuana consumption frequency and whether any consumption is recommended by a physician (information not available in the BRFSS). Based on these data, we can learn about the socio-demographic predictors of marijuana consumption and use them to impute a consumption propensity in the BRFSS. This allows us to study how people who are likely to consume under an MML regime for medical or recreational purposes are differently affected by the policy. In the same way, we try to further assess the relevance of pain as a condition for the use of medical marijuana by identifying people who are likely suffering from frequent pain and assessing the effect of an MML for this group. Using a triple difference approach allows us to interpret the differential effects as lower bound estimates under rather weak assumptions about confounding factors. To the best of our knowledge, this strategy has not been used in previous studies to deal with potential time-variant confounders and to assess the effects of MMLs on targeted groups.

Across the whole population, our simple two-way fixed-effects analyses reveal negative point estimates, which suggest reductions in the number of poor mental health days with the adoption of an MML in a state. While the point estimates for the overall treatment effect are not statistically significant, they are sizeable. Moreover, an event-study based on dynamic difference-in-difference estimates (Wooldridge, 2021) that considers recent methodological advances in the estimation of effects for staggered policy implementations also suggests a negative effect of MMLs on days with bad mental health. This negative effect is likely strongest for states that introduced MMLs early on and it builds up over time. When we focus our analysis on likely pain sufferers and consumers of marijuana for medical reasons, we observe strong and statistically significant improvements in mental health in states that adopted MMLs. The effect size for these two groups amount to around 0.3 fewer days with poor mental health per month. Our analysis contributes to an expanding literature on the public health effects of legalising marijuana (see Anderson and Rees, 2023 for a review) and points towards two groups of potential consumers for whom positive effects of MMLs on mental health can be expected.

The remainder of this paper is structured as follows. In Section 2, we elaborate on the hypothetical consequences of MMLs by discussing the relevant literature in more detail. In Section 3, we describe our data and qualify our empirical strategy. In Section 4, we present our results. Section 5 offers concluding remarks.

2. Literature on the consequences of medical marijuana laws

The introduction of an MML might affect mental health via various channels that we summarise in this section. Thereby, most effects are likely mediated by the impact on consumption behaviour, on which our detailed analyses focus. At the centre of the public and the scientific discourse is the trade-off between the value of marijuana as medicine and the risk of uncontrolled recreational use.

There is broad consensus on the therapeutic value of marijuana under controlled consumption. Comprehensive studies and reviews of the recent medical literature report medicinal benefits of marijuana compared to placebo treatments and thus show evidence of therapeutic efficacy (see e.g. National Academies of Sciences, Engineering, and Medicine, 2017; Abrams, 2018; Boehnke *et al.*, 2019*b*). In another systematic review, Kosiba *et al.* (2019) find that pain, anxiety and depression symptoms are common reasons for medical cannabis use. In contrast, the risks associated with marijuana consumption are less clear. Examples of potential harmful effects are neurological decline (Meier *et al.*, 2012), cardiovascular diseases (Hall and Degenhardt, 2009) and schizophrenia (Semple *et al.*, 2005).

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Any assessment of marijuana consumption, however, must depend on *comparative* advantages and disadvantages over alternative treatments. For example, in the context of chronic pain, controlled marijuana intake can be seen as an efficacious alternative to established analgesics, which have well-documented side-effects. This is in line with Boehnke *et al.* (2019*a*) who show in an observational study that medical cannabis users reported improved pain and health since substituting cannabis for pain medications due to fewer side effects and better pain management. Such substitution effects seem particularly important given the current upward trends in prescription drug abuse (Dart *et al.*, 2015). Various studies show lower prescriptions of opioids and other treatments (e.g. Chu, 2015; Bradford and Bradford, 2016; Ozluk, 2017; Bradford *et al.*, 2018; Wen and Hockenberry, 2018; Carrieri *et al.*, 2020; Raman and Bradford, 2022), and lower opioid-related fatalities (Bachhuber *et al.*, 2014; Powell *et al.*, 2018; Smith, 2020) when marijuana laws are put in place. However, using recent data, Shover *et al.* (2019) argue that the latter effects might be spurious. Controlled intake might still help people to cope with stressful life events and hence decrease the prevalence of suicide (Anderson *et al.*, 2014; Bartos *et al.*, 2020).

There is evidence that for the adult population, the medical use of marijuana is more widespread than the recreational use (Dai and Richter, 2019). Still, MMLs facilitate access to marijuana not only for medical but also for recreational use (Jacobi and Sovinsky, 2016). The welfare effects of potential diversion are hard to judge. They depend on the consumption value of marijuana, the risk of dependency and the degree to which diverted marijuana is a complement to or substitute for other substances. Wen *et al.* (2015) report that the implementation of MMLs leads to an increase in the probability of past-month marijuana use, regular marijuana use and dependence among adults aged 21 or above. With regard to adolescents, who are often put forward as a major risk group, they observe an increase in initiation of marijuana use, but not a higher probability of addiction. Chu (2014) finds that MMLs increase marijuana arrests and treatment admissions to rehabilitation facilities among adult males. Hollingsworth *et al.* (2022) show that it is important to distinguish between MMLs and recreational marijuana laws. They find that medical laws succeed in mitigating recreational (non-medical) use, while recreational laws are associated with stronger increases in marijuana use in the general population. Pacula *et al.* (2015) also find that states with dispensaries face increased recreational marijuana use and dependence for both adults and youth. Moreover, MMLs tend to reduce the high school graduation rate (Plunk *et al.*, 2016), expected labour earnings of young males (Sabia and Nguyen, 2018), academic performance (Marie and Zölitz, 2017), particularly of comparatively weak students and are associated with less time devoted to education-related activities (Chu and Gershenson, 2018). In contrast, Anderson *et al.* (2015), Wall *et al.* (2016) and Cerdá *et al.* (2018) find no increase in marijuana use among youths. In a systematic review and meta-analysis, Sarvet *et al.* (2018) come to the same conclusion.

Regarding potential benefits, Sabia *et al.* (2017) find that states that adopt an MML exhibit a lower prevalence of obesity among the young as well as increased physical mobility among the elderly.[2] In line with this, Andreyeva and Ukert (2019) find positive effects of MMLs on self-reported overall health, particularly for the subsample of those reporting chronic pain, and Nicholas and Maclean (2019) find that MMLs lead to lower pain and better self-assessed physical health among older adults. Moreover, recent evidence by Abouk *et al.* (2021) suggests improvements in work capacity due to the implementation of recreational marijuana laws, which likely is driven by the access to an additional form of pain management therapy. For the younger population studied by Chay and Kim (2022), only MMLs with strict regulations are associated with positive (heterogeneous) effects on overall subjective health.

With regard to externalities, the literature reports a multitude of effects (see Anderson and Rees, 2023 for an overview of the public health effects of legalising marijuana); for example,

[2]In a supplementary specification, Sabia *et al.* (2017) test potential mechanisms for the effect on physical health and find a beneficial effect of MMLs on mental health. However, they do not examine heterogeneous treatment effects on mental health conditional on differences in the law, consumption motive or health status.

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the literature reports decreased absenteeism from work (Ullman, 2017), negative environmental impact of local cultivation (Carah *et al.*, 2015), tax revenues and a decrease in crime-related drug trafficking (Gavrilova *et al.*, 2019). Furthermore, several studies report systematic relationships between MMLs and the rate of traffic fatalities, highlighting the potential substitution of alcohol with marijuana (e.g. Reiman, 2009; Anderson *et al.*, 2013; Baggio *et al.*, 2020*a*, 2020*b*; Smart and Doremus, 2023). Moreover, the effects on behaviour might even be broader, as Baggio *et al.* (2020*b*) find that the laws are associated with an increase in sexual activity and an increase in the number of births. Finally, reactions in other dimensions could be considered as well, such as redeployment of police forces, changes in the conduct of illicit suppliers and potential changes in the social stigma (see e.g. Okaneku *et al.*, 2015; Newhart and Dolphin, 2018).

Given the various effect channels, the net impact of MMLs on individuals' wellbeing is difficult to identify. However, it seems clear to us that it is insufficient to evaluate MML policies based on observed consumption behaviour. We therefore aim instead for an evaluation of the net effects on mental health, an important determinant of individual well-being and welfare. By further considering heterogeneity in the MML regimes as well as different motives for individual marijuana consumption such as medical purposes and frequent pain, we shed light on the relevance of specific channels through which MMLs impact the mental health in the population.

3. Data description and empirical strategy

3.1 Marijuana regulations in the United States

The regulation of (medical) marijuana differs widely across US states and ranges from laws that provide only minimal access to laws that permit an almost unrestricted supply of marijuana for medical as well as recreational use. While marijuana was effectively illegal in all states before 1996, California pioneered the United States' first MML in November 1996. By 31 December 2018, 31 states had followed suit in liberalising access to medical marijuana.[3] Figure 1 presents a map of the United States showing the legislation of marijuana for each state, including Washington D.C., at the end of 2018. It shows whether an MML was in place, as well as whether recreational use and possession were legal. Furthermore, the figure indicates whether or not a state was entitled to impose a jail sentence for first-time consumption or small-scale possession of marijuana.

Figure 2 shows the distribution of marijuana regime changes over time. In total, we can exploit 31 introduction dates. Ten states further abolished the jailing of first-time offenders for marijuana consumption and small-scale possession during our sampling period. Regarding recreational use, however, we only observe 11 changes from 2012 until the end of 2018. While we include these two latter regime changes as control variables, we refrain from a discussion of effect estimates due to the limited variation. As our treatment indicator, we consider the date when an MML became effective, i.e. the date when the law came into force (rather than when it passed) – many law changes applied only after a 'transition period' from the date of passage onwards during which the previous law text remains in effect. An overview of the respective dates can be found in the Appendix Table A2.

In addition, we capture and classify law heterogeneity, such as different qualifying medical conditions that give patients legal access to medical marijuana. However, this is not a trivial task. Several taxonomies for capturing distinctions in the law and their timing have been proposed (see e.g. Pacula *et al.*, 2014; Chapman *et al.*, 2016; Williams *et al.*, 2016). We follow recent analyses and consider legislation that protects individuals who possess marijuana for medical purposes, allows home cultivation, provides dispensaries and considers unspecific pain a valid

[3]In 2015, Virginia, Georgia, Oklahoma, Texas and Wyoming relaxed their regulations on low-THC, high-CBD marijuana for medical purposes. We do not classify these law changes as MMLs since they are very limited, and THC has been shown to be an important determinant of therapeutic efficacy when it comes to pain (Stith *et al.*, 2019).

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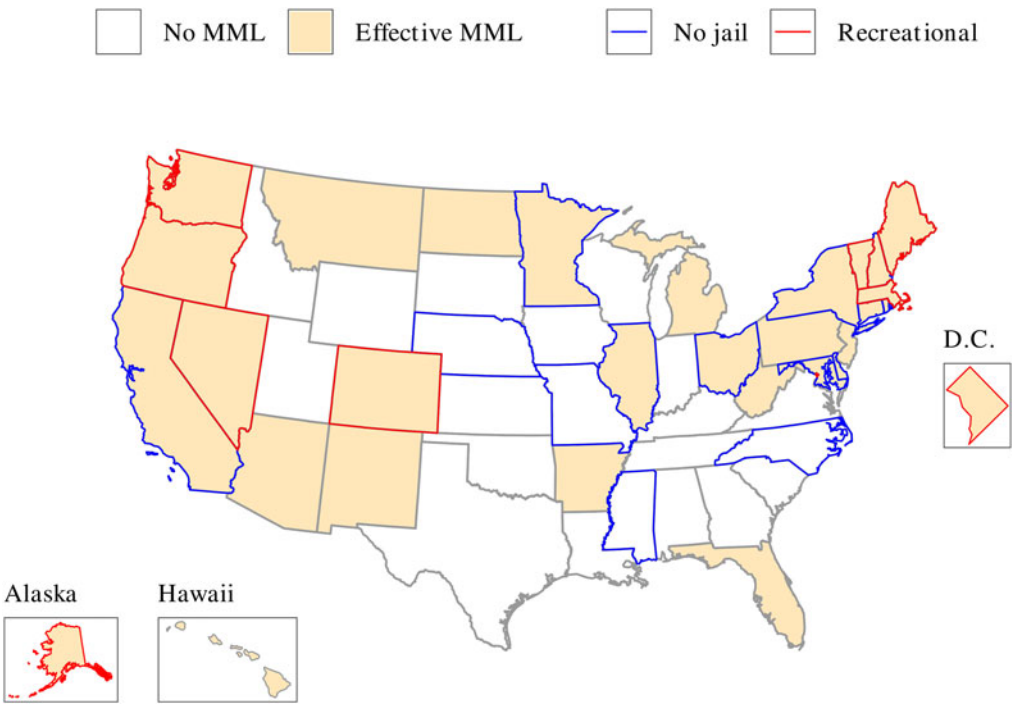

Figure 1. Regulation of (medical) marijuana across US states at the end of 2018.
Notes: 'No jail' (blue border) indicates whether first-time consumption and small-scale possession of marijuana in violation of the law are punishable by a jail sentence or not. 'Recreational' (red border) shows whether use and possession of marijuana without prescription is legal in the respective state.
Data source: Own compilation.

diagnosis for prescription of medicinal marijuana. In particular, we distinguish between MML states as follows:

- *MML* – Possession of marijuana for the treatment of certain medical conditions is legal. Under this MML regime, access is eased in so far as doctors can recommend marijuana for specific ailments, excluding unspecific pain.
- *Dispensaries* – At least one operational state-approved dispensary issues medical marijuana.
- *Private cultivation* – In addition to the juristic protection offered by a 'law only' regime, citizens who receive medical cards from a state office either as patients or caregivers can cultivate some amount of marijuana at home or in small groups.
- *Unspecific pain* – 'Pain due to an unspecified cause' is one of the conditions that allows a physician to legally issue prescriptions. This means that the experienced pain does not need to be diagnosed as resulting from an acknowledged illness.

Table A3 in Appendix A provides a summary of the variation in MMLs across states with regard to these policy dimensions. We exploit this classification in Section 4.1 when estimates for the effects of different policy dimensions are discussed.

3.2 Individual-level data

Our study builds on two primary data sources: the BRFSS and the NSDUH. The BRFSS, our main dataset, consists of repeated cross-sections of telephone surveys targeting US residents above the age of 18. In every year, respondents answer the following question about their mental state of

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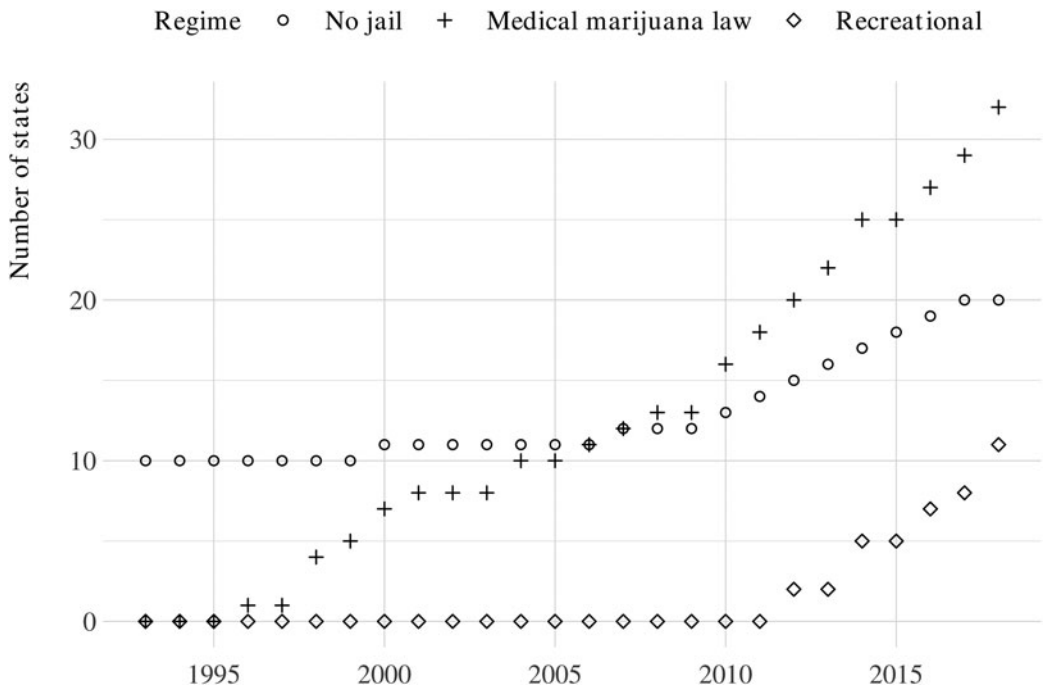

Figure 2. Timeline of marijuana regime adoptions in US states.
Data source: Own compilation.

health: '*Now thinking about your mental health, which includes stress, depression, and problems with emotions, for how many days during the past 30 days was your mental health not good?*' We use the responses to this question from the years 1993 up to and including 2018 as our outcome variable.[4] This metric is available for almost all individuals in all states and years with an item non-response of about 2 per cent, which makes for roughly 7.9 million usable observations. In the Appendix, we present summary statistics for our sample (Table A1) and illustrate the distribution of poor mental health days (Figures A1 and A2).

For our analysis, it would be valuable to know about individual marijuana consumption behaviour and whether individuals qualify for medical marijuana. However, due to the lack of this information in our sample period in the BRFSS, we make use of the information available in the NSDUH to impute the missing information in the BRFSS. It allows us to study the policies' potentially heterogeneous effects conditional on individual propensities to consume marijuana (for recreational or medical reasons) and propensities to experience frequent pain. The NSDUH is appropriate for this task since it offers national data on the use and abuse of addictive drugs in the US population aged 12 and older. It is frequently used as the basis for estimating the national prevalence of and state trends regarding, for example, opioid dependence. Our sample comprises the years 1994–2018 with about 820,000 observations in total. We are primarily

[4]The relevance of this measure is supported by various studies. For example, self-reported mental health is a good predictor of help-seeking behaviour (Hunt and Eisenberg, 2010), suicide (Bramness *et al.*, 2010) or psychological functioning and mortality (Lee, 2000). For a general discussion of self-reported health and well-being measures in policy evaluations see, for instance, Dolan *et al.* (2011) and Odermatt and Stutzer (2018). A possible objection to our main outcome variable is the risk of simultaneity. People with mental health problems might want to self-medicate using marijuana, and therefore advocate MMLs or sort into states which have such a regime in place. However, medical research does not support this objection (Harris and Edlund, 2005; Van Ours *et al.*, 2013).

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interested in three questions contained in the survey. First, in every wave respondents are asked the following question: '*During the past 30 days, on how many days did you use marijuana or hashish?*'. Based on the answers, Appendix Figure A3 shows that since 1994, the share of all age groups reporting marijuana consumption has increased. The picture is consistent with the successive liberalisation and decriminalisation of marijuana we observe over time. However, the descriptive patterns cannot tell us to what extent these trends are driven by changes in the legal status of medical marijuana. Second, from 2013 onwards, the NSDUH also asks survey participants whether some or all of their marijuana consumption is recommended by a doctor or a health care professional. The combined information provided by the two questions allows us to classify individuals in the NSDUH as either abstainers, medical marijuana consumers or marijuana consumers for recreational purposes.[5] With this classification, we can study the predictors of the respective consumption behaviour by fitting a model with the NSDUH data. In a second step, based on the predictive model for the consumer status from the NSDUH data, we impute consumption propensity scores for every individual in the BRFSS based on the personal characteristics.[6] A detailed description of the procedure is presented in Appendix C.

In order to also gain insights into the relevance of MMLs for people who suffer from frequent pain, which can be considered as a main qualifying condition for medical marijuana, we make use of a third question in the NSDUH, in which people are asked: '*During the past 30 days, for about how many days did pain make it hard for you to do your usual activities such as self-care, work or recreation?*'. We categorise respondents who suffered for a minimum of five days as being frequent pain sufferers and use a predictive model in the NSDUH to impute the propensities to experience frequent pain for the individuals from the BRFSS. Appendix C presents also the details of the propensity estimation and threshold selection regarding the experience of frequent pain.

3.3 Empirical strategy

Most of the econometric analyses are based on the following estimation specification:

$$y_{ist} = \beta\ \mathrm{mml}_{st} + \gamma Z_{st} + \omega X_{ist} + \alpha_s + \theta_t + \epsilon_{ist} \tag{1}$$

The dependent variable y_{ist} is the self-reported number of poor mental health days in the last 30 days of individual i living in state s in year t. Our primary explanatory variable is mml_{st}, a treatment dummy indicating whether state s at time t has an MML in place or not. We use the exact interview and MML introduction dates to determine the treatment status for every observation.

X_{ist} is a vector of variables at the individual level, controlling for differential socio-demographic compositions across states which might be correlated with the adoption of the policy. Specifically, we control for age, sex, ethnicity, education, marital status, employment, income and the number of children who live in the household. We further include the vector Z_{st} of state variables including beer taxes, and cigarette taxes. Lastly, we include separate indicator variables for policies that abolished jail sentences for first-time offenders charged with marijuana consumption and policies that legalised marijuana for recreational consumption. Descriptive statistics and sources of the respective variables are reported in Appendix A. Finally, we include

[5]We classify individuals as marijuana consumers if consumption occurred on at least five days during the past month (i.e. marijuana was consumed, on average, on a weekly basis). However, the results in Section 4.3 are robust to variations in the threshold used for to classify observations as (non)-consumers.

[6]For the prediction, we use only variables which are reported in both the BRFSS and the NSDUH. Beside basic socio-demographics and year effects, we include smoking status, and the number of days a person has consumed alcohol during the past 30 days. A dummy capturing whether the respondent's state had an MML in place prior to the interview, which is reported in the NSDUH from 2013 onwards, allows us to gauge an MML's effect on consumption propensities both directly and in interaction with our controls. However, we were not granted access to state identifiers and therefore cannot make use of more refined state characteristics.

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state as well as time fixed effects. Standard errors are clustered at the state level. Note that in an event-study based on dynamic difference-in-differences estimates (Wooldridge, 2021), we consider more recent methodological advances in the context of staggered policy implementations. Details regarding the estimation strategy and our choice of the preferred specification are presented in Section 4.2.

Since MMLs target patients who might benefit from the treatment option, we want to allow for differing effects of marijuana regulations on different groups, i.e. pain sufferers and medical marijuana consumers. Another subsample of interest is recreational marijuana users. While the latter might not be affected directly by the law, they might still be indirectly affected for reasons of diversion, cultural change or an impact on illicit supply. As described in the data description in Section 3.2, we have to impute the propensities for the consumer status and whether someone suffers from frequent pain in the BRFSS. Based on this information, we can then partition the sample into likely abstainers, recreational users or medical users, and additionally whether individuals likely experience frequent pain or not. We consequently estimate two alternative specifications in Section 4.3, one with group-specific effects regarding the consumption motive and another with regard to the experience of frequent pain. Note that this strategy will allow us to interpret the corresponding coefficients in terms of a triple difference, i.e. the difference of the effect between likely abstainers and marijuana consumers on the one hand, and the difference between likely pain sufferers from those who are likely pain free on the other hand.[7]

4. Results

4.1 Overall effects

The results in Table 1 show the overall effect of an MML on poor mental health in days per month. The main variable of interest is the dummy variable 'MML', which captures the net effect for all the years after the adoption of the law. The specification in column (1) shows a coefficient of −0.09, suggesting a reduction in the number of poor mental health days per month when a state adopts an MML. This is potentially a sizeable reduction when considering that it refers to the average treatment effect for the adult population in a state. However, the coefficient is not precisely estimated and lacks statistical significance. In this first specification, we consider only a parsimonious set of control variables, including state and time fixed effects, as well as socio-demographic variables.

In column (2), we extend the set of control variables to include beer and cigarette taxes, as well as the additional policies regarding marijuana consumption, including whether illegal marijuana possession may be punished with incarceration in first-time offenses, and whether marijuana is legalised for recreational consumption. The effect size and precision of the estimate remain similar. The point estimate suggests that the average adult experiences approximately one poor mental health day fewer per year due to the adoption of the law. A full estimation output is presented in Appendix Table B1.[8]

[7]The regressions involving propensity scores require an adjustment of the standard errors, since they involve an estimated explanatory variable which is itself subject to sampling variability. We use a two-stage bootstrapping approach to correct for this. This procedure resamples on the first stage, where we estimate propensities based on a model fit to the NSDUH data, as well as on the second stage, where we feed the imputed propensities into our regressions to estimate the impact of MMLs on mental health. Based on an empirical investigation of convergence rates of standard errors, we sampled 1000 times throughout.

[8]In a robustness analysis in column (1) of Table B2 in Appendix B, we further include variables such as the unemployment rate as well as expenditures per capita for the Medicaid, without much impact on the results. However, as these controls might be endogenous to the introduction of an MML, we do not include them in our preferred specification. In column (2) of Table B2, we additionally test whether the effect of the adoption of an MML depends on neighbouring states already having a less restrictive regime towards marijuana in place. The estimates provide weak evidence that MMLs might create spill-over effects in neighbouring states. Finally in column (3) of the same table, we add state-specific linear time trends as additional controls, which increases the size and precision of the estimate. To further test the influence of spurious heterogeneous state-trend components, we perform placebo tests that randomise the effective MML introduction dates. Figure B1 in Appendix B

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Table 1. Two-way fixed-effects estimates of the overall treatment effect of medical marijuana laws (MML) on the number of days per month with poor mental health (dependent variable)

	(1)	(2)	(3)	(4)	(5)
MML	−0.090 (0.057)	−0.085 (0.056)	–	–	–
Legal dispensaries	–	–	−0.077 (0.075)	–	–
Private cultivation	–	–	–	−0.093 (0.092)	–
Unspecific pain	–	–	–	–	−0.114 (0.076)
Other MML regime	–	–	−0.090* (0.048)	−0.076 (0.051)	−0.037 (0.073)
State/time FE	✓	✓	✓	✓	✓
Essential controls	✓	✓	✓	✓	✓
Extended controls	–	✓	✓	✓	✓
Sample mean	3.44	3.44	3.44	3.44	3.44
Observations	7.9 M	7.9 M	7.9 M	7.9 M	7.9 M
Adjusted R^2	0.089	0.089	0.089	0.089	0.089

Significance: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.
Notes: 'Essential controls' comprise three-way interactions between age, sex and ethnicity as well as education, employment, marital status, income and the number of children living in the household. 'Extended controls' add beer taxes, cigarette taxes, whether illegal marijuana possession may be punished with incarceration in first-time offenses, and whether marijuana is legalised for recreational consumption. The row 'sample mean' reports the average number of poor mental health days per month.
Standard errors are clustered on the state level. *Data source:* BRFSS. Calculated using survey weights.

As there is substantial heterogeneity in the design of the MMLs across states, we consider the differential effects of some key policy dimensions. In particular, as described in Section 3.1, we distinguish laws that protect individuals who possess marijuana for medical purposes from laws that allow home cultivation or the opening of dispensaries, and laws that consider unspecific pain a valid diagnosis for prescription of medicinal marijuana. Columns (3)–(5) in Table 1 exploit this variation in order to estimate differences in the effects of MMLs on mental health depending on the specifics of the law. Column (3) presents the result when allowing different effect sizes for MML states with and without dispensaries. The two dummy variables in column (3) are mutually exclusive and can thus be interpreted independently. The estimates suggest that the effect of MMLs in states without dispensaries are slightly bigger compared to states in which access to medical marijuana is regulated through dispensaries. In column (4), we report a separate dummy for MML regimes that allow private cultivation, and column (5) for MML regimes that recognise pain due to an unspecified cause as a qualifying condition for access to medical marijuana. While there are not pronounced differences across different regimes, the estimates indicate the biggest effect for states that recognise unspecific pain as a qualifying condition. The introduction of such an MML regime is associated with a decrease in poor mental health by 0.11 days per month, while the estimate for MML regimes that do not allow for unspecific pain as a qualifying condition is two-thirds smaller.[9]

documents the results. The specifications of the procedure can be found in the notes to the figure. The placebo test suggests that our results cannot simply be explained by spurious heterogeneous state-trend components.

[9]Table B3 in Appendix B provides a refined analysis of potential interactions of the three policy dimensions. Again, the most pronounced negative effect emerges in states where the regime allows for 'unspecific pain' as a qualifying condition, specifically when access to marijuana is granted through private cultivation. In supplementary analyses (reported in Appendix B 2.3), we explore more refined aspects of heterogeneity in our data pool, such as the distributional changes induced by MMLs with respect to different levels of mental health, and heterogeneity across demographic groups. The results suggest that the biggest shift in the distribution of bad mental health days is from the category reporting one to seven days to the category reporting none. Moreover, we find the strongest reduction of bad mental health days for young women.

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4.2 Event-study analyses using dynamic difference-in-differences estimates

A growing literature discusses the econometric properties of statistical analyses that exploit the staggered introduction of treatments across different units, as it is done in our analysis (e.g. De Chaisemartin and d'Haultfoeuille, 2020; Callaway and Sant'Anna, 2021; Goodman-Bacon, 2021; Sun and Abraham, 2021; Athey and Imbens, 2022; Roth *et al.*, 2023). These papers show that the standard difference-in-differences regressions rely on both a parallel trends assumption and treatment effects that are constant over time. However, in case of heterogeneous treatment effects, where treatment effects vary across units and over time, the two-way fixed-effects estimates identify a weighted average of pairwise state and period comparisons, which also includes the comparison between newly versus already treated units, which is not easy to interpret (Callaway and Sant'Anna, 2021; Goodman-Bacon, 2021).[10]

In this section, we incorporate the latest insight from this literature by applying 'dynamic' difference-in-differences estimates in an event study design. In particular, we employ Wooldridge (2021)'s extended two-way fixed-effects estimator for staggered, binary and irreversible interventions. In a model without controls beside unit and time effects, the method extends the usual two-way fixed-effects specification with interactions between the MML dummy and states' initial period of treatment (if any), as well as each time period which passed since the intervention was implemented. Consequently, heterogeneous treatment effects across time (i.e. *when* treatment started) as well as with regard to duration (i.e. *how long* a unit has been treated) are identified. Importantly, Wooldridge (2021)'s approach excludes the problematic comparisons between early and later treated units. The estimates for the dynamic treatment effects are then calculated by averaging across the (many) individual estimates. For the event study, this averaging is by treatment duration.

Figure 3 illustrates the corresponding results for the dynamic effects of MMLs in an event study. They confirm the previous results and show that the effects of MMLs tend to be negative, suggesting a reduction in days with bad mental health, on average. Moreover, the event study suggests stronger reductions in bad mental health days for the years further away from treatment initiation. There are two ways how to interpret such a pattern: either the effect needs time to build up, or the effect is disproportionately driven by the selection of states which introduced MMLs early on. These possibilities are not mutually exclusive, however.[11]

Lastly, another advantage of the approach suggested by Wooldridge (2021) is that it allows to easily consider non-linear estimators. Specifically, Figure 3 also reports the results based on a dynamic Poisson estimate in the event-study design. The results remain robust under this alternative specification.

4.3 Effects on likely medical marijuana users and pain sufferers

In the interpretation of the effect of MMLs for the overall population, one needs to bear in mind that the targeted group of patients is only a small fraction of the population. So in the following, we want to allow for differing effects of marijuana regulations on medical marijuana consumers in general and pain sufferers in particular. In addition, recreational marijuana users are another

[10]Appendix Figure B3 illustrates how the two-way fixed-effects estimator without control variables decomposes into a weighted sum of pairwise state and period comparisons. The output suggests that our estimates are neither driven by comparisons with extreme relative weights nor by the problematic comparisons between late- to early-treated states.

[11]Note that in contrast to the previous regressions, the estimates with this method require a pseudo-panel, where the repeated cross-sections are collapsed on the state-year level. States are classified as treated in a given year if the majority of respondents are surveyed after the MML introduction. Furthermore, we cannot control for states' time-varying compositions of socio-demographic variables: these controls would need dynamic interactions as well, and our database of 1326 state-year cells does not offer sufficient variation to include the 'extended controls' we used in Table 1. Hence, only state and year fixed effects are included beside the treatment variable and its interactions.

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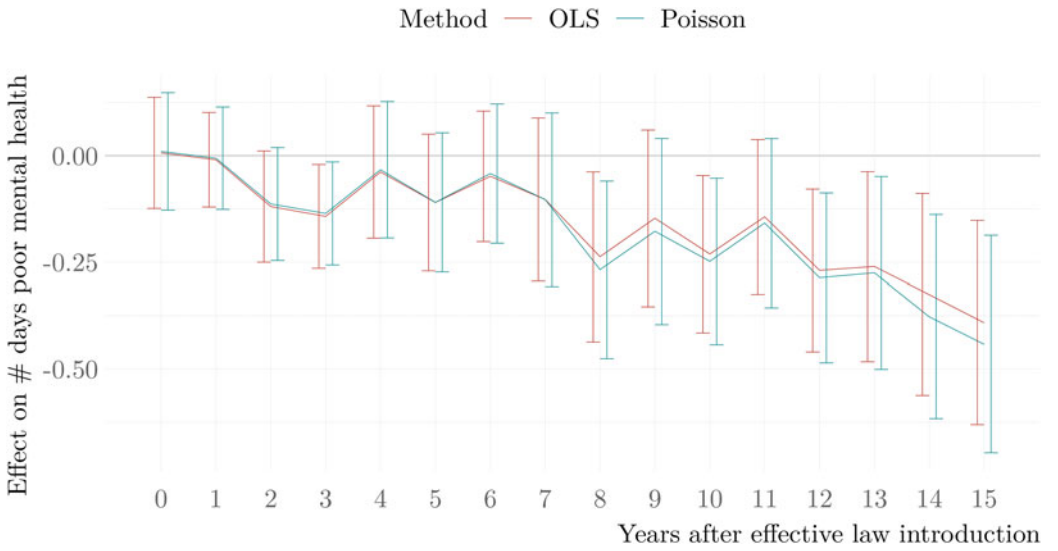

Figure 3. Dynamic overall treatment effects of medical marijuana laws.
Notes: The repeated cross-sections have been collapsed on the state-year level, resulting in a total of 1326 observations. We use Wooldridge (2021)'s extended two-way fixed-effects estimator as implemented in the R package etwfe (McDermott, 2023). Following the terminology of generalised linear models, method 'OLS' refers to the identity link function and 'Poisson' to the natural log kernel suitable for count variables with many zeroes. Pre-treatment periods are not reported since their coefficients equal zero by construction. Confidence intervals are set at 95 per cent.
Data source: BRFSS. Calculated using survey weights.

subsample of interest. As described in Section 3.3, we analyse the differential MML effects for these subgroups by partitioning the sample into likely abstainers, recreational users, medical users and additionally whether individuals likely experience frequent pain or not, based on estimated propensities for the consumer status and whether one suffers from frequent pain. We consequently estimate two alternative specifications, one with group-specific effects regarding the consumption motive and another with regard to the experience of frequent pain.

Figure 4 summarises the results. First, the red dots show the estimates for the three groups of likely abstainers, recreational users and medical users. Appendix Table B5 reports the corresponding OLS estimates. We find major differences regarding the impact of MMLs on the three groups. For likely medical users, the effect size is more than three times bigger compared to previous results for the whole population. For likely abstainers and likely recreational users, we do not find a systematic relationship between the adoption of an MML and mental health. For the interpretation, it is important to note that the group of likely abstainers – due to our imputation strategy – still includes some people who are potentially affected because they consume marijuana. Overall, the results indicate that the effects of MMLs differ across consumption motives with clear reductions of bad mental health days for likely medical marijuana consumers.

The results in Table B5 allow a further interpretation in terms of a triple difference. Under the restrictive assumption that the effect on likely abstainers is spurious due to time-*variant* unobserved confounders, i.e. factors correlated with the adoption of an MML that are negatively related to poor mental health, the difference from the effect on likely medical users offers a lower bound estimate for this latter group. In other words, the most conservative interpretation indicates a positive effect of MML on the mental health of likely medical users (around 3 per cent of our sample population) of 0.25 days fewer poor mental health days a month.

Second, the blue dots show the corresponding results for the group of those who likely suffer from frequent pain and the group of people who do not. Appendix Table B6 reports the corresponding OLS estimates. The effect of an MML on these latter individuals who are unlikely to

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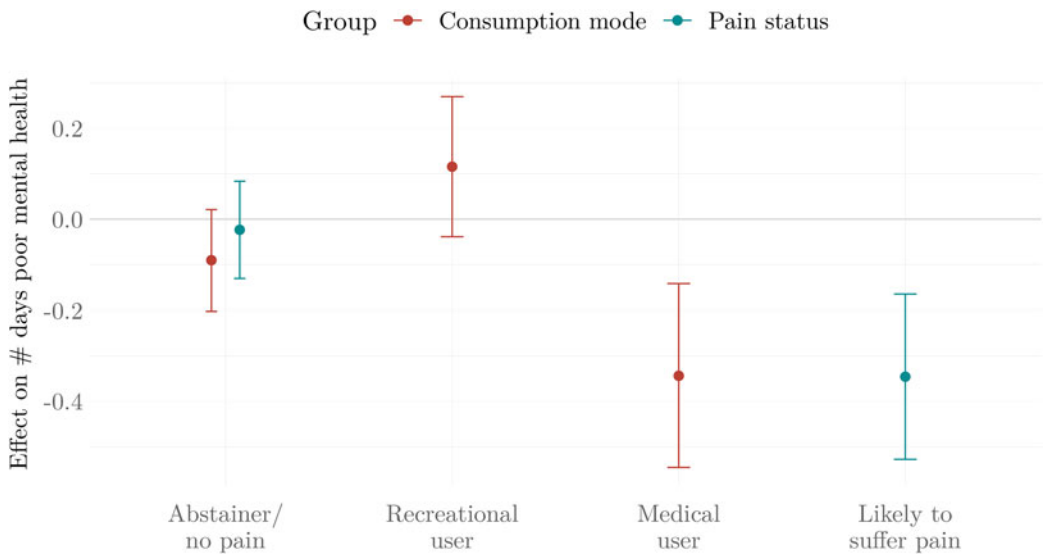

Figure 4. Treatment effects of medical marijuana laws on the mental health of people differing in terms of likely experienced pain and the reason for potential marijuana consumption.
Notes: The results are based on separate two-way fixed-effects estimations for the mode of consumption (red) and the suffering from pain (blue), respectively. Beside the dummy indicating an effective MML, interacted with individuals' imputed consumption motive or pain status, we include group-specific linear time trends and the 'extended controls' from Table 1. Appendix C describes the details of the imputation procedure. Confidence intervals are calculated with a block bootstrap at the state-level, including the imputation stage, and are set at 95 per cent.
Data source: BRFSS and NSDUH. Calculated using survey weights.

suffer from pain is both smaller than the general effect reported in Table 1. In line with the results for MMLs which allow unspecific pain as a qualifying condition in Section 4.1, the improvements in mental health for people likely to suffer pain are more than twice as large as they are for the overall population. The effect amounts to about one day less of poor mental health every three months. In a similar way to the analysis for medical marijuana consumers, we can interpret the coefficients in terms of a triple difference, i.e. the difference of the effect between likely pain sufferers from those who are likely pain free. This most conservative interpretation indicates a positive effect of MML on the mental health of likely pain sufferers of 0.32 days fewer poor mental health days a month.

5. Conclusions

The consequences of legal access to medical marijuana for individual welfare are a matter of controversy. We contribute to the ongoing discussion by evaluating the impact on self-reported mental health of the staggered introduction and extension of MMLs across US states. Our analysis is based on individual-level data with almost eight million observations, and exploits 32 interventions over 26 years on the state-level. Employing two-way fixed effects, we present and discuss net effects on mental health outcomes for the population as a whole and relevant subgroups to assess potential effect channels. We thereby focus on different motives for consumption as well as on the experience of frequent pain as a condition to consume marijuana.

We find weak evidence of positive effects on mental health due to the liberalisation of medical marijuana for the US population overall. While the estimated overall reduction in poor mental health days is not statistically significant, the result still implies an absence of evidence for the critical perspectives that highlight the risk of aggravated mental health problems due to MML introductions. Examining substantive differences between marijuana laws suggests that states

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that list unspecific pain as a qualifying condition for access to medical marijuana and allow for home cultivation exhibit potentially the biggest benefits. This indicates that easier access for patients might compensate for other potentially adverse effects, such as increased harmful diversion.

Importantly, we find large differential responses to MMLs conditional on marijuana consumption motive. While we do not observe statistically significant effects for likely abstainers and recreational users, likely medical users experience systematic gains in terms of their mental well-being. For the latter group, our estimates indicate that individuals report reductions in poor mental health of approximately four days a year, on average, under a less restrictive marijuana regime. This effect size is bigger than the negative impact of frequent alcohol binge drinking on US adults (Okoro *et al.*, 2004). In an alternative partition, we concentrate on people who are likely to suffer from frequent pain. Similarly, we estimate a reduction of around four poor mental health days per year for this group if an MML is in place. Combined with the result for medical users, the findings suggest that direct consumption effects are the main drivers behind the benefits.

Overall, our results are in line with the hypothesis that MMLs benefit those individuals for whom they are nominally designed without systematically harming other groups. Whether the results carry over to further liberalisations requires additional research, however, and should be carefully considered when deciding on the regulatory regime for marijuana in the future.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1744133124000033.

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