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The Effect of Medical Marijuana Laws on Marijuana-Related Attitude and Perception Among US Adolescents and Young Adults

Hefei Wen[1] · Jason M. Hockenberry[2] · Benjamin G. Druss[2]

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Abstract
Marijuana liberalization policies are gaining momentum in the USA, coupled with limited federal interference and growing dispensary industry. This evolving regulatory landscape underscores the importance of understanding the attitudinal/perceptual pathways from marijuana policy to marijuana use behavior, especially for adolescents and young adults. Our study uses the restricted-access National Survey on Drug Use and Health (NSDUH) 2004–2012 data and a difference-in-differences design to compare the pre-policy, post-policy changes in marijuana-related attitude/perception between adolescents and young adults from ten states that implemented medical marijuana laws during the study period and those from the remaining states. We examined four attitudinal/perception pathways that may play a role in adolescent and young adult marijuana use behavior, including (1) perceived availability of marijuana, (2) perceived acceptance of marijuana use, (3) perceived wrongfulness of recreational marijuana use, and (4) perceived harmfulness of marijuana use. We found that state implementation of medical marijuana laws between 2004 and 2012 was associated with a 4.72% point increase (95% CI 0.15, 9.28) in the probability that young adults perceived no/low health risk related to marijuana use. Medical marijuana law implementation is also associated with a 0.37% point decrease (95% CI − 0.72, − 0.03) in the probability that adolescents perceived parental acceptance of marijuana use. As more states permit medical marijuana use, marijuana-related attitude/perception need to be closely monitored, especially perceived harmfulness. The physical and psychological effects of marijuana use should be carefully investigated and clearly conveyed to the public.

Keywords Medical marijuana laws · Marijuana use · Risk perception

Introduction

Marijuana reform, including liberalization of medical and recreational use of marijuana, has been a subject of heated debates in the USA for decades. As of January 2018, 29 states and the District of Columbia have passed medical marijuana laws (MMLs) that protect patients from state prosecution for their medical marijuana use (Office of National Drug Control Policy (ONDCP) 2016). Although the legislative intent of MMLs is to provide restricted legal protection and access to marijuana for a select group of patients, concerns have been voiced that MMLs would "send messages" to young people that marijuana is safe and that marijuana use is a socially acceptable behavior and not subject to legal punishment (Cerdá et al. 2012). Adolescents and young adults are of particular concern to the public and policymakers, because their developing brain and body are particularly vulnerable to the lasting damage from marijuana use (Hall and Degenhardt 2009; Volkow et al. 2014; Hall 2015; Hall and Lynskey 2016).

The majority of previous studies examining the effect of MMLs on marijuana use behavior found no significant increase in marijuana use among adolescents and young adults attributable to MMLs (see, for instance, Hasin et al. 2015; Pacula et al. 2015a; Johnson et al. 2017). In contrast, older adults' marijuana use was found to be sensitive to MMLs (see, for instance, Pacula et al. 2015a; Williams et al. 2017).

✉ Hefei Wen
hefei.wen@uky.edu

Jason M. Hockenberry
jason.hockenberry@emory.edu

Benjamin G. Druss
bdruss@emory.edu

[1] Department of Health Management & Policy, College of Public Health, University of Kentucky, 111 Washington Avenue, Lexington, KY 40536, USA

[2] Department of Health Policy & Management, Emory University Rollins School of Public Health, 1518 Clifton Road NE, Atlanta, GA 30322, USA

Although MMLs may not affect adolescents' and young adults' marijuana use in the short run, there may be changes in their attitude/perception that set the stage for the changes in marijuana use behavior later in life (Keyes et al. 2011). According to health belief model and deterrence theory, attitude/perception refers to the judgment that individuals make about the scope and the severity of the consequences associated with a given behavior. The perceived consequences of a behavior are then linked to the subjective intentions and decisions to engage in the behavior (Becker 1974; Janz and Becker 1984; Paternoster 1987). Both theories suggest that reduced sanctions against unhealthy or otherwise risky behavior would alter multiple dimensions of individual attitude/perception about the target behavior and eventually produce corresponding behavioral changes. In the context of marijuana use, we hypothesize that MMLs may affect four dimensions of marijuana-related attitude/perception, including (1) perceived harmfulness of marijuana use, (2) perceived acceptance of marijuana use, (3) perceived wrongfulness of recreational marijuana use, and (4) perceived availability of marijuana.

First, a formal recognition of marijuana as valid medical therapy to alleviate symptoms and treat diseases may encourage people to downplay the potential physical and psychological harmfulness associated with marijuana use. There have been well-documented short-term effects of marijuana use such as anxiety, panic reactions, memory deficits, and cognitive impairments. Long-term, regular marijuana use may also be a contributory factor in marijuana dependence syndrome, respiratory problems, cardiovascular diseases, schizophrenia, and other psychotic symptoms, as well as histopathological changes that may become precursors to malignancy and cancer (Hall and Degenhardt 2009; Volkow et al. 2014; Hall 2015; Hall and Lynskey 2016). Although such physical and psychological effects of marijuana use can be detrimental to neurobiological development especially during adolescence and young adulthood, the scientific understanding of marijuana's effect on the human brain and body are still at a nascent stage and often surrounded by controversy and attacks in public debate over MMLs.

Second, the recognition of marijuana's therapeutic value may go beyond the medical realm and give rise to the normalization of marijuana use behavior in general, and adolescents and young adults are susceptible to shifting public opinions (Hathaway et al. 2011).

Third, the restricted legal protection of medical marijuana use under MMLs may be interpreted as a de facto decriminalization of recreational use. Young people are more likely to misunderstand the legislative intent of MMLs and embrace the "de facto decriminalization" notion, especially in areas where prosecution of a marijuana offense is law enforcement's "low priority" (Sekhon 2009; U.S. Department of Justice, Office of Public Affairs 2009).

Fourth, MMLs may increase the likelihood of marijuana diversion. Many state MMLs allow licensed retail dispensaries and/or home cultivation to provide medical marijuana patients with access to the drug. These supply channels, however, may make their way through streets and eventually into the hands of young people (Pacula et al. 2010; Anderson et al. 2013).

Theories have conceptualized marijuana-related attitude/perception as a key mechanism in the causal chain between MMLs and marijuana use, especially for young people. Empirical evidence is, however, still limited with regard to whether and to what extent MMLs affect the various dimensions of attitude/perception. Marijuana-related attitude/perception varied by states and changed over time among adolescents and young adults (Khatapoush and Hallfors 2004; Miech et al. 2015). Only a handful of studies to date have explicitly examined the association between marijuana-related attitude/perception and MMLs. Using the Monitoring the Future (MTF) surveys of 8th, 10th, and 12th grade students in the USA, Keyes et al. (2016) focused on perceived harmfulness of marijuana use and found that the enactment of MMLs was associated with a relative increase in perceived harmfulness among 8th grade students between 1991 and 2014. Using the National Drug Use and Health surveys of US adolescents and adults, Schuermeyer et al. (2014) also focused on perceived harmfulness of marijuana use and found a reduction in perceived harmfulness among 12–17 years olds in Colorado that paralleled the rapid growth of medical marijuana industry in the state between 2009 and 2011. Furthermore, Martins et al. (2016) used NSDUH data to study perceived availability of marijuana in the context of MML implementation between 2004 and 2013. No change in adolescents' and young adults' perception of marijuana availability was found to be associated with MMLs.

Nonetheless, perceived availability and harmfulness studied in the previous studies are only two of the potential attitudinal/perceptual mechanisms through which MMLs may affect marijuana use. Our study contributes to the literature by expanding the understanding of the multiple attitudinal/perceptual pathways from marijuana policy to marijuana use behavior in adolescent and young adult populations. We use nationally representative data and differences-in-difference (DD) design to examine the effect of implementation of MMLs in ten states between 2004 and 2012 on four dimensions of marijuana-related attitude/perception. As MMLs continue to gather momentum in state legislatures, the study findings are informative for states' current discussion, implementation, and iteration of MMLs and other related marijuana policies.

Methods

Data and Sample

Nine years of individual-level cross-sectional data were pooled from a restricted-access version of the National Survey on Drug Use and Health (NSDUH) 2004–2012. NSDUH is sponsored by the Substance Abuse and Mental Health Services Administration (SAMHSA) and provides the primary source of nationally and state-representative information on substance use behavior by the US civilian, non-institutionalized population aged 12 or above. The majority of the NSDUH interview is conducted by audio computer-assisted self-interviewing (ACASI) technology, a highly private and confidential mode that encourages honest reporting of sensitive topics. The response rates ranged from 73 to 76% between 2004 and 2012 (SAMHSA 2013).

From the original sample of respondents in NSDUH 2004–2012, we excluded approximately 3% of the observations with missing data on study variables, leaving us with a final sample size of approximately 388,200 with complete data available for analysis. We stratified the analytic sample into two age groups, adolescents aged 12–17 (N ≈ 191,700) and young adults aged 18–25 (N ≈ 196,500). We studied adolescent population and young adult population separately in light of the age heterogeneity found in previous studies with regard to the effect of MMLs on marijuana use behavior (Johnson et al. 2017; Pacula et al. 2015b; Wen et al. 2015). A possible source of this age heterogeneity may originate in the MML itself. All state MMLs have more restrictive requirements for minors under 18 (in some states, under 21) to be certified as medical marijuana patients (ONDCP 2016). Since MMLs treat adolescent medical marijuana use with more caution, adolescents and young adults may receive a differential "message" from the laws.

Study Variables

We studied four attitudinal/perception pathways that may play a role in adolescent and young adult marijuana use behavior.

Perceived Availability of Marijuana

NSDUH respondents were asked about the difficulty of obtaining marijuana for personal use. We created a dichotomous indicator for whether a respondent perceived that marijuana was very easy/easy (vs. difficult/impossible) to get.

Perceived Acceptance of Marijuana Use

Adolescent respondents were asked whether they disapprove of an adolescent of their own age using marijuana, as well as how they perceived their parents' attitude towards children using marijuana. We created an indicator for whether an adolescent respondent held no disapproval (vs. somewhat/strong disapproval) of adolescent marijuana use. We created a second indicator whether an adolescent believed that his/her parents held no disapproval (vs. somewhat/strong disapproval) of children's marijuana use. Young adult respondents were not asked about parental attitude, so we only created an indicator for personal acceptance of marijuana use among young adults.

Perceived Wrongfulness of Recreational Marijuana Use

Respondents were asked the maximum legal penalty for first-offense possession of an ounce or less of marijuana for recreational use in states of residence. We created a dichotomous indicator for whether a respondent perceived the legal consequence to be none/fine penalty, with reference category being jail/prison sentence, diversion-program penalty (e.g., probation, community service), or punishment uncertain.

Perceived Harmfulness of Marijuana Use

Respondents were asked to assess the physical and psychological harm of using marijuana once or twice per week. We created, accordingly, an indicator for whether a respondent's perceived marijuana use to be no/low health risk (vs. moderate/high risk).

Independent Variables

The key independent variable of interest is an indicator for state implementation of MMLs in ten states between 2004 and 2012. Note that since December 2012, Oregon and Washington have implemented recreational marijuana laws permitting adult use of marijuana for recreational purpose. However, the limited post-policy window did not allow us to study the effect of recreational marijuana laws. Therefore, this study only focused on MMLs. Please see Table 1 for the detailed information on MMLs. We assigned the MML-implementation indicator a value of 1 for each full month subsequent to the effective date of the laws. This month-to-month matching minimizes the potential measurement error from misclassification of pre-MML and post-MML outcomes. We assigned the MML-implementation indicator a value of 0 for the remaining periods and for the comparison states. Comparison states in the main analyses include eight states that already had MMLs in place at the beginning of 2004 (i.e., "always MML states") and those that did not have any MML by the end of 2012 (i.e., "no MML states").

We controlled for individual-level and state-level factors that are correlated both with individual attitude/perception about marijuana and with state decisions about MMLs. Individual-level covariates for adolescents and

Table 1 Summary of state medical marijuana laws

	Approved date[a]	Effective date[a]
2004–2012 (10 states)		
Vermont	2004/05	2004/07
Montana	2004/11	2004/11
Rhode Island	2005/06	2006/01
New Mexico	2007/03	2007/07
Michigan	2008/11	2008/12
New Jersey	2010/01	2010/10[b]
District of Columbia	2010/05	2010/07
Arizona	2010/11	2011/04
Delaware	2011/05	2011/07
Connecticut	2012/05	2012/05[c]
1996–2003 (8 states)		
California	1996/11	1996/11
Washington	1998/11	1998/11
Oregon	1998/11	1998/12
Alaska	1998/11	1999/03
Maine	1999/11	1999/12
Hawaii	2000/06	2000/12
Colorado	2000/11	2001/06
Nevada	2000/11	2001/10

[a] Office of National Drug Control Policy (ONDCP) (2016)

[b] The effective date of New Jersey MML is 2010/07 as specified in the statute, while the state governor Chris Christie delays its implementation

[c] Most sections of Connecticut MML came into effect from its passage (2012/05), while a few sections on 2012/10

young adults include (1) age (linear and squared terms), (2) gender, (3) race/ethnicity (non-Hispanic White, Hispanic, non-Hispanic African/Black, non-Hispanic Asian, or other racial/ethnic origins), (4) self-reported health (excellent, very good, good, or fair/poor health), (5) past-month cigarette smoking (daily smoker, non-daily smoker, or non-smoker), (6) urban residence (living in a metropolitan, micropolitan, or non-core-based statistical area), (7) family income relative to federal poverty level (living below 100% FPL, 100%–200% FPL, or above 200% FPL). For young adults, we also included measures of (8) marital status (never married, married, divorced/separated, or widowed), (9) educational attainment (less than high school, high school graduate, some college, or college graduate), and (10) employment status (full-time employed, part-time employed, unemployed, or not in labor force).

In addition to the individual-level sociodemographic characteristics, we controlled for the time-variant state-level economic and policy environment. State-level covariates include three continuous measures reflecting the fluctuation in state economic conditions: (1) unemployment rate, (2) average personal income, and (3) median household income of the state, as well as a dichotomous measure reflecting relevant changes in state policy environment. A major policy change during the study period concerns marijuana decriminalization/depenalization: Massachusetts, California, and several local jurisdictions relaxed penalties for recreational marijuana use or placed it "the lowest law enforcement priority." We created an indicator for (4) the implementation of decriminalization/depenalization policies. Please see Table 2 for the descriptive statistics of all study variables.

Analytic Strategies

We estimated the effect of state implementation of MMLs on individual perceived availability, acceptance, wrongfulness, and harmfulness related to marijuana use. We conducted stratified analyses for adolescents and for young adults.

We used a quasi-experimental difference-in-differences (DD) design, operationalized through state and year two-way fixed effects, to account for unobserved factors in individual attitude/perception that are systematically correlated with state MMLs. The DD approach allows us to estimate the policy effect of MMLs net of the potential confounding effect of the time-invariant state heterogeneity and the national secular trend in marijuana-related attitude/perception (Wooldridge 2010). We also included state-specific linear trends to account for unobservable social norms and sentiments that evolve over time at different rates across states.

We estimated Logistic regressions in light of the dichotomous nature of our dependent variables: Logit (**Marijuana-related attitude/perception**$_{i,s,t}$) = β_1 + β_2 **MML implementation**$_{s,t}$ + $\beta_3 X_{1\,i,s,t}$ + $\beta_4 X_{2\,s,t}$ + ρ_s + τ_t + $\rho s \times t$ + $\varepsilon_{s,t}$.

where i denotes individual, s denotes state, t denotes year; MML Implementation$_{s,t}$ is the DD indictor of interest; $X_{1\,i,s,t}$ is a vector of individual-level covariates, $X_{2\,s,t}$ is a vector of state-level covariates; ρ_s is the state fixed-effects, τ_t is the year fixed effects; $\rho s \times t$ is the state-specific linear trends.

For ease of interpretation, we converted the regression coefficients into marginal additive effects, which can be interpreted as the percentage point change in an outcome associated with state implementation of MMLs (i.e., the MML-implementation indicator changing from 0 to 1). In other words, the marginal additive effects are risk differences in the predicted probabilities of an outcome between when the populations were exposed to MMLs and when the populations were not exposed. We incorporated NSDUH sampling weights to correct for the non-coverage, non-response, and post-stratification biases in a complex survey design. We clustered standard errors at the state level to correct for the within-state serial correlation in a DD design (Bertrand et al. 2004).

Table 2 Descriptive statistics of study variables

	Age 12–17		Age 18–25	
	Mean	S.D.	Mean	S.D.
Number of Age	14.54	(1.69)	21.39	(2.28)
% Male	51.08	(49.98)	50.30	(50.00)
Race/ethnicity: non-Hispanic White (ref.)	58.29	(49.31)	59.84	(49.02)
% Hispanic/Latino	19.52	(39.63)	18.85	(39.11)
% Non-Hispanic African Black	14.79	(35.50)	13.97	(34.67)
% Non-Hispanic Asian	4.33	(20.36)	4.79	(21.35)
% Other origins	3.07	(17.24)	2.56	(15.80)
Self-reported health: excellent (ref.)	33.88	(47.33)	29.97	(45.81)
% Very good	41.78	(49.32)	40.97	(49.18)
% good	20.73	(40.54)	23.44	(42.36)
% Fair/poor	3.61	(18.65)	5.62	(23.03)
Cigarette smoking: non-smoker (ref.)	91.01	(28.61)	64.47	(47.86)
% Non-daily smoker	6.78	(25.14)	18.71	(39.01)
% Daily smoker	2.21	(14.71)	16.82	(37.41)
Urbanicity: non-CBSA (ref.)	7.98	(27.10)	6.65	(24.91)
% Living in a micropolitan	40.45	(49.08)	41.95	(49.35)
% Living in a metropolitan	51.58	(49.98)	51.40	(49.98)
Family income: > 200% FPL (ref.)	58.51	(49.27)	50.49	(50.00)
% Living 100–200% FPL	22.03	(41.44)	24.40	(42.95)
% Living < 100% FPL	19.46	(39.59)	25.11	(43.37)
Marital status: married (ref.)			12.04	(32.54)
% Never married			86.16	(34.53)
% Separated/divorces			1.73	(13.04)
% Widowed			0.07	(2.67)
Education attainment: college graduate (ref.)			13.81	(34.49)
% Some college			33.65	(47.25)
% High school graduate			34.57	(47.56)
% Less than high school			17.97	(38.40)
Employment: full-time employed (ref.)			42.08	(49.37)
% Part-time employed			26.60	(44.19)
% Unemployed			10.50	(30.66)
% Not in labor force			20.82	(40.60)
Number of observations	≈ 191,700		≈ 196,500	

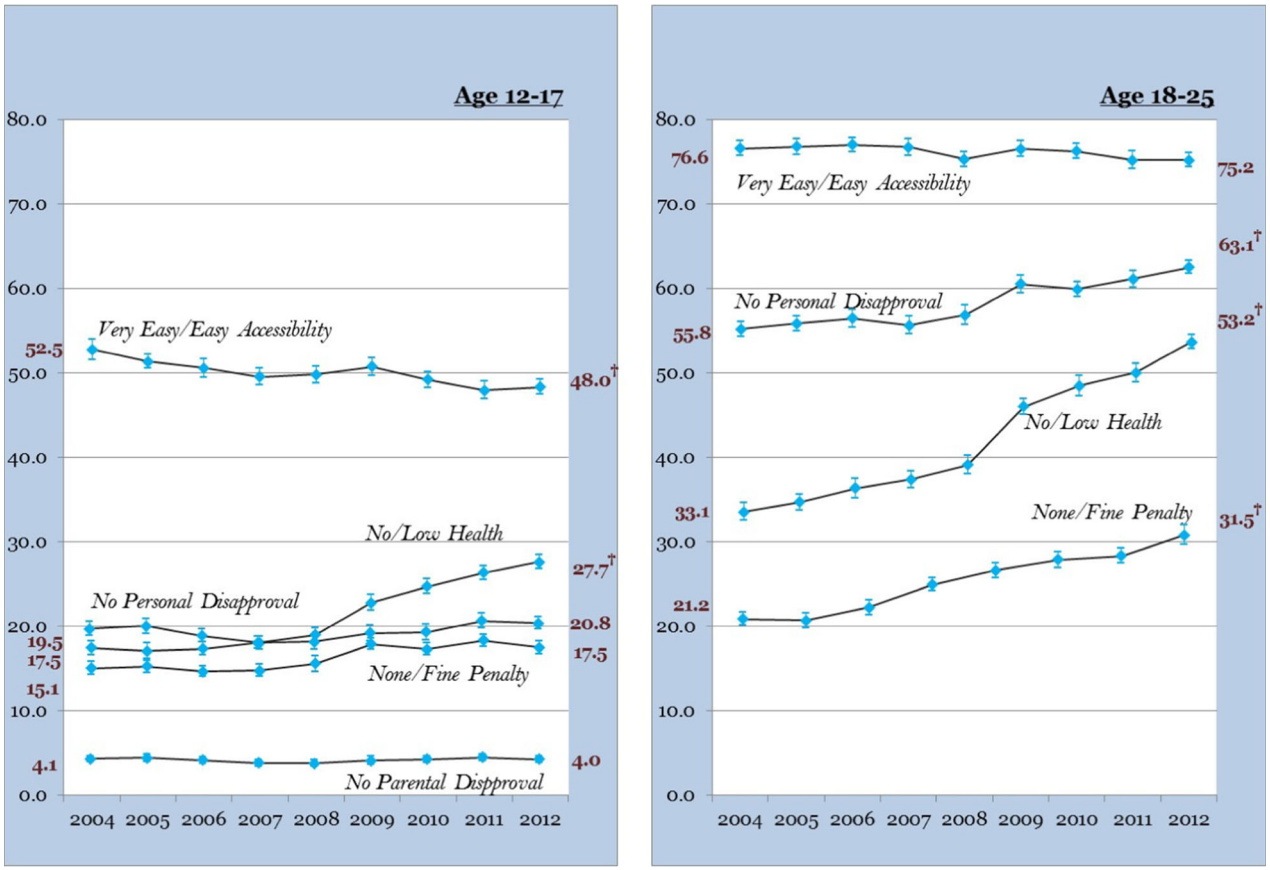
Results

Temporal Trends in Marijuana-Related Attitude/Perception and Marijuana Use Behavior

Figure 1 demonstrates the weighted trends in marijuana-related attitude/perception and marijuana use behavior from 2004 to 2012. During this study period, we observed increases in perceived no/low health risk related to marijuana use in both adolescent and young adult populations. Increases were also seen in personal acceptance of marijuana use, perceived none/fine penalty for recreational use, and past-month any use of marijuana among young adults. Nonetheless, it is unclear from Fig. 1 as to whether and to what extent those upward trends can be attributed to the growing number of state MMLs and other marijuana liberalization policies.

Effect of MML Implementation on Marijuana-Related Attitude/Perception

Table 3 presents the main estimates of the effect of MML implementation on marijuana-related attitude/perception, adjusted for the two-way fixed effects, state-specific linear trends, full vector of individual- and state-level covariates, sampling weights, and state-level clusters.



† Significant difference from 2004 to 2012 at the 0.05 level.

Fig. 1 Weighted trends of marijuana-related attitude/perception, 2004–2012. The dagger symbol signifies difference from 2004 to 2012 at the 0.05 level

For both age groups, we found no change in perceived availability of marijuana that can be attributed to the implementation of MMLs.

With respect to perceived acceptance of marijuana use, we found that the implementation of MMLs was associated with a 0.37% point (95% CI − 0.72, − 0.03) decrease in the probability that adolescents perceived acceptance (i.e., no disapproval) of marijuana use from their parents, but no change in adolescent personal acceptance of marijuana use. In contrast to the decreased parental acceptance of children's marijuana use, we found a marginally significant increase in young adult personal acceptance of marijuana use as a result of MML implementation.

No change in perceived wrongfulness of recreational marijuana use was attributable to MML implementation, which suggests that residents in MML states were not likely to misinterpret the restricted legal protection of medical marijuana use as an overall reduction in legal penalty for any marijuana-possession offense.

Concerning perceived harmfulness of marijuana use, we found that the implementation of MMLs was associated with a 4.72% point (95% CI 0.15, 9.28) increase in the probability that young adults perceived no/low health risk related to marijuana use. Among adolescents, in contrast, we found no discernible effect of MML implementation on perceived harmfulness of marijuana use.

Discussion

Our findings provide some of the first empirical evidence based on nationally representative data concerning the potential effects of MML implementation on marijuana-related attitude/perception. We found that, after states began to implement the laws, adolescents were less likely to perceive parental acceptance of children's marijuana use. The reduction in parental acceptance was suggested by previous studies showing that, in the wake of major marijuana liberalization policies, parents remained strongly opposed to their children's marijuana use (Kosterman et al. 2016). And concerned with the controversial or contradictory messages surrounding young people, parents may provide more counter-marijuana messages to their adolescent children (Keyes et al. 2016). Nonetheless, when deciding whether to engage in marijuana use, adolescents were not likely to take parental disapproval into full consideration.

Table 3 Estimated effects of medical marijuana law (MML) implementation on marijuana-related attitude/perception

	Age 12–17			Age 18–25		
	% Difference in predicted proportion[a] (95% CI[b])	% Predicted proportion		% Difference in predicted proportion[a] (95% CI[b])	% Predicted proportion	
		Non-/always-MML	MML		Non-/always-MML	MML
Perceived Availability: pr (very easy/easy access to marijuana)	0.17 (− 0.85, 1.18)	[50.35]	[50.52]	0.98 (− 1.21, 3.17)	[75.03]	[76.01]
Personal acceptance: pr (no personal disapproval of marijuana use)	0.24 (− 0.62, 1.10)	[20.26]	[20.40]	2.63† (− 0.06, 5.32)	[58.44]	[61.07]
Parental acceptance: pr (no parental disapproval of marijuana use)	− 0.37* (− 0.72, − 0.03)	[4.09]	[4.46]	n/a	n/a	n/a
Perceived wrongfulness: pr (none/fine penalty for recreational use)	− 0.67 (− 2.36, 1.02)	[16.92]	[17.59]	1.03 (− 1.45, 4.52)	[27.12]	[28.16]
Perceived harmfulness: pr (no/low health risk of marijuana use)	− 0.30 (− 8.62, 8.01)	[22.34]	[22.54]	4.72* (0.15, 9.28)	[41.20]	[45.92]
Number of observations	≈ 191,700			≈ 196,500		

† $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

[a] 95% confidence intervals in parentheses are calculated based on state-clustered standard errors

[b] Baseline-predicted means of the dependent variables in square brackets are calculated as the average of predicted probabilities when setting the policy indicators for MML implementation to 0 and leaving the other covariates as the observed values

We also found that the implementation of MMLs was associated with an increase in the probability that young adults perceived no/low health risk related to marijuana use from 41.20 to 45.92% points. This 4.72% point increase is equivalent to a relative 11.46% increase (i.e., 4.72 ÷ 41.20). A similar sizable increase in the perceived harmfulness was also found in a recent survey among a cohort of 39-year-old parents after the marijuana legalization in Washington (Kosterman et al. 2016). Perceived harmfulness of marijuana use may further play a major role in shaping marijuana use behavior in response to the MML implementation. Today in the USA, marijuana liberalization policies are gaining momentum, coupled with limited federal interference and growing dispensary industry. In this evolving regulatory landscape, our study sheds new light on the importance of health risk messaging in marijuana policy arena. When debating, crafting, and refining MMLs and similar liberalization policies, policymakers and advocates should carefully navigate the balance between informing the public about the medical value of marijuana and alerting the public to its potential physical and psychological harm. Evidence to date has only lent limited support to medical use of marijuana in a few debilitating medical conditions (e.g., HIV-AIDS, cachexia, cancer, glaucoma, epilepsy and other seizure disorders, muscle spasms from multiple sclerosis, or Crohn's disease), for which the potential benefits of marijuana would likely outweigh the health risks (Hill 2015; Hoffmann and Weber 2010). Furthermore, as D'Souza and Ranganathan (2015) pointed out, "[unless state MMLs] is merely a veiled step towards legalization of recreational marijuana, the medical communities should not be left out of the process." To avoid unintended increases in marijuana use, the health policy and medical communities should join efforts in conveying evidence-based health information to the policymakers and the public and clarifying common misperceptions related to marijuana and other substances. Targeted investments in marijuana-related research, education, and surveillance are critical to provide evidence base for such efforts, get the "right messages" across, and provide timely feedback.

The study findings should be viewed in light of the following limitations. First, institutionalized individuals (e.g., in jails/prisons or hospitals), homeless or transient persons not in shelters, and military personnel on active duty were excluded from the NSDUH sample. These excluded populations, despite their small population sizes, may represent some of the high risk groups that respond differently to MMLs from the general household population. Second, NSDUH data on marijuana-related attitude/perception were self-reported, and most constructs were single-item measures. Thus, they were subject to reporting bias and measurement errors. Nonetheless, the majority of the NSDUH interview is conducted by self-administrated audio computer-assisted self-interviewing (ACASI), a highly private and confidential mode that encourages honest reporting of sensitive topics (Johnson et al. 2010). Ramo et al. (2012) also provided evidence that lent weight to the reliability and validity of the self-reported attitude/perception data in NSUDH. Third, it is interesting to notice that states which have implemented MMLs are

concentrated in the West and Northeast. This geographic proximity implies that states were not *randomly* assigned to MMLs. To alleviate the potential policy endogeneity in MMLs, our DD model included not only the typical two-way fixed effects but also the state-specific linear trends, the latter accounting for heterogonous linear trajectories across states in social norms and sentiments related to marijuana use. We further conducted sensitivity analyses restricting comparison states to the "always MML states" that had existing MMLs before 2004 to account for the ripple effect of policy adoption throughout the region and other regional interconnection in marijuana culture and market. Our main estimates were consistent with the ones from the sensitivity analyses (available upon request). Another limitation is that our main analyses treated MMLs as a homogenous set of policies, which may obscure the potential heterogeneous effects across individual components of MMLs (Pacula et al. 2015b). We performed additional sensitivity analyses which decomposed a single indicator for MML implementation into a series of indicators for different MML provisions, including (1) "non-specific pain" provision, which lists a generic "chronic pain" in the eligible conditions for medical marijuana, rather than specifying diseases causing the pain; (2) "patient registry" provision, which requires a patient registry/renewal system; (3) "retail dispensary" provision, which allows licensed marijuana retailers to dispense marijuana legally to medical marijuana patients; and (4) "home cultivation" provision, which allows qualified patients and caregivers to grow a certain amount of marijuana plants indoors for the patients' own medical use. Although we did not detect any significant and consistent pattern (available upon request), we acknowledge that lack of statistical power often makes it difficult to pin down the individual effects of each component and the statistical differences across them. With more MMLs and provisions take effect and more data become available, future research would have sufficient policy variation and sample size to explore the policy heterogeneity and identify the key components in MMLs.

Conclusions

Our study highlights the importance of health risk messaging in MMLs. The implementation of ten state MMLs between 2004 and 2012 may lower perceived harmfulness of marijuana use in young adults, which may shape their marijuana use behavior in the future. As more states permit medical marijuana use and dispensaries, individual attitude/perception related to marijuana use need to be closely monitored, especially perceived harmfulness. Marijuana's health effect should be carefully investigated and clearly conveyed to the public.

Compliance with Ethical Standards

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent For this type of study formal consent is not required.

Conflict of Interest The authors declare that they have no conflict of interest.

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