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Policy analysis

# The effects of medical marijuana laws on potency

Eric L. Sevigny[a,*], Rosalie Liccardo Pacula[b], Paul Heaton[b]

[a] Department of Criminology and Criminal Justice, University of South Carolina, 1305 Greene Street, Columbia, SC 29208, USA
[b] RAND Drug Policy Research Center, RAND Corporation, 1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138, USA

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ABSTRACT

*Background:* Marijuana potency has risen dramatically over the past two decades. In the United States, it is unclear whether state medical marijuana policies have contributed to this increase.
*Methods:* Employing a differences-in-differences model within a mediation framework, we analyzed data on $n = 39{,}157$ marijuana samples seized by law enforcement in 51 U.S. jurisdictions between 1990 and 2010, producing estimates of the direct and indirect effects of state medical marijuana laws on potency, as measured by $\Delta^9$-tetrahydrocannabinol content.
*Results:* We found evidence that potency increased by a half percentage point on average after legalization of medical marijuana, although this result was not significant. When we examined specific medical marijuana supply provisions, results suggest that legal allowances for retail dispensaries had the strongest influence, significantly increasing potency by about one percentage point on average. Our mediation analyses examining the mechanisms through which medical marijuana laws influence potency found no evidence of direct regulatory impact. Rather, the results suggest that the impact of these laws occurs predominantly through a compositional shift in the share of the market captured by high-potency sinsemilla.
*Conclusion:* Our findings have important implications for policymakers and those in the scientific community trying to understand the extent to which greater availability of higher potency marijuana increases the risk of negative public health outcomes, such as drugged driving and drug-induced psychoses. Future work should reconsider the impact of medical marijuana laws on health outcomes in light of dramatic and ongoing shifts in both marijuana potency and the medical marijuana policy environment.


## Introduction

Marijuana (cannabis) is the most widely used illicit substance in the United States, with about 17.4 million past-month users in 2010. Recent trends reveal an increase in marijuana prevalence, especially among younger populations. Between 1990 and 2010, rates of past-month marijuana use increased about 68% for youth aged 12–17, 46% for young adults aged 18–25, and 12% for adults aged 26–34 (Substance Abuse and Mental Health Services Administration, 2011). Over the same time period, average concentrations of $\Delta^9$-tetrahydrocannabinol (THC)—the main psychoactive component of marijuana—nearly tripled from 3.4% to 9.6% (ElSohly, 2008, 2012). This epidemiology has important public health implications, as mounting evidence links higher potency marijuana to an array of adverse outcomes, especially among novice users (Hall & Degenhardt, 2006, 2009; McLaren, Swift, Dillon, & Allsop, 2008). In particular, research supports claims of dose-dependency between THC levels and risk of acute anxiety (Crippa et al., 2009), psychosis (Di Forti et al., 2009), cognitive impairment (Ramaekers et al., 2006), and vehicular accidents (Li et al., 2012; Ramaekers, Berghaus, van Laar, & Drummer, 2004).

Although there has been some recent attention in the academic literature to the question of whether permissive state medical marijuana laws (MMLs) have contributed to the recent rise in recreational use of marijuana, with results from published studies appearing quite mixed (e.g., Friese & Grube, 2013; Harper, Strumpf, & Kaufman, 2012), virtually no attention has been given to the possible impact these state laws might have on consumption through their effects on the average potency of the marijuana consumed. Indeed, it is entirely possible that a rise in the average potency of marijuana could be associated with a decline in total quantity of marijuana consumed, as users consuming higher potency marijuana require less marijuana to reach the same level of intoxication (van Laar, Frijns, Trautmann, & Lombi, 2013; Reinarman, 2009).

In light of the public health concerns associated with rising rates of high-potency marijuana use, particularly among youth, and the possible mediating effect this rise would have on total marijuana consumed, an obvious first question to ask is whether medical marijuana laws have contributed to rising potency trends over the past two decades. Although no state law directly regulates the THC

* Corresponding author. Tel.: +1 803 777 7043.
*E-mail address:* sevigny@mailbox.sc.edu (E.L. Sevigny).

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content of medical marijuana, there is some evidence to suggest that the typical potency of medical marijuana is higher than that of recreational marijuana sold in black markets (Burgdorf, Kilmer, & Pacula, 2011). It may be the case that the general allowance for growing high-grade marijuana for medical purposes—including specific rules governing retail outlets or dispensaries, home cultivation, and patient caregivers—has contributed to the upward trend in potency observed in recreational markets.

The focal relationship we examine in this study, therefore, concerns the effect of state medical marijuana laws on cannabis potency. Specifically, we investigate state-level variations in potency for the years 1990–2010 using data from the University of Mississippi's Potency Monitoring Program (PMP), a federally-funded surveillance program that forensically analyzes marijuana samples seized by federal, state, and local law enforcement agencies (see Mehmedic et al., 2010). Recognizing that alternative state policies and programs may also affect potency, we explore the competing effects of rival explanatory factors, including marijuana decriminalization and law enforcement efforts. In the next section, we further explicate these policies and possible mechanisms of action.

## State marijuana policies, markets, and potency

Marijuana is not a uniform product, varying considerably by strain (indica, sativa, hybrid), cultivation technique (hemp, sinsemilla, hydroponic), and manner of processing (herb, resin, oil). The resulting cannabis phenotypes contribute to wide variations in potency across both time and place (Burgdorf et al., 2011; Slade, Mehmedic, Chandra, & Elsohly, 2012). Although direct empirical evidence is limited, insider and journalistic accounts suggest that MMLs—and the medical marijuana industry built up around them—have greatly enhanced the development and diffusion of high-potency cannabis cultivars and sophisticated technologies of production (Downs, 2012; Geluardi, 2010; Rendon, 2013; West, 2011). As Rendon (2013, p. 147) explains about developments in the earliest adopting medical marijuana state, "the legalization of marijuana for medical use in California has changed everything about the market for pot and is pushing changes for growers, breeders, and the plant itself."

Given the relatively small size of legitimate medical marijuana markets (Bowles, 2012; General Accountability Office, 2002), one possible concern regarding our hypothesized policy effect is that any potential impact will be swamped by trends in the much larger recreational market. However, if there is substantial technology and product transfer between medical and recreational marijuana markets, as we suspect, the influence of these policies will be more broadly detectable. Indeed, the available evidence suggests that the two markets are quite interrelated, especially where oversight is lax, and that substantial quantities of medical marijuana are being overproduced and diverted into recreational markets (Finlaw & Brohl, 2013; Rendon, 2013; Wirfs-Brock, Seaton, & Sutherland, 2010). A recent investigation by the Rocky Mountain High Intensity Drug Trafficking Area program, for instance, documented dozens of cases of diversion of Colorado medical marijuana by dispensaries, registered patients, and licensed caregivers (Investigative Support Center, 2012). Indicative of such leakage, recent research with in-treatment adolescents in Denver found that one-half to three-quarters had previously used diverted medical marijuana for nonmedical reasons (Salomonsen-Sautel, Sakai, Thurstone, Corley, & Hopfer, 2012; Thurstone, Lieberman, & Schmiege, 2011).

Decriminalization policies and law enforcement efforts can potentially influence potency as well, so we also assess the competing effects of these rival factors. We hypothesize that the effects of these various policies may operate, at least partly, through state-level contextual features such as product composition and overall size of the marijuana market. In other words, we surmise these policies help shape state markets, which in turn influence the quality and type of marijuana supplied to and demanded by users in these markets. We examine these various policies and propositions in more detail in the following sections.

### *Medical marijuana laws*

As of mid-2013, twenty states (including the District of Columbia) have adopted laws affording qualifying patients the right to possess and use marijuana for medical purposes without the threat of state prosecution and punishment.[1] Researchers have only recently begun to investigate the policy impacts of these laws. Most of these studies have focused on marijuana use, especially among youth, and in general they find no association between these policies and youth use (Anderson, Hansen, & Rees, 2012; Cerdá, Wall, Keyes, Galea, & Hasin, 2012; Friese & Grube, 2013; Gorman, Huber, & Charles, 2007; Harper et al., 2012; Khatapoush & Hallfors, 2004; Lynne-Landsman, Livingston, & Wagenaar, 2013; Wall et al., 2011). Studies considering adults have found very modest correlations (Anderson, Hansen, & Rees, 2013). Other studies have examined a range of alternative outcomes, finding that MMLs are not significantly related to emergency department visits (Gorman et al., 2007) and positively related to marijuana prices (Pacula, Kilmer, Grossman, & Chaloupka, 2010), with mixed results on treatment service utilization (Anderson et al., 2012), and even apparent benefits with respect to alcohol-related traffic fatalities (Anderson et al., 2013). However, to date, all of these studies have grouped medical marijuana laws as homogenous policies, ignoring the extent to which particular aspects of state laws (e.g., allowance of dispensaries) have influenced these results (Pacula, Powell, Heaton, & Sevigny, 2013).

Presently, thirteen states have implemented, or are in the process of establishing, state-licensed medical marijuana dispensary systems. Marijuana supplied under a state-sanctioned distribution regime is likely to be relatively more potent and of consistently higher quality than either home-grown or black market marijuana due to greater quality control, efficiency gains in production and reduced enforcement risks. In the Netherlands, for instance, marijuana sold through coffee shops and pharmacies for recreational and medical use, respectively, is more potent on average than marijuana available in the illicit markets of neighboring countries (Hazekamp, 2006; King, Carpentier, & Griffiths, 2004; Pijlman, Rigter, Hoek, Goldschmidt, & Niesink, 2005). In Switzerland, Killias, Isenring, Gilliéron, and Vuille (2011) report that the mean THC content of recreational marijuana dropped from 15.7% (range: 7.9–28.4%) to 12.0% (range: 3.7–17.6%) between 2004 and 2009 after the government shut down previously tolerated retail cannabis shops.

Personal home cultivation currently offers another supply option in fifteen medical marijuana states. These policies might promote the production of less potent marijuana if the majority of patients, especially those who are seriously ill, lack the necessary amenities, resources, or skills to cultivate and maintain their own supply of medical-grade marijuana (Chapkis & Webb, 2008; Feldman & Mandel, 1998). There is evidence to suggest that some

[1] We include Maryland in this group, a state that provides only an affirmative defense for possession of medical marijuana but does not permit home cultivation or regulate other sources of supply. We also distinguish current medical marijuana laws from the more circumscribed (and often unfunded) state therapeutic research programs enacted in the 1970s and 1980s that allowed investigational access to marijuana strictly within a clinical research setting.

medical marijuana patients actually prefer lower-THC cannabis because it treats their symptoms without the accompanying psychoactive high (Downs, 2012; Harris et al., 2000; Swift, Gates, & Dillon, 2005). On the other hand, a recent web-based survey of U.S. and Canadian home cultivators, most of whom reported growing for medical purposes (78%), found that a majority cultivate to secure more potent marijuana than they can obtain elsewhere (54%) (Potter, Barratt, Decorte, Malm, & Lenton, 2013). In short, although home cultivation policies might foster the cultivation of lower-potency marijuana due to the general proclivities of home growers, there also appears to be tendency among U.S. home cultivators toward growing higher potency medical marijuana than what is otherwise generally available.

Certain provisions governing home cultivation might also promote a more business-like model of personal production. For example, in some states practically any willing adult can serve as a designated caregiver (or provider/grower) to legally assist patients with home cultivation, whereas other states require the caregiver to be a family member or another person who has significant caretaking responsibilities for the patient. Similarly, some states allow caregivers to grow for multiple patients (occasionally without limit), whereas other states limit the number of patients per caregiver to one. Finally, certain states explicitly allow collective cultivation, whereas others prohibit it (although the majority of states are silent on this matter). We suspect that less restrictive home supply provisions (i.e., few limits on who can be a caregiver, multiple patients per caregiver, allowances for collective gardening) may encourage a cottage industry model of production that facilitates growing higher potency marijuana.

In 2012, two states, Colorado and Washington—both of which had previously legalized medical marijuana—passed ballot initiatives providing for legalized recreational use of marijuana. Implementation of these laws is only beginning in both states, so data are not yet available that would permit an assessment of how these policy changes affect potency. Clearly, however, this latest evolution in marijuana policy merits scholarly attention once post-implementation data emerge.

### *Marijuana decriminalization policies*

As of mid-2013, sixteen states have formally decriminalized marijuana by removing penalties for possessing small amounts of marijuana intended for personal use.[2] Many studies have investigated the effects of these policies on marijuana use, and the empirical evidence remains quite mixed (Damrongplasit & Hsiao, 2009; Pacula, Chriqui, & King, 2004). However, no studies have directly examined the effect of marijuana decriminalization on potency, so we can only speculate about possible impacts. As with medical marijuana legalization, there are plausible mechanisms through which decriminalization might increase average potency. For example, if decriminalization leads to higher demand and a more stable market, growers may be more willing to invest in advanced production technologies that facilitate the cultivation of higher-potency marijuana, or they may grow a more potent cultivar as a means of product differentiation. On the other hand, market expansion might lead to product availability with a broader range of THC content, appealing to those who have different preferences regarding the psychoactive properties of their marijuana.

### *Marijuana enforcement and eradication programs*

Research in different contexts suggests that targeted drug law enforcement operations aimed at increasing seizures and arrests produce few sustained changes in price, purity, or availability in street-level drug markets (Best, Strang, Beswick, & Gossop, 2001; Ciccarone, Unick, & Kraus, 2009; Dobkin & Nicosia, 2009; Weatherburn & Lind, 1997). The one study that examined outcomes in marijuana markets (Best et al., 2001) found that the majority of drug users perceived no changes in marijuana quality during the two-week period following a police crackdown. This is probably least surprising for marijuana, since it takes time for existing stocks to be depleted. Moreover, dealers cannot readily “cut” marijuana in response to supply shortages as they can with heroin and cocaine.

Over the longer-term, other studies have found positive associations between mandatory sentencing laws and purity of heroin and cocaine (Davies, 2010) and precursor control laws and methamphetamine purity (Nonnemaker, Engelen, & Shive, 2011). As Nonnemaker et al. (2011) suggest, this counterintuitive finding may be the consequence of an adaptive response by traffickers to seek higher-quality international sources of supply. Marijuana markets seem to have undergone a similar but more protracted transformation (Szendrei, 1997; United Nations Office on Drugs & Crime, 2006). According to this argument, the marijuana industry adapted to greater law enforcement pressure, first, by shifting from foreign to domestic production in the 1970s and early 1980s as importation became increasingly risky and, second, by relocating domestic production indoors beginning in the mid-1980s to reduce risk of detection and seizure from expanding stateside eradication programs. These developments may have spurred increases in marijuana potency as production moved closer to consumers and domestic growers mastered progressively sophisticated indoor cultivation techniques (e.g., hydroponics, cloning) that maximized per-plant potency, yields, and profits (Bouchard & Dion, 2010; Potter, Gaines, & Holbrook, 1990; Reinarman, 2009).

### *Aggregate market effects: an intervening variable hypothesis*

While the above discussion illustrates that the mix of state marijuana policies governing medical use, decriminalization, and enforcement can seemingly influence potency in a number of cross-cutting ways, it is important to reiterate that none of these laws and policies directly control or place limits on potency. Rather, these policies explicitly influence the structure and organization of the marijuana marketplace—whether by allowing medical use and related distribution for a clinical population, tolerating recreational use more broadly, or curtailing local illicit production and distribution. Moving from a constrained illegal market with high enforcement to a medical market could shift the methods and modes of production, legal and illegal points of distribution, the types and forms of available marijuana, the actors and organizations involved, the presence of ancillary industries and services (e.g., hydroponic equipment stores), and prices. It is these shifts in larger market supply and demand factors that are, in turn, most likely to influence potency. Thus, rather than a direct effect, we suspect state marijuana policies will primarily influence potency *indirectly* through their market-shaping effects. In other words, we hypothesize that changes in the size and composition of marijuana markets serve as a key causal pathway through which state marijuana policies exert their influence on potency.

## Methods

### *Data*

The measures for this study come from several data sources. Marijuana potency and state-level marijuana market indicators

[2] More recently, states have also begun exploring the outright legalization of marijuana for recreational use, with Washington and Colorado voters passing legalization measures in November 2012. Since the enactment of these laws falls completely outside our study period (1990–2010), we do not address them further here. However, see Caulkins, Lee and Kasunic (2012) for a discussion of the general policy implications and consequences of these measures.

**Table 1**
State medical marijuana laws, 1990–2010.

| State | MML/amendment effective year[a] | Dispensaries | | Home supply | | | |
|---|---|---|---|---|---|---|---|
| | | Legally operating[b] | De Facto operating | Home cultivation | Caregiver model[c] | Multiple patients per caregiver | Collective growing |
| Alaska | 1999 | No | No | Yes | Provider | No | Law silent |
| California | 1997 | No | Yes | Yes | Caretaker | Yes | Law silent |
| | 2004 | Yes | Yes | Yes | Caretaker | Yes | Allowed |
| Colorado | 2001 | No | No | Yes | Caretaker | Yes | Law silent |
| | 2005 | No | Yes | Yes | Caretaker | Yes | Law silent |
| | 2010 | Yes | Yes | Yes | Provider | Yes | Prohibited |
| Hawaii | 2001 | No | No | Yes | Caretaker | No | Prohibited |
| Maine | 2000 | No | No | Yes | Caretaker | Yes | Law silent |
| | 2010 | No | No | Yes | Provider | Yes | Law silent |
| Maryland | 2004 | No | No | No | n/a | n/a | n/a |
| Michigan | 2009 | No | No | Yes | Provider | Yes | Law silent |
| | 2010 | No | Yes | Yes | Provider | Yes | Law silent |
| Montana | 2005 | No | No | Yes | Provider | Yes | Law silent |
| | 2009 | No | Yes | Yes | Provider | Yes | Law silent |
| Nevada | 2002 | No | No | Yes | Caretaker | No | Law silent |
| New Mexico | 2007 | No | No | No | n/a | n/a | n/a |
| | 2008 | No | No | Yes | Provider | Yes | Law silent |
| | 2009 | Yes | Yes | Yes | Provider | Yes | Law silent |
| Oregon | 1999 | No | No | Yes | Caretaker | Yes | Law silent |
| | 2000 | No | No | Yes | Caretaker | Yes | Prohibited |
| | 2006 | No | No | Yes | Provider | Yes | Prohibited |
| | 2009 | No | Yes | Yes | Provider | Yes | Prohibited |
| Rhode Island | 2006 | No | No | Yes | Provider | Yes | Law silent |
| Vermont | 2004 | No | No | Yes | Provider | No | Law silent |
| Washington | 1999 | No | No | Yes | Caretaker | No | Law silent |
| | 2009 | No | Yes | Yes | Caretaker | No | Law silent |

[a] The indicated year reflects laws effective as of July 1st. Note that this table does not reflect MML statutes or other legal changes that came into effect after 2010, including new laws in Arizona, Connecticut, Delaware, District of Columbia, Massachusetts, and New Jersey.
[b] During the study period 1990–2010, both Maine (2010) and Rhode Island (2009) enacted dispensary laws, but the first dispensaries did not become operational until March 2011 and April 2013, respectively.
[c] Under the *caretaker* model, designated caregivers assisting with home cultivation must be a family member and/or individual with prior significant caretaking responsibilities; under the *provider* model, designated caregivers can be most any adult who has agreed to assist the patient. Note that Alaska's original Measure 8 (effective: 3/4/99) articulated a caretaker model, but immediate amending legislation S.B. 94 (effective: 6/2/99) changed this to a provider model.

were derived from the University of Mississippi's Potency Monitoring Program (PMP), a federally funded forensic surveillance program that analyzes seized marijuana samples (see Mehmedic et al., 2010). The micro-level PMP data used for the current study comprise $n = 39{,}157$ observations of dried herbal marijuana seized by law enforcement in the 50 U.S. states and the District of Columbia over the 1990–2010 study period. Herbal marijuana includes samples identified as either sinsemilla, mid-grade, or kilobrick, but excludes ditchweed (or wild grown marijuana), hashish, and hash oil. Sinsemilla, meaning without seeds, refers to the buds of unpollinated female plants cultivated for high THC content. Kilobrick refers to marijuana, typically of Mexican origin and lower quality, that has been compressed into bricks for easy transport into the United States. Mid-grade refers to marijuana product of moderate quality that is classified as neither sinsemilla nor kilobrick.

Despite their potential utility, the PMP data have important limitations. First, as shown in appendix Table A.1, the $n = 39{,}157$ samples populate 950 of a possible 1071 state-year cells (88.7%) with an average of 41.2 (SD = 114.5) observations per populated cell, indicating an unbalanced dataset with wide variability in data saturation at the state-year level. Second, even with the available data, they reflect a nonrandom sample of law enforcement seizures, and therefore might not be representative of the marijuana available to consumers. Despite these limitations, the PMP data provide the only comprehensive, long-running source of information on state-level potency trends.

We merged state-year policy, enforcement, and demographic variables with the PMP data. State policy variables were coded using a previously developed legal database protocol (Pacula, Chriqui, Reichmann, & Terry-McElrath, 2002), adapted and updated for purposes of the current study. Marijuana enforcement indicators were derived from the Domestic Cannabis Eradication/Suppression Program (DCE/SP). Although DCE/SP participation and reporting may vary by state (Office of the Inspector General, 1995), this is the only national program that provides data on enforcement activity against marijuana growers and producers. Finally, sociodemographic covariates were obtained from the CDC WONDER online database (Centers for Disease Control and Prevention, 2013) and the Bureau of Economic Analysis.

### *Measures*

The dependent variable, *THC%*, measures the concentration of $\Delta^9$-tetrahydrocannabinol by weight in the seized samples of dried marijuana. This measure reflects PMP analysis by gas chromatography-flame ionization detection (Mehmedic et al., 2010) and is reported for all $n = 39{,}157$ observations within the study period.

As shown in Table 1, the focal independent variables include laws regulating access to medical marijuana. In addition to a general *medical marijuana law* indicator, we created policy variables capturing additional aspects of these laws. In each case, the indicator reflects laws in effect as of July 1 of every year. *Legally operating dispensaries* equals one if state law explicitly allows retail sales of marijuana *and* the regulatory and distribution regime was in place and operational. Given that the actual rulemaking process of implementing a legal dispensary system can take years, this operationalization ensures that we are measuring actual policy changes. In a handful of states that do not explicitly permit retail sales, dispensaries have opened nonetheless due to legal loopholes. To capture this quasi-legal policy environment, we also code *de facto operating dispensaries* equal to one if the state has a functional dispensary system, officially sanctioned or otherwise.[3] *Home cultivation* is set equal to one if qualified patients are legally permitted to grow their own personal supply of marijuana. Finally, we created a *home supply index* where one point was added to the index for the presence of each of the following conditions: home cultivation, provider-type caregiver model, multiple patients per caregiver, and allowance for collective growing. For the latter provision, we also added a half-point when the law was silent on the matter. A higher score on the index indicates a more permissive set of home supply regulations.

A set of rival independent variables captures state decriminalization policies and marijuana enforcement efforts. *Decriminalization policy* equals one if the state is generally recognized as having removed criminal penalties for the possession of small amounts of marijuana intended for personal use.[4] State marijuana enforcement activity, as reported by the Domestic Cannabis Eradication/Suppression Program, measures the number of *outdoor plots seized* and *indoor grows seized per 100,000 population*. In each case, we logged these variables (after adding a constant of one) and lagged them by one year to account for delayed enforcement effects.[5] Note that eradication data for the District of Columbia are missing because it does not participate in the DCE/SP. According the National Drug Intelligence Center (2002:18), "cannabis is not cultivated in large quantities in D.C., primarily because the urban landscape is not conducive to outdoor grows." Thus, we assumed the annual number of outdoor plots seized was zero over the study period. Alternatively, for indoor grows seized, we employed single hotdeck imputation to fill in missing data from randomly selected donor observations stratified by year of seizure.

Aggregate marijuana market characteristics at the state-year level measure the broader context through which state policies are hypothesized to indirectly influence potency. While not perfect, we use aggregated statistics from the PMP to capture elements of the broader marketplace. We recognize that these aggregate statistics are potentially biased, as they could simply reflect priorities of law enforcement rather than the true evolution of the market itself. This would be a problem if law enforcement began targeting more indoor grows in response to medical marijuana laws. If the medical marijuana market supplies the recreational market, however, then this change in enforcement priorities might be consistent with a true shift in the recreational market. Moreover, for the purposes of this analysis, even if these aggregate marijuana market measures are affected predominantly by law enforcement priorities they would to some extent still capture how those caught by law enforcement have modified their production and distribution of marijuana in response to legal changes within the state. So long as the shift in production and distribution of marijuana by those who get caught is not substantially different from those that are not caught, then the data should provide real information of the policy impact on the market. Thus, we use these measures to help us consider the possible indirect effect of marijuana policies on potency.

As noted above, marijuana comes in different forms (i.e., sinsemilla, mid-grade, kilobrick), and the relative share of these forms as measured by PMP captures compositional effects of the marijuana marketplace. Thus, both *sinsemilla %* and *mid-grade %* quantify the percentage of seizures for these respective product types by state-year (with *kilobrick %* serving as the reference category). It would also be ideal to include a measure of the size of the market to control for the degree of competition and penetration marijuana has in different states. As no direct measures of total supply in the market are available by state, we attempt to proxy the relative size of the aggregate marijuana market by state-year, using an indicator of *log mean kilograms seized* (adding a constant of one prior to log transformation). While we recognize that seizures are a function of both law enforcement effort as well as the amount of the product trading in the market and that there could be systematic changes in the capture rate of law enforcement over time that are independent of the size of the market, we think that this measure will still accurately reflect the relative importance of a given state market to law enforcement personnel who are primarily interested in reducing drug supply. Note that $n = 613$ observations (1.6%) were missing quantity information, so these samples did not factor into the mean calculation.

Finally, our analyses include additional control variables that relate to broader market factors. Sevigny (2013) found that the testing lag in the PMP data between marijuana seizure and analysis dates has generally decreased over time, so we control for such testing effects as the *seizure-to-analysis lag* in months. For the $n = 93$ (0.2%) cases with missing or invalid date information, we imputed lag time using hotdeck imputation selecting data randomly from donor observations stratified by year and state of seizure. We also include covariates for demographic characteristics at the state-year level. Specifically, we operationalized measures for *% male*; *% non-Hispanic white*; *% aged 20–29*, *% aged 30–59*, and *% aged 60+* (with *% aged 0–19* serving as the reference category); *log per capita income* (in thousands), and *log population* (in hundred thousands).

## *Empirical approach*

Our analysis proceeds in several stages. First, we estimate a differences-in-differences linear regression model to assess the effect of MMLs on individual potency observations in each of the 50 U.S. states and the District of Columbia over the period 1990–2010. The unit of analysis is the individual seized marijuana specimen. To control for potential heteroskedasticity and serial correlation, we clustered standard errors by state (Bertrand, Duflo, & Mullainathan, 2004).

The basic specification of our differences-in-differences regression model is as follows:

$$\text{THC\%}_{ist} = \alpha + \tau \text{MML}_{st} + \omega Z_{st} + \beta X_{st} + \rho L_{ist} + \gamma_s + \theta_t + \varepsilon_{ist} \quad (1)$$

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[3] Determining exactly when unregulated dispensaries began operating in a particular state was difficult, as there is no legal documentation of or timeline for their implementation. Our decision as to the relevant "effective date" was based on evidence gleaned from newspaper reports and other contemporaneous sources.

[4] The following states were coded as having a decriminalization policy as of the year indicated (or 1990 if earlier): Oregon (1973), Alaska (1975), Colorado (1975), California, (1975), Maine (1975), Minnesota (1976), Ohio (1976), Mississippi (1977), Nebraska (1977), New York (1977), North Carolina (1977), Nevada (2002), Massachusetts (2009). While California is widely recognized as having a decriminalization statute in 1975, the actual removal of the criminal status of the offense did not occur until 2008. Nonetheless, we code it in a manner consistent with previous work (MacCoun & Reuter, 2001; Pacula, et al., 2004). In addition, although they fall outside the study period, Connecticut (2011), Rhode Island (2013), and Vermont (2013) have recently decriminalized marijuana.

[5] Since we had DCE/SP data for 1989, we were able to operationally lag these variables without loss of observations.

**Table 2**
Descriptive statistics, 1990–2010.

| Variable | MML state (N = 8198) | | Non-MML state (N = 30,959) | | Total (N = 39,157) | |
|---|---|---|---|---|---|---|
| | Mean | (SD) | Mean | (SD) | Mean | (SD) |
| THC % | 9.08 | (6.15) | 5.60 | (4.01) | 6.33 | (4.79) |
| Medical marijuana law | 1.00 | (0.00) | 0.00 | (0.00) | 0.21 | (0.41) |
| Legally operating dispensaries | 0.40 | (0.49) | 0.00 | (0.00) | 0.08 | (0.28) |
| De Facto operating dispensaries | 0.74 | (0.44) | 0.00 | (0.00) | 0.16 | (0.36) |
| Home cultivation | 0.97 | (0.17) | 0.00 | (0.00) | 0.20 | (0.40) |
| Home supply index | 2.54 | (0.69) | 0.00 | (0.00) | 0.53 | (1.08) |
| Decriminalization policy | 0.79 | (0.41) | 0.33 | (0.47) | 0.43 | (0.49) |
| Log outdoor plots seized per 100,000 population (lagged 1 year) | 1.75 | (0.71) | 1.54 | (1.03) | 1.58 | (0.98) |
| Log indoor grows seized per 100,000 population (lagged 1 year) | 1.05 | (0.39) | 0.62 | (0.44) | 0.71 | (0.46) |
| Sinsemilla % | 40.92 | (26.67) | 10.68 | (18.32) | 17.01 | (23.79) |
| Mid-grade % | 30.13 | (12.36) | 48.47 | (27.08) | 44.63 | (25.84) |
| Log mean kilograms seized | 3.24 | (0.93) | 3.39 | (1.52) | 3.35 | (1.42) |
| Seizure-to-analysis lag (months) | 6.62 | (3.45) | 7.00 | (3.92) | 6.92 | (3.83) |
| % Male | 49.75 | (0.37) | 49.15 | (0.75) | 49.28 | (0.73) |
| % Non-hispanic white | 54.58 | (15.98) | 64.22 | (14.70) | 62.27 | (15.52) |
| % Aged 20–29 | 14.33 | (0.63) | 14.66 | (1.63) | 14.59 | (1.48) |
| % Aged 30–59 | 41.63 | (0.87) | 40.41 | (1.58) | 40.66 | (1.55) |
| % Aged 60+ | 15.48 | (1.75) | 16.38 | (2.62) | 16.19 | (2.49) |
| Log per capita income (thousands) | 3.61 | (0.14) | 3.32 | (0.28) | 3.38 | (0.28) |
| Log population (hundred thousands) | 5.17 | (1.12) | 4.57 | (1.09) | 4.69 | (1.12) |

where $THC\%_{ist}$ is the potency of seizure $i$ in state $s$ during year $t$. The focal policy indicator $MML_{st}$ captures whether a medical marijuana law was operational in state $s$ and year $t$. The vector $Z_{st}$ includes the rival independent variables (i.e., marijuana decriminalization and enforcement measures), and the vector $X_{st}$ includes observed state-level sociodemographic controls for state $s$ and year $t$. The variable $L_{ist}$ captures the testing lag in months for seizure $i$ in state $s$ during year $t$. Finally, state fixed effects ($\gamma_s$) and year fixed effects ($\theta_t$) control for potential unobserved confounders that are invariant across jurisdiction and time.

This specification essentially implements a before and after design with an untreated control group, comparing within-state changes in potency pre- and post-MML adoption to potency changes in states that did not adopt such a law (Angrist & Pischke, 2009; Bertrand et al., 2004; Meyer, 1995; Wooldridge, 2010). The coefficients for the rival independent variables are interpreted in the same way, although the enforcement variables measuring indoor and outdoor eradication reflect "intervention intensity" rather than the effect of a discrete policy change (Angrist & Pischke, 2009; Wooldridge, 2010).

Next, in order to investigate potential sources of heterogeneity in the effects of state medical marijuana laws, we estimate a series of differences-in-differences models in which we replace the generic MML indicator in Eq. (1) with different sets of policy variables capturing the specific supply provisions of these laws.

Finally, we assess the mediating effects of aggregate marijuana market characteristics on the association between MMLs and potency. In a mediation context, the specification in Eq. (1) estimates the *total effect*, $\tau$, of MML on THC% (Baron & Kenny, 1986; MacKinnon, 2008). This total effect can be partitioned into an *indirect effect*, which reflects the influence of MMLs on potency operating through the context of the broader marketplace, and a *direct effect*, which estimates the relation of MMLs to potency not mediated through these ecological factors. Parceling the total effect, $\tau$, of MMLs on potency begins by estimating the direct effect, $\dot{\tau}$, of the law per the following equation:

$$THC\%_{ist} = \alpha + \dot{\tau}MML_{st} + \omega Z_{st} + \delta M_{st} + \beta X_{st} + \rho L_{ist} + \gamma_s + \theta_t + \varepsilon_{ist} \quad (2)$$

where $M_{st}$, the vector of mediating aggregate market variables for state $s$ and year $t$, has been added to Eq. (1). We then estimate the indirect effect, $\tau - \dot{\tau}$, as the difference between the coefficients for the total effect and the direct effect (Clogg, Petkova, & Cheng, 1995; MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002). In similar fashion, we also decompose the total effects of both the rival independent variables held in $Z_{st}$ and, in supplementary analyses, specific medical marijuana supply provisions. All analyses were conducted using Stata MP 12.1.

## Results

Table 2 presents descriptive statistics for the sample, stratified by MML status at the state-year level. Notably, mean potency is nearly 3.5 percentage points higher in states with a medical marijuana law. Overall, about 21% of the observations were seized in medical marijuana states. For jurisdictions with an active MML, 40% of seizures were from states with legally operating dispensaries, 74% from states with de facto operating dispensaries, and 97% from states that allow home cultivation. The home supply index averaged 2.5 in MML states. Seizures in MML versus non-MML states were more likely to occur in jurisdictions with marijuana decriminalization policies. Eradication activity was also more likely to occur in MML states. Aggregate market characteristics show substantial compositional differences in marijuana type across MML and non-MML states, with mean sinsemilla percentages nearly four times greater in the former. On the other hand, the average size of the seizures, as well as the seizure-to-analysis lag, was somewhat larger in the latter. Finally, sociodemographic characteristics were largely similar by MML status, with the exception that non-MML states tended to have a relatively larger population of non-Hispanic whites.

Table 3 presents our differences-in-differences estimates of the effect of MMLs on potency. As one looks across the table from left to right, each model gets sequentially more sophisticated by adding in our indicated controls and rival independent variables. Model (1) depicts the simple bivariate model, demonstrating a positive and statistically significant association of MMLs with potency. Model (2) adds our observable control variables, which reduces the magnitude of the MML coefficient by more than half but it still retains its significance and positive association. Model (3) adds state and year fixed effects, which reduces the MML effect on potency even further and, while still positive, is no longer significant. Model (4) includes the marijuana decriminalization variable, which, despite its large

**Table 3**
Differences-in-differences estimates of the effect of medical marijuana laws on potency (THC%), 1990–2010.

| Variables | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Medical marijuana law | 3.48 (0.59)*** | 1.49 (0.66)** | 0.55 (0.56) | 0.54 (0.56) | 0.53 (0.55) |
| Decriminalization policy | | | | 2.61 (0.95)*** | 2.62 (1.05)** |
| Log outdoor plots seized per 100,000 population (lagged 1 year) | | | | | 0.01 (0.16) |
| Log indoor grows seized per 100,000 population (lagged 1 year) | | | | | −0.27 (0.15)* |
| Seizure-to-analysis lag (months) | | −0.14 (0.01)*** | −0.11 (0.01)*** | −0.11 (0.01)*** | −0.11 (0.01)*** |
| % Male | | 0.56 (0.30)* | −0.31 (0.72) | −0.31 (0.71) | −0.39 (0.74) |
| %Non-hispanic white | | 0.03 (0.01)* | 0.01 (0.10) | 0.02 (0.10) | 0.01 (0.09) |
| % Aged 20–29 | | −0.24 (0.15) | −0.24 (0.13)* | −0.22 (0.13)* | −0.22 (0.13)* |
| % Aged 30–59 | | −0.28 (0.16)* | −0.12 (0.26) | −0.05 (0.25) | −0.06 (0.24) |
| % Aged 60+ | | 0.06 (0.11) | 0.08 (0.28) | 0.11 (0.27) | 0.05 (0.27) |
| Log per capita income (thousands) | | 8.20 (1.06)*** | 3.40 (2.40) | 3.48 (2.28) | 3.23 (2.33) |
| Log population (hundred thousands) | | −0.33 (0.19)* | −4.49 (3.96) | −4.57 (4.00) | −4.76 (4.03) |
| Constant | 5.60 (0.51)*** | −34.70 (18.88)* | 36.03 (49.86) | 31.28 (48.39) | 38.63 (52.14) |
| State fixed-effects | No | No | Yes | Yes | Yes |
| Year fixed-effects | No | No | Yes | Yes | Yes |
| $R^2_{adj}$ | 8.7% | 29.1% | 33.8% | 33.8% | 33.9% |

*Note*: Cluster robust standard errors are reported in parentheses. $N$ = 39,157.
* Significance level: 10%.
** Significance level: 5%.
*** Significance level: 1%.

positive and significant effect, provides no additional explanatory power and has a negligible impact on the focal MML coefficient. During our study period, the decriminalization effect is identified off variation in just two states (Nevada and Massachusetts), and Nevada's decriminalization and medical marijuana laws both became effective in 2002, so we believe this effect is largely an artifact of our data. Finally, model (5) adds the enforcement measures, which also do little to elaborate the previous model. Still, we note the significant negative effect that increased eradication of indoor grows (but not outdoor plots) has on marijuana potency during the following year. In sum, our fully elaborated model shows that MMLs increase average THC content by about 0.5 percentage points post-law, although this effect is not significant.

In Table 4, we extend this fully elaborated model in column 5 of Table 3 by examining the impact of specific medical marijuana supply provisions on potency. Specifically, we investigate various combinations of dispensary and home cultivation regulations (although we exclude measures of home cultivation and home supply index from the same model due to collinearity). The results are generally consistent across models, with legally operating dispensaries associated with significant increases in THC levels of about one percentage point on average in states that permit retail sales. In contrast, states with de facto operating dispensaries show a decrease in average potency, although the effect is insignificant. It may be that the lack of state protection of dispensaries means they have not reached a level of concentration within the state to compete very rigorously with the black market for recreational users. By comparison, home cultivation appears to increase potency by about one-half to three-quarters of a percentage point on average, and our index of home supply falls in the expected positive direction, but both effects are generally small and insignificant. Overall, these results suggest that the state-level allowances for retail dispensary sales are associated with small but significant increases in the average potency of illicit marijuana.

We now turn to our analysis examining the mediating effects of contextual market factors on the association between medical marijuana laws and potency. These results are presented in Table 5, where we examine general medical marijuana laws in Panel A and specific supply provisions in Panel B. In Panel A, the total effects specification corresponds to our fully elaborated model (5) in Table 3. With the inclusion of the mediating variables measuring aggregate compositional and size characteristics of the marijuana marketplace, we are able to decompose the effects of our focal and rival policy variables on potency into direct and indirect (or mediated) effects. Again, an indirect effect in the present context implies that a given policy produces structural shifts in the marijuana market, which in turn has a causal influence on potency (MacKinnon, Krull, & Lockwood, 2000).

In Panel A, the combination of an insignificant direct effect and significant positive indirect effect for medical marijuana policies indicates the presence of complete (or indirect-only) mediation (Zhao, Lynch, & Chen, 2010). In other words, these results offer no evidence of a direct regulatory effect of medical marijuana laws on potency. Instead, consistent with our expectations, we find that medical marijuana laws significantly increase the relative share of sinsemilla available or trading within a state. This compositional

**Table 4**
Differences-in-differences estimates of effects of medical marijuana supply provisions on potency (THC %), 1990–2010.

| Variables | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Legally operating dispensaries | 0.99 (0.46)** | | 0.91 (0.39)** | 1.02 (0.44)** | 0.90 (0.40)** |
| De Facto operating dispensaries | | −0.29 (0.56) | | −0.41 (0.53) | −0.26 (0.47) |
| Home cultivation | 0.46 (0.51) | 0.61 (0.59) | | 0.72 (0.60) | |
| Home supply index | | | 0.13 (0.17) | | 0.19 (0.18) |
| Decriminalization policy | 2.79 (1.06)** | 2.51 (1.04)** | 2.86 (1.14)** | 2.65 (1.02)** | 2.79 (1.13)** |
| Log outdoor plots seized per 100,000 population (lagged 1 year) | −0.02 (0.18) | 0.01 (0.17) | −0.02 (0.18) | −0.02 (0.18) | −0.01 (0.18) |
| Log indoor grows seized per 100,000 population (lagged 1 year) | −0.19 (0.15) | −0.26 (0.15)* | −0.20 (0.15) | −0.19 (0.15) | −0.20 (0.15) |
| Constant | 18.40 (57.30) | 46.70 (55.45)* | 27.07 (57.64) | 22.55 (59.53) | 31.26 (60.64) |
| $R^2_{adj}$ | 33.9% | 33.9% | 33.9% | 33.9% | 33.9% |

*Note*: Cluster robust standard errors are reported in parentheses. All models include state and year fixed effects and control variables. $N$ = 39,157.
* Significance level: 10%.
** Significance level: 5%.
*** Significance level: 1%.

**Table 5**
Mediation Analysis of the effects of medical marijuana laws on potency (THC%), 1990–2010.

| Variables | Total effects ($\tau$) | Direct effects ($\tau'$) | Indirect effects ($\tau - \tau'$) |
|---|---|---|---|
| *Panel A* | | | |
| Medical marijuana law | 0.53 (0.55) | −0.09 (0.30) | 0.61 (0.35)* |
| Decriminalization policy | 2.62 (1.05)** | 0.93 (0.67) | 1.70 (0.50)*** |
| Log outdoor plots seized per 100,000 population (lagged 1 year) | 0.01(0.16) | −0.09 (0.12) | 0.10 (0.10) |
| Log indoor grows seized per 100,000 population (lagged 1 year) | −0.27 (0.15)* | −0.13 (0.15) | −0.14 (0.09) |
| Sinsemilla % | | 0.07 (0.01)*** | |
| Mid-grade % | | 0.00 (0.00) | |
| Log mean kilograms seized | | −0.06 (0.03)* | |
| Constant | 38.63 (52.14) | 3.47 (41.74) | |
| Adj. $R^2$ | 33.9% | 35.4% | |
| *Panel B* | | | |
| Legally operating dispensaries | 0.99 (0.46)** | −0.02 (0.36) | 1.01 (0.32)*** |
| Home cultivation | 0.46 (0.51) | −0.26 (0.30) | 0.72 (0.28)*** |
| Decriminalization policy | 2.79 (1.06)** | 0.94 (0.71) | 1.86 (0.49)*** |
| Log outdoor plots seized per 100,000 population (lagged 1 year) | −0.02 (0.18) | −0.09 (0.12) | 0.06 (0.10) |
| Log indoor grows seized per 100,000 population (lagged 1 year) | −0.19 (0.15) | −0.14 (0.16) | −0.06 (0.08) |
| Sinsemilla % | | 0.07 (0.01)*** | |
| Mid-grade % | | 0.00 (0.00) | |
| Log mean kilograms seized | | −0.06 (0.03)** | |
| Constant | 18.40 (57.30) | 10.66 (45.61) | |
| $R^2_{adj}$ | 33.9% | 35.4% | |

*Note*: Cluster robust standard errors are reported in parentheses. All models include state and year fixed effects and control variables. $N$ = 39,157.
* Significance level: 10%.
** Significance level: 5%.
*** Significance level: 1%.

shift in state marijuana markets toward boutique or high-end product, in turn, drives the observed increase in cannabis potency.

We are primarily interested in the effects of medical marijuana laws, but it is also instructive to examine outcomes for the rival marijuana decriminalization and enforcement variables. Although we do not consider the effect of marijuana decriminalization to be reliable given the noted lack of policy variation, we do find evidence of complementary mediation where the direct and indirect effects point in the same direction. However, given that the indirect effect accounts for about two-thirds of the total effect, this result is more consistent with our intervening variable thesis. With respect to our enforcement measures, the observed direct and indirect effects are generally small and insignificant. Still, we find it useful to speculate about the general direction of these effects in order to highlight the uncertainties (as well as possibilities for future research). First, the decomposition of our measure of outdoor eradication into direct and indirect effects suggests there are two causal paths that cancel each other out. That is, the direct effect of outdoor eradication is to reduce potency (perhaps by forcing growers to harvest prematurely), but this is counterbalanced by a roughly equivalent indirect effect in the opposite direction (perhaps by pressuring growers to move operations indoors). In contrast, the total effect of enforcement activity against indoor grows is to reduce potency, with about half the effect operating directly (perhaps by removing high-quality product from the market) and the other half indirectly (perhaps by opening the market to less experienced growers).

In Panel B, we examine medical marijuana supply mechanisms for legally operating dispensaries and home cultivation (i.e., corresponding to model (1) in Table 4). For dispensaries, we observe evidence of complete mediation, whereby the law's effect on potency operates fully and indirectly through the aforementioned structural shifts in the marketplace. The effect of home cultivation is more complex and suggests possible inconsistent (or competitive) mediation (MacKinnon et al., 2000; Zhao et al., 2010). Specifically, as with dispensaries, the significant and positive indirect effect of home cultivation suggests a similar avenue of action on potency through contextual features of the marketplace. At the same time, there is a sizable, albeit insignificant, direct effect in the opposite direction, which is consistent with an interpretation of home growers as being less proficient cultivators and/or preferring less psychoactive marijuana. Lastly, the effects of the rival independent variables in this mediation model remain consistent with the above interpretation.

## Discussion

A fundamental question that has of yet remained unanswered in the academic literature is whether state medical marijuana laws lead to a rise in the average potency of marijuana available on the market. Indeed, prior research by Pacula et al. (2010), which examined the impact of medical marijuana laws on self-reported price paid per gram among the arrestee population in the 2000–2003 Arrestee Drug Abuse Monitoring (ADAM) data, showed that self-reported marijuana prices were higher in states that had adopted medical marijuana laws than those states that did not, which the authors interpreted as evidence of a demand shift. It is also possible, however, that the rise in price is indicative of the availability of more potent product on the market. Indeed such an interpretation is entirely consistent with journalistic accounts of the impact of these laws on development and diffusion of high-potency cannabis cultivation techniques (Downs, 2012; Geluardi, 2010; Rendon, 2013; West, 2011).

This paper provides a direct assessment of the impact of state medical marijuana laws on the potency of marijuana seized through regular law enforcement activities. We find evidence that the average potency of marijuana seized by law enforcement increases by a half percentage point on average after legalization of medical marijuana, although this result was not significant. However, when we examined specific medical marijuana provisions, our results suggested that in states that legally permit dispensaries average potency significantly increases by about one percentage point over time. Future research will need to confirm these findings using additional years of data that include more than just three legally operating dispensary states.

While we recognize the potential endogeneity of the aggregate marijuana market measures to enforcement priorities, our mediation analyses examining the mechanisms through which medical marijuana laws influence potency suggest that the impact of these

**Table A.1**
Observed THC % and number of observations by state and year.

| State | | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alabama | % | | 2.6 | | 4.0 | 0.7 | 3.2 | 3.1 | 5.6 | 5.5 | 2.3 | 4.0 | | 4.7 | 4.0 | 4.2 | | 6.0 | 6.5 | 8.2 | 7.6 | 4.8 | 4.2 |
| | *N* | 0 | 8 | 0 | 5 | 1 | 3 | 3 | 3 | 1 | 9 | 3 | 0 | 3 | 2 | 6 | 0 | 1 | 4 | 2 | 4 | 2 | 60 |
| Alaska | % | | | 10.0 | 1.8 | | | | 10.0 | 6.4 | 10.2 | 1.1 | 5.1 | 5.2 | 14.3 | 13.3 | 4.4 | 12.0 | 6.9 | 12.9 | 12.3 | 10.5 | 9 |
| | *N* | 0 | 0 | 14 | 1 | 0 | 0 | 0 | 1 | 3 | 2 | 3 | 8 | 2 | 5 | 2 | 8 | 12 | 9 | 6 | 3 | 7 | 86 |
| Arizona | % | 4.4 | 3.5 | 3.4 | 4.3 | 4.6 | 4.6 | 4.6 | 7.0 | 6.3 | 6.4 | 7.3 | 8.3 | 8.3 | 8.2 | 8.6 | 8.1 | 10.6 | 9.6 | 9.4 | 9.5 | 9.2 | 5.9 |
| | *N* | 187 | 209 | 266 | 203 | 213 | 260 | 34 | 63 | 46 | 59 | 80 | 64 | 26 | 66 | 72 | 84 | 51 | 85 | 79 | 91 | 66 | 2304 |
| Arkansas | % | | | 3.0 | | | | | 4.2 | 7.8 | 3.6 | 2.0 | 5.6 | | 6.0 | 4.3 | 3.8 | 6.5 | 6.0 | | 15.3 | 8.4 | 6.7 |
| | *N* | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 2 | 0 | 4 | 1 | 1 | 2 | 3 | 0 | 5 | 5 | 35 |
| California | % | 3.7 | 3.4 | 3.0 | 3.7 | 3.8 | 3.9 | 4.5 | 5.0 | 5.1 | 5.3 | 5.1 | 6.0 | 7.4 | 6.7 | 7.9 | 8.3 | 9.8 | 11.1 | 10.9 | 9.6 | 10.8 | 5.8 |
| | *N* | 306 | 482 | 909 | 912 | 1139 | 2358 | 347 | 333 | 328 | 395 | 326 | 426 | 305 | 263 | 273 | 489 | 548 | 523 | 499 | 343 | 573 | 12,077 |
| Colorado | % | 2.1 | 3.7 | 4.5 | 3.7 | 3.1 | 3.4 | 4.8 | 4.9 | 5.6 | 5.4 | 6.2 | 7.1 | 7.1 | 8.0 | 8.3 | 6.6 | 10.5 | 10.6 | 12.1 | 9.5 | 13.8 | 7.3 |
| | *N* | 4 | 3 | 9 | 21 | 25 | 12 | 30 | 27 | 35 | 32 | 18 | 15 | 45 | 20 | 43 | 11 | 8 | 9 | 43 | 49 | 24 | 483 |
| Connecticut | % | 2.0 | 2.2 | 1.3 | 2.6 | 2.7 | 0.6 | 4.9 | 4.4 | 3.8 | 2.6 | 7.5 | 10.7 | 9.4 | 6.5 | 7.0 | 7.3 | 8.5 | 10.4 | 9.2 | 10 | 13.7 | 6.2 |
| | *N* | 7 | 14 | 11 | 4 | 3 | 1 | 10 | 7 | 9 | 14 | 3 | 11 | 10 | 5 | 6 | 17 | 8 | 6 | 14 | 9 | 5 | 174 |
| Delaware | % | | 1.9 | | | | 3.3 | | 4.4 | 4.0 | 5.0 | 6.9 | 5.5 | 5.0 | 7.2 | 10.5 | 11.8 | 7.7 | 11.7 | 8.2 | 12.9 | 12.2 | 9.2 |
| | *N* | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 5 | 6 | 3 | 8 | 2 | 1 | 3 | 13 | 11 | 2 | 11 | 6 | 6 | 12 | 92 |
| District of Columbia | % | | 0.3 | | | 3.9 | 3.0 | 4.2 | 4.6 | 4.4 | 4.7 | 5.4 | 5.6 | 6.5 | 7.3 | 7.9 | 8.2 | 8.7 | 9.2 | 9.6 | 9.0 | 10.6 | 6.3 |
| | *N* | 0 | 1 | 0 | 0 | 1 | 39 | 124 | 89 | 86 | 143 | 130 | 102 | 112 | 108 | 104 | 95 | 83 | 61 | 55 | 16 | 14 | 1363 |
| Florida | % | 4 | 3.6 | 3.4 | 3.8 | 3.5 | 4.2 | 5.0 | 5.2 | 4.3 | 5.4 | 5.0 | 7.0 | 5.6 | 6.2 | 7.6 | 5.7 | 7.1 | 8.5 | 7.7 | 8.1 | 9.8 | 6.2 |
| | *N* | 44 | 75 | 145 | 89 | 79 | 99 | 70 | 96 | 80 | 95 | 98 | 78 | 95 | 137 | 142 | 162 | 200 | 190 | 182 | 113 | 145 | 2414 |
| Georgia | % | 2.2 | 2.7 | 2.9 | 4.3 | 3.0 | 3.8 | 4.0 | 4.1 | 3.1 | 4.1 | 4.6 | 4.3 | 4.7 | 4.5 | 5.6 | 7.3 | 6.9 | 8.5 | 8.5 | 7.7 | 11.7 | 5.8 |
| | *N* | 5 | 19 | 35 | 33 | 17 | 30 | 41 | 24 | 19 | 50 | 50 | 29 | 23 | 35 | 34 | 53 | 42 | 50 | 41 | 46 | 57 | 733 |
| Hawaii | % | 1.4 | 14.1 | 7.9 | 6.6 | 0.4 | 10.0 | 15.8 | 7.6 | 9.5 | 13.9 | 11.6 | 8.4 | 5.3 | 9.4 | 10.5 | 10.1 | 17.4 | 8.0 | 14.7 | 13.1 | 6.7 | 9.6 |
| | *N* | 4 | 6 | 16 | 5 | 8 | 2 | 1 | 5 | 5 | 5 | 8 | 4 | 5 | 11 | 9 | 17 | 11 | 10 | 10 | 6 | 16 | 164 |
| Idaho | % | | | | | | | 4.4 | 3.6 | 6.7 | 3.7 | | | 15.6 | 20.0 | 10.0 | 13.7 | | 9.5 | | 13.3 | | 8.8 |
| | *N* | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 5 | 4 | 7 | 0 | 0 | 2 | 1 | 5 | 6 | 0 | 4 | 0 | 5 | 0 | 43 |
| Illinois | % | 3.2 | 5.6 | 3.3 | 2.7 | 2.9 | 4.0 | 4.7 | 4.2 | 4.1 | 4.0 | 4.6 | 5.2 | 4.9 | 6.2 | 5.4 | 8.7 | 7.2 | 8.6 | 9.9 | 9.1 | 8.4 | 6.2 |
| | *N* | 10 | 26 | 26 | 24 | 23 | 29 | 29 | 35 | 25 | 49 | 38 | 48 | 61 | 56 | 58 | 87 | 48 | 53 | 60 | 49 | 57 | 891 |
| Indiana | % | 0.6 | 3.6 | 2.8 | 3.4 | 1.9 | 3.5 | 3.0 | 5.2 | 4.5 | 3.7 | 3.8 | 5.0 | 6.4 | 5.1 | 5.9 | 6.9 | 7.3 | 8.2 | 7.8 | 8.4 | 8.4 | 5.9 |
| | *N* | 4 | 21 | 15 | 21 | 9 | 15 | 4 | 13 | 12 | 20 | 49 | 24 | 22 | 34 | 25 | 47 | 40 | 39 | 29 | 33 | 57 | 533 |
| Iowa | % | | 5.1 | 2.1 | 4.3 | | | 5.9 | 5.2 | 2.4 | 3.8 | 5.4 | 5.9 | 5.9 | 5.3 | 5.0 | 8.9 | 7.2 | 6.5 | 7.3 | 5.4 | 11.3 | 6.1 |
| | *N* | 0 | 4 | 5 | 2 | 0 | 0 | 1 | 7 | 7 | 10 | 12 | 20 | 10 | 11 | 16 | 16 | 16 | 9 | 13 | 6 | 10 | 175 |
| Kansas | % | 2.1 | 2.6 | 3.1 | 4.5 | 3.4 | 4.3 | 4.8 | 5.7 | 4.7 | 4.9 | 7.0 | 5.4 | 5.1 | 5.5 | 6.2 | 5.4 | 7.3 | 8.2 | 8.0 | 6.4 | 6.8 | 5.9 |
| | *N* | 5 | 3 | 4 | 1 | 18 | 11 | 18 | 15 | 30 | 34 | 40 | 17 | 31 | 42 | 42 | 26 | 40 | 30 | 17 | 17 | 28 | 469 |
| Kentucky | % | 3.9 | 1.6 | 4.3 | 1.9 | 5.4 | 3.7 | 4.9 | 5.2 | 5.1 | 2.8 | 6.1 | 3.6 | 5.2 | 6.7 | 5.4 | 7.1 | 5.5 | 7.7 | 8.9 | 10.6 | 7.4 | 5.9 |
| | *N* | 5 | 4 | 8 | 12 | 14 | 17 | 35 | 34 | 15 | 22 | 12 | 14 | 21 | 43 | 25 | 45 | 16 | 35 | 20 | 18 | 16 | 431 |
| Louisiana | % | 3.4 | 3.6 | 2.7 | 4.1 | | 3.2 | 3.6 | 2.5 | 3.6 | 1.4 | 3.7 | 5.7 | | 4.5 | 3.1 | 5.7 | | 8.4 | 6.0 | 13.8 | | 3.9 |
| | *N* | 1 | 8 | 7 | 3 | 0 | 5 | 6 | 1 | 4 | 1 | 1 | 1 | 0 | 2 | 10 | 3 | 0 | 2 | 1 | 1 | 0 | 57 |
| Maine | % | | 1.0 | | | 3.1 | 4.9 | 6.0 | 3.7 | | 7.4 | 5.6 | 6.4 | | | 11.9 | 9.6 | 10.7 | 12.4 | 9.7 | 12.0 | 10.3 | 8.7 |
| | *N* | 0 | 1 | 0 | 0 | 4 | 19 | 5 | 2 | 0 | 2 | 1 | 8 | 0 | 0 | 10 | 3 | 2 | 4 | 12 | 15 | 24 | 112 |
| Maryland | % | | | | | | 4.1 | 4.8 | 4.9 | 4.8 | 4.3 | 5.4 | 5.3 | 8.2 | 6.7 | 7.1 | 8.5 | 9.5 | 10.2 | 11.2 | 10.3 | 11.8 | 6.7 |
| | *N* | 0 | 0 | 0 | 0 | 0 | 21 | 45 | 38 | 36 | 111 | 65 | 24 | 16 | 31 | 21 | 53 | 37 | 28 | 29 | 30 | 12 | 597 |
| Massachusetts | % | 3.2 | 2.0 | 1.4 | 3.4 | 4.0 | 4.1 | 3.3 | 5.6 | 5.1 | 3.9 | 4.3 | 8.1 | 8.1 | 8.6 | 7.6 | 8.2 | 8.1 | 9.0 | 10.0 | 11.3 | 13.5 | 7.2 |
| | *N* | 14 | 9 | 7 | 9 | 7 | 12 | 13 | 16 | 18 | 14 | 17 | 14 | 21 | 24 | 18 | 26 | 11 | 24 | 19 | 33 | 19 | 345 |
| Michigan | % | 3.2 | 2.1 | 2.7 | 3.2 | 4.0 | 4.3 | 4.4 | 6.7 | 5.9 | 4.6 | 4.3 | 5.8 | 7.1 | 7.8 | 9.3 | 9.7 | 8.6 | 9.2 | 8.7 | 9.6 | 10.3 | 7 |
| | *N* | 10 | 9 | 32 | 52 | 76 | 39 | 29 | 49 | 53 | 41 | 89 | 54 | 53 | 61 | 66 | 86 | 76 | 79 | 63 | 81 | 69 | 1167 |
| Minnesota | % | 3.4 | 1.8 | 3.7 | 4.5 | 7.0 | 4.1 | 3.0 | 6.7 | 5.1 | 4.2 | 7.2 | 7.9 | 5.7 | 8.7 | 8.9 | 6.3 | 8.8 | 8.7 | 8.3 | 7.9 | 14.3 | 6.9 |
| | *N* | 1 | 3 | 7 | 12 | 3 | 14 | 4 | 7 | 8 | 5 | 1 | 5 | 10 | 9 | 6 | 6 | 11 | 13 | 16 | 14 | 7 | 162 |
| Mississippi | % | | 5 | | 2.9 | | 3.9 | 5.3 | 1.5 | 2.0 | 1.3 | | 6.6 | | 4.2 | 4.8 | 10.8 | 4.0 | 6.8 | 5.4 | 6.6 | 6.3 | 4.8 |
| | *N* | 0 | 1 | 0 | 2 | 0 | 5 | 2 | 2 | 1 | 3 | 0 | 1 | 0 | 4 | 1 | 1 | 2 | 7 | 2 | 2 | 2 | 38 |
| Missouri | % | 3.4 | 3.2 | 2.2 | 3.5 | 4.6 | 3.9 | 4.5 | 4.7 | 4.6 | 3.5 | 4.9 | 5.3 | 5.9 | 6.3 | 6.2 | 6.4 | 6.8 | 7.7 | 10.0 | 9.8 | 9.4 | 6.3 |
| | *N* | 8 | 13 | 31 | 17 | 21 | 25 | 17 | 23 | 29 | 21 | 40 | 24 | 25 | 57 | 78 | 88 | 42 | 48 | 47 | 53 | 58 | 765 |
| Montana | % | 2.3 | | 3.7 | 8.3 | 4.2 | 4.7 | 4.9 | 4.6 | | 7.8 | 9.5 | 7.1 | 6.1 | 5.5 | 8.7 | 7.4 | 12.3 | 12.0 | 12.0 | 15.5 | 15.5 | 8.8 |
| | *N* | 3 | 0 | 7 | 4 | 4 | 1 | 9 | 2 | 0 | 17 | 15 | 40 | 30 | 33 | 42 | 38 | 14 | 49 | 21 | 18 | 9 | 356 |
| Nebraska | % | | 7.7 | 2.5 | 2.7 | | 3.6 | | | 6.6 | 5.0 | 4.2 | 6.7 | | 6.9 | 5.1 | 4.8 | 6.8 | 6.0 | 8.5 | 1.5 | 7.3 | 5.7 |
| | *N* | 0 | 3 | 3 | 1 | 0 | 1 | 0 | 0 | 1 | 6 | 8 | 3 | 0 | 1 | 5 | 3 | 10 | 7 | 4 | 1 | 6 | 63 |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nevada | % | 6.7 | 1.6 | 4.2 | 3.1 | 4.0 | 3.2 | 4.5 | 4.8 | 4.4 | 5.9 | 3.2 | 6.3 | 4.1 | | 14.9 | 5.4 | 7.6 | | 16.9 | 11.7 | 13.1 | 6.1 |
| | *N* | 2 | 6 | 9 | 8 | 19 | 12 | 10 | 13 | 17 | 11 | 4 | 1 | 4 | 0 | 2 | 2 | 1 | 0 | 3 | 7 | 19 | 150 |
| New Hampshire | % | | | 2.2 | | | | | 4.4 | | 3.3 | | | | | 8.6 | 6.6 | 9.5 | 13.0 | 11.9 | 13.5 | 11.8 | 8.7 |
| | *N* | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 5 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 6 | 2 | 1 | 6 | 9 | 7 | 47 |
| New Jersey | % | 2.7 | 3.3 | 3.1 | 3.3 | 2.1 | 3.6 | 5.1 | 3.2 | 4.6 | 6.2 | 3.4 | 4.6 | 4.3 | 9.3 | 6.6 | 6.7 | 11.9 | 10.4 | 9.3 | 9.6 | 14.0 | 7.1 |
| | *N* | 5 | 1 | 1 | 1 | 11 | 21 | 8 | 3 | 5 | 8 | 4 | 14 | 4 | 10 | 8 | 6 | 6 | 17 | 11 | 10 | 18 | 172 |
| New Mexico | % | 3.8 | 3.1 | 3.1 | 3.4 | 4.0 | 3.9 | 4.6 | 4.5 | 5.6 | 3.6 | 4.8 | 6.1 | 6.0 | 5.8 | 10.9 | 7.3 | 8.2 | 8.8 | 9.0 | 10.1 | 8.1 | 4.8 |
| | *N* | 2 | 78 | 103 | 117 | 41 | 79 | 56 | 48 | 27 | 39 | 41 | 30 | 47 | 30 | 6 | 41 | 42 | 23 | 16 | 10 | 18 | 894 |
| New York | % | 3.3 | 2.8 | 2.4 | 2.7 | 3.1 | 4.0 | 3.5 | 4.3 | 4.5 | 4.7 | 5.5 | 7.7 | 11.5 | 10.1 | 10.5 | 10.9 | 10.9 | 11.2 | 12.3 | 13.0 | 14.6 | 9.1 |
| | *N* | 35 | 53 | 94 | 65 | 53 | 73 | 62 | 41 | 50 | 69 | 102 | 113 | 165 | 135 | 151 | 140 | 121 | 117 | 155 | 172 | 211 | 2177 |
| North Carolina | % | 2.9 | 1.3 | 2.8 | 4.0 | 4.4 | 4.3 | 4.8 | 4.2 | 3.6 | 3.3 | 4.2 | 8.7 | 4.2 | 3.9 | 6.3 | 6.1 | 8.7 | 8.0 | 11.2 | 8.9 | 7.2 | 6.8 |
| | *N* | 2 | 3 | 7 | 3 | 4 | 4 | 5 | 5 | 8 | 8 | 5 | 5 | 1 | 15 | 16 | 22 | 26 | 23 | 18 | 26 | 32 | 238 |
| North Dakota | % | | | 1 | | | | | 4.9 | | 3.1 | | | 1.9 | 13.6 | 8.7 | | 9.7 | 15.5 | 9.7 | | | 7.8 |
| | *N* | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 5 | 0 | 3 | 0 | 0 | 1 | 1 | 3 | 0 | 3 | 3 | 2 | 0 | 0 | 22 |
| Ohio | % | 4.0 | 4.2 | 4.1 | 4.1 | 3.2 | 4.7 | 4.7 | 5.0 | 6.6 | 4.3 | 6.3 | 5.9 | 6.2 | 6.7 | 8.1 | 8.7 | 10.1 | 8.4 | 8.8 | 9.3 | 6.7 | 6.8 |
| | *N* | 3 | 9 | 26 | 9 | 10 | 57 | 48 | 26 | 30 | 49 | 62 | 34 | 18 | 63 | 89 | 67 | 36 | 62 | 29 | 53 | 42 | 822 |
| Oklahoma | % | | 3.3 | 2.2 | 3.8 | | 2.9 | 1.6 | 2.8 | 2.6 | 2.2 | 4.5 | | 4.6 | 4.7 | 4.5 | 4.6 | 6.7 | 3.8 | 5.7 | 6.0 | 4.3 | 3.6 |
| | *N* | 0 | 8 | 14 | 5 | 0 | 4 | 2 | 2 | 2 | 5 | 3 | 0 | 5 | 6 | 1 | 3 | 2 | 2 | 2 | 2 | 2 | 70 |
| Oregon | % | 8.1 | 5.0 | 2.4 | 4.2 | 4.3 | 4.3 | 4.8 | 7.6 | 6.2 | 3.5 | 6.6 | 7.8 | 8.3 | 9.1 | 9.2 | 7.2 | 7.5 | 11.3 | 9.9 | 9.4 | 11.8 | 8.4 |
| | *N* | 14 | 20 | 10 | 23 | 8 | 7 | 8 | 15 | 14 | 10 | 16 | 4 | 28 | 29 | 28 | 29 | 36 | 78 | 41 | 39 | 45 | 502 |
| Pennsylvania | % | | 3.1 | 2.4 | 2.0 | 3.4 | 4.1 | 4.3 | 5.1 | 5.4 | 2.9 | 7.5 | 4.9 | 8.1 | 7.0 | 8.9 | 7.9 | 9.4 | 7.7 | 10.1 | 8.1 | 12.5 | 6.5 |
| | *N* | 0 | 9 | 21 | 20 | 50 | 27 | 17 | 16 | 25 | 53 | 38 | 44 | 21 | 40 | 43 | 42 | 30 | 39 | 48 | 32 | 26 | 641 |
| Rhode Island | % | 4.4 | 2.8 | 0.9 | 4.6 | | 4.3 | | 6.5 | 4.5 | 2.5 | 1.5 | 8.4 | 6.0 | 6.1 | 11.8 | 6.2 | | 10.2 | 7.7 | 10.0 | 13.8 | 6.5 |
| | *N* | 4 | 1 | 5 | 1 | 0 | 6 | 0 | 5 | 3 | 3 | 1 | 3 | 3 | 5 | 6 | 1 | 0 | 4 | 5 | 4 | 1 | 61 |
| South Carolina | % | 2.4 | 3.3 | 2.7 | 4.0 | 3.8 | 3.7 | 5.0 | 3.4 | 3.8 | 4.3 | 4.1 | 5.4 | 3.9 | 4.6 | 4.9 | 6.6 | 7.0 | 5.4 | 6.7 | 8.7 | 8.5 | 4.5 |
| | *N* | 1 | 12 | 10 | 11 | 6 | 19 | 6 | 9 | 13 | 14 | 17 | 16 | 13 | 8 | 10 | 4 | 9 | 6 | 6 | 4 | 4 | 198 |
| South Dakota | % | | | | | 1.7 | 1.9 | | 4.2 | 16.3 | 5.3 | 3.9 | 5.0 | 4.7 | 5.1 | 0.8 | | 4.7 | 9.2 | 6.6 | 3.9 | 7.6 | 5.8 |
| | *N* | 0 | 0 | 0 | 0 | 3 | 3 | 0 | 2 | 4 | 2 | 8 | 7 | 3 | 2 | 1 | 0 | 1 | 2 | 7 | 2 | 5 | 52 |
| Tennessee | % | 2.4 | 4.1 | 3.5 | 2.9 | 3.8 | 4.0 | 4.0 | 3.5 | 3.3 | 3.3 | 4.3 | 4.1 | 5.7 | 4.4 | 5.6 | 6.6 | 6.7 | 8.2 | 9.2 | 6.8 | 10.0 | 5.9 |
| | *N* | 4 | 3 | 11 | 9 | 22 | 11 | 19 | 20 | 43 | 22 | 62 | 13 | 17 | 25 | 27 | 43 | 65 | 36 | 19 | 30 | 77 | 578 |
| Texas | % | 3.5 | 2.8 | 3.0 | 3.3 | 3.3 | 3.8 | 4.3 | 4.3 | 4.4 | 2.8 | 3.8 | 4.7 | 4.7 | 4.5 | 5.8 | 5.0 | 5.8 | 6.8 | 7.7 | 7.0 | 6.6 | 4.1 |
| | *N* | 33 | 365 | 519 | 228 | 120 | 359 | 212 | 151 | 137 | 202 | 254 | 233 | 233 | 171 | 74 | 129 | 97 | 97 | 83 | 88 | 87 | 3872 |
| Utah | % | 4.2 | 1.5 | 5.6 | 3.8 | 4.8 | 5.6 | 4.5 | 5.1 | 4.7 | 5.4 | 4.8 | 8.1 | 7.8 | 5.2 | 7.7 | 7.4 | 11.2 | 11.3 | 8.8 | 11.5 | 7.9 | 7.1 |
| | *N* | 4 | 2 | 4 | 8 | 8 | 8 | 5 | 6 | 10 | 21 | 19 | 13 | 3 | 9 | 16 | 7 | 15 | 19 | 22 | 6 | 8 | 213 |
| Vermont | % | 3.1 | 7.7 | 3 | 0.8 | 6.7 | | 8.9 | 5.7 | 2.3 | 1.9 | 8.9 | 8.8 | 13.3 | 12.6 | 15.5 | 14.8 | 14.7 | 13.2 | 13.3 | 15.1 | 13.7 | 11.8 |
| | *N* | 3 | 1 | 5 | 2 | 8 | 0 | 1 | 3 | 4 | 1 | 9 | 13 | 15 | 13 | 15 | 10 | 12 | 13 | 12 | 19 | 11 | 170 |
| Virginia | % | | 3.6 | | 6.9 | | 4.0 | 4.3 | 4.1 | 3.9 | 5.1 | 5.2 | 5.6 | 5.4 | 6.0 | 7.8 | 6.6 | 7.7 | 8.7 | 8.8 | 9.9 | 12.5 | 7.1 |
| | *N* | 0 | 1 | 0 | 1 | 0 | 9 | 20 | 12 | 17 | 24 | 36 | 29 | 34 | 54 | 49 | 37 | 59 | 35 | 45 | 31 | 36 | 529 |
| Washington | % | 4.6 | 5.0 | 7.5 | 6.8 | 7.4 | 6.9 | 8.8 | 8.1 | 7.1 | 9.4 | 11.0 | 10.8 | 14.3 | 14.0 | 15.8 | 11.6 | 11.0 | 11.4 | 13.3 | 13.8 | 13.8 | 11.9 |
| | *N* | 10 | 19 | 32 | 19 | 8 | 13 | 14 | 28 | 31 | 43 | 75 | 41 | 92 | 104 | 117 | 137 | 94 | 71 | 82 | 70 | 33 | 1133 |
| West Virginia | % | | | 1.8 | | | 7.9 | 5.1 | 5.4 | 2.4 | 4.6 | 5.4 | 4.6 | 5.8 | 6.4 | 5.0 | 7.7 | 10.6 | 7.6 | 8.7 | 10.4 | 8.2 | 7.2 |
| | *N* | 0 | 0 | 1 | 0 | 0 | 6 | 2 | 3 | 4 | 15 | 18 | 10 | 3 | 10 | 17 | 11 | 5 | 32 | 17 | 31 | 10 | 195 |
| Wisconsin | % | 3.3 | 1.5 | 1.9 | 3.4 | 3.5 | 1.3 | 4.4 | 2.6 | | 3.2 | 4.2 | 6.5 | 6.3 | 8.3 | 5.0 | 12.5 | 9.4 | 6.9 | 12.1 | 8.1 | 11.3 | 7.3 |
| | *N* | 1 | 4 | 8 | 12 | 5 | 1 | 5 | 1 | 0 | 7 | 2 | 4 | 8 | 34 | 27 | 13 | 19 | 8 | 3 | 5 | 30 | 197 |
| Wyoming | % | | | | 5.7 | 2.7 | 2.7 | 5.5 | 4.8 | 2.2 | 4.3 | 1.5 | | | | 5.0 | 4.9 | 9.0 | | 5.0 | | 20.8 | 5.1 |
| | *N* | 0 | 0 | 0 | 3 | 1 | 4 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 17 | 1 | 1 | 0 | 2 | 0 | 1 | 35 |
| Total | % | 3.8 | 3.3 | 3.2 | 3.7 | 3.8 | 4.0 | 4.5 | 5.0 | 4.9 | 4.6 | 5.4 | 6.1 | 7.3 | 7.2 | 8.3 | 8.1 | 8.8 | 9.6 | 10.0 | 9.9 | 10.7 | 6.3 |
| | *N* | 741 | 1519 | 2452 | 1978 | 2042 | 3742 | 1382 | 1323 | 1307 | 1783 | 1894 | 1665 | 1647 | 1832 | 1858 | 2233 | 2015 | 2080 | 1924 | 1717 | 2023 | 39,157 |

laws occurs predominantly through a compositional shift in the share of the market captured by high-potency sinsemilla. In other words, rather than influencing marijuana potency through direct regulatory action, these policies primarily affect potency by influencing the types of marijuana sold in a given market in terms of the proportion of high potency versus low potency products.

This study has a number of important limitations. First, the primary source of information on marijuana potency comes from law enforcement data. We do not have a random sample, and to the extent that the behavior of growers/distributors who are caught by law enforcement differ systematically from those who are not apprehended, these findings might not hold for the entire marijuana market. This is particularly true of states with relatively few potency observations. Moreover, our compositional measures of the aggregate marijuana market are potentially even more susceptible to bias caused by purposeful law enforcement strategies. It would be important to see if future work using data from other sources that is just now coming on line (e.g. Weedmaps) validate our findings here, although we are unaware of any other publicly available source of longitudinal data on marijuana potency capturing both the medical and nonmedical markets.

Second, it is very difficult in our data to tease out independent effects of particular elements of the state policies and a broad medical marijuana policy itself, as many of the policies tend to have very similar characteristics (e.g. allowing for home cultivation). Variation in key characteristics stems largely from just a few unique states, and hence results from these analyses may not be fully generalizable. However, state marijuana policies are evolving at a rapid pace, and analysis of just a few years of additional data would remedy some of these concerns.

Finally, it should be reiterated that none of the state policies we examined explicitly specified a minimum or maximum potency that could be sold or, for that matter, provide any general guidelines for potency. To the extent that medical marijuana laws emerge that provide greater specificity regarding the allowable amount of THC in medical-grade marijuana, it is possible that the mediated effects of this policy could change over time.

Additionally, one policy innovation not addressed by this study that merits further examination is the legalization of recreational marijuana, which has already occurred in Washington and Colorado, and which may spread to other states. Recreational legalization carries the potential to exert more profound effects on potency than medical legalization. For example, the structure of the Colorado law, which limits legal possession to relatively small quantities, might encourage production of higher potency strains. More generally, opening a licit recreational market might change the user base in ways that affect demand for different types of marijuana. It remains to be seen how these broader policies of legalization will affect potency.

Should the findings from this study be replicated, the results have very important implications for policymakers and those in the scientific community trying to interpret the literature of the effects of MMLs on marijuana use. In particular, even if medical marijuana policies do not lead to an increase in the prevalence of marijuana use, it is important to understand the extent to which greater availability of higher potency marijuana increases the risk of negative outcomes among the current stock of users, such as drugged driving, drug-induced psychoses, and other harmful public health outcomes. Research is also needed to understand the practical significance of, say, a one, two, or five percentage point increase in average THC content. By the same token, it is also critical to develop a broader understanding of how changes in the cannabinoid profile of recreationally available marijuana, such as the ratio of CBD (cannabidiol) to THC, may attenuate the unintended negative effects of marijuana use (Deiana, 2013). In short, future work should reconsider the impact of MMLs on health outcomes in light of dramatic shifts in both marijuana potency and the medical marijuana policy environment.

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## Appendix A.

See Table A.1

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