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Early Impacts of Marijuana Legalization: An Evaluation of Prices in Colorado and Washington

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Abstract

Following the legalization and regulation of marijuana for recreational purposes in states with medical markets, policymakers and researchers are in need of empirical evidence related to how, and how fast, supply and demand have changed over time. Because prices constitute an indication of how suppliers and consumers respond to policy changes, we used a difference-indifference approach to capitalize on the timing of policy implementation and to identify the effects of legalization on marijuana prices four to five months after markets opened. We used a unique longitudinal survey of self-reported prices and a web-scraped dataset of dispensary prices advertised online in three U.S. states that had legalized medical marijuana, and which later legalized recreational marijuana as well. Results indicate there were no effects on the prices paid for medical or recreational marijuana among state-representative samples of residents within the short four- to five-month window following legalization. However, there were differences in how much people paid if they obtained marijuana for recreational purposes from a recreational store. Further analyses of advertised prices confirmed this result, but also demonstrated heterogeneous responses in prices across types of commonly advertised strains; prices either did not change or they increased depending on the strain type. A key implication of our findings is that there are both supply and demand responses at work in the opening of legalized markets, suggesting that evaluations of immediate effects may not accurately reflect the long run impact of legalization on marijuana consumption.

Keywords

Marijuana prices; Marijuana policy; Legalization; Affordability; Policy impact

Introduction

In November 2012, the voters in Colorado (CO) and Washington State (WA) steered their states into uncharted territory by passing ballot initiatives legalizing the processing, sale, distribution, possession and consumption of marijuana for personal use. These were the first two jurisdictions in the world that legally sanctioned the full supply chain for marijuana for

Conflict of Interest

The authors declare they have no conflicts of interest.

recreational[1] purposes since countries signed onto the 1961 Single Convention (UN, 2016), which required all signatory countries to limit the possession, use, cultivation, production, distribution, import, export and trade or sale of narcotic drugs, including cannabis, to medical and scientific purposes only. The change to legal, recreational retail commercial markets in these two states was not immediate, however. It took over a year for both states to set up the regulatory and licensing processes that would enable the opening of stores in 2014, and even longer for additional regulations to emerge dealing with unexpected consequences of these markets, such as the gaming of the three tier system in WA to avoid paying taxes, rules regarding the processing, packaging, and sale of edibles (in both WA and CO), and additional restrictions on signage and advertising (CO – new rules in 2013). Before many of the details of these regulated markets could be fully fleshed out, Alaska (AK) and Oregon (OR) passed similar ballot initiatives in November 2014, and Washington DC at that same time became the first jurisdiction to adopt a legalization policy using a non-commercial model. As of November 2016, four more states adopted legalization initiatives (California, Massachusetts, Maine and Nevada), and serious questions are being asked concerning what can be learned about the effects of legalization from the states that have already implemented these policies.

Although stories make the national headlines describing some of the effects of legalization in CO and WA, the data remain largely descriptive and in many instances contradictory. For example, there are stories about how legalization has led to both less (Balko, 2014) and more (Sabet, 2014) reported crime. Some newspapers and news agencies report on increasing trends in hospitalizations (Warren, 2015), emergency department visits (Manella, 2016), poison calls (Johnson, 2015) and drugged driving (Hasley III, 2015), while others report that these are simply overreactions or incorrect characterizations of the problems (Hesse, 2016; Sun, 2016). Some news stories also describe no effect of these laws on youth consumption (Bentley, 2015), while other suggest there is an effect on youth (Haun, 2015; Ingold, 2014). Unless better evidence is put forward soon, policymakers and the public will only have descriptive evidence on which to base their opinions and policy decisions regarding the desirability of legalization.

Why is better information not more forthcoming? There are at least three reasons. First, as mentioned already, the markets in CO and WA did not unfold magically overnight. While voters passed legislation in November 2012, retail stores opened in 2014 and continued to grow and expand after the initial opening, as will be discussed in greater detail below. Identifying the specific point at which the policy can be considered fully implemented, therefore, is difficult to pin down but necessary for a rigorous evaluation. A second reason is that the administrative datasets that are typically used to identify the downstream unintended consequences of these markets, such as emergency department visits, drugged driving arrests, and marijuana-involved crashes, take time to process before they get publicly released and can be accessed, unlike data on tax revenue from sales. Therefore, analyzing outcomes for both treated and comparison states using large administrative data files has not been possible until very recently, when data for the year 2014 was released (in 2016). But as

[1]Defined as “used for pleasure instead of for medical purposes” (“Recreational,” n.d.).

mentioned already, the year 2014 may not accurately reflect the right time period for capturing implementation effects.[2] Third, relevant data that systematically distinguishes beneficial from harmful or risky consumption simply do not exist. Information on patterns of use, such as amount of intoxicant per dose, doses consumed per use episode, intoxicating use episodes per day, and time of day of use episodes, are necessary for researchers to differentiate potentially harmful or risky use from regular casual or light use, and also necessary for linking consumption to harms in a dose-response fashion.

In order to truly understand market responses to legalization and thus implications for prevention strategies, there is a pressing need for quasi-experimental evidence identifying effects on both the supply of and demand for marijuana. In this paper, we take a step toward providing some of the initial evidence by examining the extent to which transitioning from a medical marijuana market to a legal recreational market influences the short run prices of marijuana immediately (e.g., four to five months) following the opening of stores. By examining the immediate effect of legalization on prices paid by consumers and offered by suppliers, we make two important contributions to the literature. First, our study provides the first robust evidence of the immediate effect of opening recreational stores on the availability of marijuana in a market, as indicated by changes in the prices of both medical and recreational marijuana. Second, we provide a basis for helping researchers determine the appropriate time window for examining effects on consumption and harm, following policy implementation. If marijuana prices are not affected by the opening of recreational markets (or alternatively they rise because of a shortage of supply in the short run), then the immediate or short run consumption response associated with legalization may not be indicative or fully reflect the longer term effects of the policy change. However, if prices start to fall immediately following the opening of stores, then the incremental change from medical marijuana stores to recreational stores is more substantial, suggesting that an examination of consumption and other outcomes immediately following the opening of stores is an appropriate window for considering the effect of the policy.

We start with a justification for why we should study prices to better understand these new and developing markets. We then provide a description of both the Colorado and Washington medical marijuana markets prior to the opening of retail recreational stores, which is important for understanding how and why prices might differ initially between these two states. Next, we present data and conduct analyses that are designed to answer the following main questions: (1) What were the levels of prices in the medical and (illegal) recreational markets before recreational stores opened in these two states, and how did they change a few months after stores opened there? (2) Were there other shifts in the market that might help explain why prices moved in the direction they moved over time or across states? (3) To what extent are descriptive findings about changes in average prices from the self-reported data validated by findings from dispensary data? And finally, (4) To what extent does the legalization of state recreational markets influence either medical or recreational

[2]When the CO Department of Public Safety produced its required mandatory report to the Senate in March 2016, it only could analyze data up to 2014 because that was all that was publicly available. Recognizing that the administrative data lagged substantially behind the roll out of the stores, and in light of the clear growth in the volume of plants sold subsequent to 2014, the CO Department of Public Safety suggests that findings contained within its report of the public safety effect be viewed more as a baseline assessment of where things stood before commercialization of the recreational marijuana market (CO Department of Public Safety, 2016).

average prices a few months after retail stores opened, holding constant changes in the location and amount purchased?

Why study prices to understand policy implications for prevention?

There are at least three reasons why prevention researchers, practitioners, and policymakers should care about the effects of laws on marijuana prices in particular. First, there is clear evidence that marijuana users, even chronic users and adolescents, respond to prices (Davies et al., 2016; Pacula et al., 2001; Pacula et al., 2014; Williams et al., 2004). Therefore, if legalization results in price changes to marijuana, then we can expect changes in use, particularly among these users. Second, if marijuana prices fall, then fiscal revenues generated from taxes tied to the sales price of marijuana will also decline on a per unit basis. That makes the gains from legalization in terms of tax revenue lower than projected, unless sales expand beyond expectations modelled. If these fiscal resources are earmarked for prevention programs, then less funding than expected will be available. Finally, the relevant prevention strategies may change over time depending on the environment, and prices are a very good indication of how slowly or quickly the retail market is emerging and what the likely effects will be on overall consumption. To understand this last point, one must understand how the current price of marijuana relates to the cost of production, the known quality of the product, and overall market demand.

With some exceptions[3], prices are an important way for suppliers to signal their costs and level of inventory to consumers, and for consumers to signal how much they want or can afford of a given product. So when a new drug policy is implemented, we can study the prices to understand its effect on the supply and consumption of the drug of interest. When the new drug policy causes a change from an illegal to a legal market, the implications for prices are more nuanced. Illegal markets raise the cost of production of any illegal good in three ways. First, if strictly enforced, there are legal risks associated with every stage of supply, including cultivation, processing, transportation and sale. Owners of businesses engaging in any of these activities must be compensated for incurring these legal risks associated with producing an illegal market, and they then pass this cost on to the consumer through higher prices (Reuter et al., 1986). Second, while owners of illegal businesses must compete for inputs to production with the legal market, those inputs (e.g., workers, land) are at greater risk when engaged in illegal than in legal production or distribution. As a result, unit input costs are higher in an illegal market than for the same inputs that contribute to legal production. Similarly, businesses that choose to operate in these illegal markets must receive a higher rate of return on their investment to be willing to incur their own risks (Kilmer et al., 2010). Finally, illegal production forces suppliers to produce the good in less efficient ways in order to hide the production from detection, which raises the cost of the production above what it would cost were it produced in the open (Kilmer et al., 2010). The lack of efficiency in production of a good like marijuana could be substantial given the significant returns to scale in the production of most agricultural goods.

[3]Monopoly markets.

In addition to raising the cost of production, illegal markets introduce additional information barriers that allow suppliers to charge higher prices than they could in a legal market where information about the quality of the good, the location of other suppliers, or the availability of other products is more widely available (Galenianos et al., 2012). Where markets are allowed to operate legally, products can be regulated so as to ensure the quality of the good and retailers can be held accountable for selling products that are below the quality advertised. Although regulation is not free, the net effect on product cost depends on regulatory efficiency and effectiveness.

This basic understanding of how illegal markets operate is what causes numerous policy experts to conclude that the price of marijuana will fall precipitously with legalization over the long run (Caulkins et al., 2015; Caulkins & Bond, 2012; Kilmer et al., 2010; Reuter & Kleiman, 1986). However, because current policies are being implemented by state jurisdictions alone while the Federal government maintains its policy of prohibition, it is not clear to what extent production costs will fall even if information asymmetries are reduced. Although the Deputy Attorney General James Cole's memo to all U.S Attorney Generals on August 29, 2013, attempted to provide some guidance regarding the Federal government's enforcement priorities as they pertained to state laws experimenting with legalization, this guidance could be changed with a new administration. Thus, the general expectation is that state legalization will stimulate some decline in prices, although not to the extent that would be observed if the Federal government legalized recreational markets.

However, it is also the case that in the short run, prices may not respond in the same way as long run prices, particularly if the supply is initially constrained. For example, Pacula et al. (2010) examined the effect of medical marijuana laws and reduced user sanctions on self-reported quarterly prices of marijuana over the relatively short period from 2000–2003 in a selection of cities collecting data on arrestees through the Arrestee Drug Abuse Monitoring System.[4] They found that self-reported prices by the arrestee population in states that passed medical marijuana laws during this time period (Hawaii, Nevada, and CO) were higher even after controlling for reductions in user penalties (Pacula et al., 2010). The authors interpreted their results as indicative of the relative inelasticity of supply to respond to increased demand created by the demand-related policies in the short run. Indeed, similar stories of supply shortages were initially reported out of CO immediately following the opening of its first stores in January 2014 (Ferner, 2014). The question is how long such supply shortages persist, and at what point new entry into the market generates longer term pressure on prices within the market.

If marijuana potency rises in response to the policy changes, then prices could also rise on average in the short run due to a shift in the average quality of marijuana purchased (i.e., consumers may switch to higher quality products, which cost more on average), rather than a true product shortage. This additional explanation for a temporary rise in prices is supported by a study looking at the potency of marijuana seized through regular law enforcement activity following state adoption of medical marijuana policies. Sevigny et al. (2014) found

[4]Note that during this period medical marijuana dispensaries were open in some cities in both California and CO, but neither state legally protected the dispensaries during the period being evaluated.

that states that provided legal protections to medical marijuana dispensaries experienced a rise in the average potency of the marijuana seized, with the effect growing over time.

The main point of discussing the disparate short and long run pressure on prices in the market is to recognize that price can be a very good indicator of where the market is in terms of its transition from an illicit to legal product. If prices do not decline immediately, or in fact rise for a period after legalization, than it is likely that short run factors are dominating the current market. It is also the case that consumption is unlikely to change much, particularly among regular and heavy users who spend a bigger share of their disposable income on cannabis, or adolescents who are very responsive to price. Thus, measurement of potential harms by these user groups immediately following the transition to a legal market are not likely to show much of an effect. However, if prices start to fall and have not yet bottomed out, then it is likely that the transition to the long run equilibrium is not fully complete, and continued changes in consumption should be expected.

A critical question for evaluation purposes, therefore, is how long it takes for the legal recreational market to start transitioning from a short to a longer run status. In the case of the medical marijuana market, Anderson et al. (2013) found after examining evidence from 15 years of state medical marijuana policies that prices started to decline three years post policy adoption. Using advertised prices of various strains of marijuana in *High Times* magazine from 1990–2011, Anderson et al. (2013) showed that the price of high quality marijuana (Californian and Hawaiian sinsemilla) experienced a 25- to 28-percent decrease in states that passed medical marijuana policies. However, they found no change in the price of low quality strains of marijuana (Colombian and Mexican commercial grade).

There is good reason to believe that the recreational markets within these states may not take as long to transition as medical markets have, particularly in light of the fact that all the states that adopted commercial recreational markets already had robust medical markets in place. Indeed, early evidence based on sales data from WA using the state legal tracking system suggest that average prices of recreational marijuana began to fall within months of the stores opening (Hansen et al., 2016). Thus, it is important to understand how legalized markets were implemented in both states.

Colorado—There are three important structural factors to understand about the CO marijuana market at the point it opened stores for recreational purposes. First, prior to establishment of any recreational stores, many medical marijuana stores were already in existence throughout the state. As of January 2014, there were 493 licensed medical marijuana centers or medical outlets operating in 88 out of its 321 city and county jurisdictions within the state (Colorado Department of Revenue, 2016). These centers supplied over 110,000 registered patients, a number that had been rising steadily since December 2008 when the number of registered patients with a valid identification was only 4,819 (Ghosh et al., 2015). So, medical marijuana was already a fairly vibrant business prior to the drug's legalization for recreational use. Moreover, this business existed even with a state legal allowance for home cultivation of up to six plants, three of which could flower at any one time.

Second, only medical marijuana dispensaries with an existing license or pending application in process as of December 10, 2012 were allowed to sell marijuana for recreational purposes in January 2014 (Colorado Department of Revenue, 2015). Those in good standing had to apply for a new retail license no sooner than October 1, 2013, and at that time designate in advance how much of their medical marijuana business they were planning to convert to recreational sale, to ensure that all recreational marijuana was tracked in the state retail marijuana tracking system. Given that licensing rules would not allow marijuana product to be shifted between these two markets to meet the current demand at will, both of these actions effectively limited the initial supply of not only recreational but also medical marijuana. Additional stores not previously selling medical marijuana were not legally allowed to enter these markets until nine months after their initial opening, thereby limiting competition even though existing stores could slowly expand their supply by growing more plants. The number of retail stores licensed to sell recreational marijuana more than doubled from 156 to 322 between January of 2014 and December of 2014 (Colorado Department of Revenue, 2015). The amount of retail flower/bud sold more than quadrupled during this same period, from 1,070 pounds to 4,949 pounds.[5] Because a license did not necessarily mean a retail store was open and selling to the public, these increases were driven both by the increasing number of stores that were open and an increased volume per store. These upward trends continued into 2015 as well, with 424 retail stores licensed by December 31, 2015 and a recorded volume of 10,008 pounds of flower/bud sold in those retail stores, more than double what was sold in December 2014. At the same time, the retail markets were fairly concentrated in particular geographic areas, as only 72 of CO's 321 local jurisdictions (22%) allowed retail stores in 2014 (Colorado Department of Revenue, 2015), and only 12 more jurisdictions allowed them by September 2015 (Colorado Department of Revenue, 2016). The vast majority of CO local jurisdictions banned both medical and retail marijuana outlets (Colorado Department of Revenue, 2016). Taken together, these statistics suggest that recreational stores emerged somewhat slowly over time, with the amount of product available on the market growing substantially, but only in particular parts of the state.

A third important point to consider about the CO marketplace was that the law required vertical integration for the first nine months to two years, depending on locality, following a model that was used to regulate medical marijuana centers. Each licensed marijuana provider had to cultivate at least 70% of the marijuana it sold. Business could sell up to 30% of its on-hand inventory to another licensee without reporting it to the state, but anything above that would have to be reported. Vertical integration typically generates efficiencies by reducing transaction costs, increases supply security, and improves coordination in the production of marijuana, but it can also introduce inefficiencies such as unevenly distributed throughput (i.e., scale requirements differ across a supply-chain, so forcing a producer to supply one distributor can be inefficient), reduced specialization, and greater inflexibility.

Washington State—The WA medical and recreational markets are fundamentally different than CO's, which helps to explain why prices in the two states' markets differ, and

[5]Typically stores sell the flowers (or "buds") of the marijuana plant rather than the whole plant, as these are the parts of the plant containing the most THC. Hence, the Colorado Department of Revenue actually tracks sales in terms of bud/flower sold even though it tracks cultivation in terms of whole plants.

provides some insights as to why prices might not move uniformly in the same direction as CO with the transition to recreational markets. First, WA did not initially allow either home cultivation of marijuana or legally protected dispensaries with its medical marijuana law. Home cultivation was not allowed until May 2007, and medical marijuana collective gardens (which were defined as no more than 10 patients who could share resources to cultivate medical marijuana for personal use only) were not legally permitted until July 2011. Even then, these 'collectives' were only legally allowed to grow up to 45 plants until 2015, when formal regulation of the medical marijuana industry was finally passed (Cambron et al., 2017). Since medical outlets were not licensed or registered, they operated in a legal grey area, making it difficult to know their actual number (i.e. the size of the market). Thus, when voters legalized recreational marijuana in November 2012, there was not a vibrant legal medical marijuana system in place, as was the case in CO.

Second, since the 2012 legalization law did not allow non-medical users to grow for personal consumption and medical marijuana stores were not legally protected under state law (only collectives were legally protected), there was no immediate source in which one could access marijuana for non-medical purposes until the first stores opened in July 2014. Moreover, the roll out of retail stores was particularly slow in Washington, in part because of the cap on the total number of retail stores that would be allowed (334 by state law), requiring a lottery in some locations and delaying applicant background checks and requirements. As of January 2015, only 85 licensed retail stores were open in the state, even though there were 270 licensed growers operating, causing a collapse of wholesale prices because they could not legally get rid of their product (Associated Press, 2015).

A third important difference was the recreational supply structure allowed in WA vis-à-vis that in CO. WA recreational stores were not legally permitted to be vertically integrated. Specifically, WA developed a three-tier supply system[6] (similar to alcohol) where the cultivation/production, processing, and retail sale of marijuana could not be vertically integrated; although subsequently the state allowed for cultivation and processing to be so integrated. As described above, the separation of stages of productions should, theoretically, raise the cost of bringing the good to market, particularly because WA law initially imposed a 25% tax at each level of supply (production, processing, and retail sales). The tax was subsequently changed in 2015 into a 37% flat excise tax on all "taxable sales" of marijuana and its derivatives.

Method

Data

RAND Marijuana Use in West Coast States Survey—Information on self-reported prices paid by consumers were obtained from the RAND Marijuana Use in West Coast States Survey (Pacula et al.,2016), an instrument that was added to the GfK Knowledge Group panel in four Western states. The GfK Knowledge Group survey is a state-representative, probability-based web panel of the non-institutionalized household adult

[6]Tier 1 allows for 2,000 square feet or less of dedicated plant canopy; Tier 2 is 2,000 to 10,000 sq. ft.; and Tier 3 is 10,000 to 30,000 sq. ft. (Washington State Liquor and Cannabis Board, n.d.)

population in each state. It is maintained by the market research firm GfK Group. KnowledgePanel® members are recruited using a published sample frame of residential addresses that covers approximately 97% of U.S. households. Individuals are invited by telephone or mail to participate in the panel, and those who agree are given unique log-in information for accessing surveys online. People who do not have internet access are provided at no cost a laptop with ISP connection so they can participate. Emails are sent throughout the month inviting participants to log-in and partake in monthly surveys that are administered for a variety of research purposes. At present, the full KnowledgePanel® consists of about 50,000 adult members (ages 18 and older) and includes persons living in cell phone only households. The RAND Marijuana Use in West Coast States Survey was added to the regular survey instrument of panel members living in CO, WA, OR and New Mexico at three distinct points in time (October, 2013, May, 2014, and October, 2014). A thorough description of the survey and baseline data from all four states is available in Pacula et al. (2016).

Our analysis excluded respondents living in New Mexico due to very low response rates for questions pertaining to marijuana purchases. Excluding New Mexico, the total sample size was 5,576, which represented approximately 2,200 unique individuals over three waves of data. Wave 1 (October 2013) was our pre-period; wave 2 (May 2014) constituted the treatment period for residents in CO; and wave 3 (October 2014) was the treatment period for residents in WA state. Waves 2 and 3 included refresher samples randomly sampled on age and location.

The RAND Marijuana Use in the West Coast States Survey asked respondents a series of questions regarding their lifetime, past year, and past month use of marijuana for medical and recreational purposes and their simultaneous use of marijuana and alcohol, as well as a series of questions regarding where and how cannabis was acquired and the price paid. The study was purposefully designed so that respondents would clearly differentiate use (and acquisition) for medicinal relative to recreational purposes. For example, the first item of the survey was: “Have you ever used marijuana for medicinal purposes?”[7] If the respondent replied *yes*, we then asked the age at initiation for medical purposes, the number of times they used marijuana in the past 30 days for medical purposes, the number of times they purchased marijuana for these purposes, the amount purchased and price paid. We were able, therefore, to construct use and acquisition measures for medical and recreational purposes separately. “Medical use” was determined by the respondents; i.e., it was not defined for them. A separate question inquired as to whether the respondent had a medical recommendation, and if so, who was the source.

The total analytical sample in this study for all three waves, without missing data, was 153 for recreational and 164 for medical purchases. Reduction in the sample size was predominately due to excluding respondents who had not used in the last 30 days. Approximately 5% of the full sample indicated they used medical marijuana in the past 30 days (n=282), 61% of whom (n=172) responded that they bought the marijuana, and 95%

[7]In the United States, the term “marijuana” is more commonly used to reference various cannabis material, and hence survey questions (and the name of the survey) reflect the common nomenclature used here.

(*n*=164) of those provided the price they paid. Altogether, 5.6% (*n*=308) of the sample had used marijuana for recreational purposes in the past month and of those, 53% (*n*=166) had bought the marijuana, and 92% (*n*=153) provided a price. We conducted an attrition analysis to determine whether prices were correlated with remaining in the sample and found no relationship between prices and attrition.[8]

The RAND Marijuana Use in West Coast States Survey was a state representative household panel population that included some individuals who reported purchasing marijuana in the last 30 days. It was not designed to be a state representative sample of marijuana users, nor was it designed to represent individuals who bought marijuana at dispensaries. As such, our sample size fell dramatically when we focused our analysis on individuals who reported information about marijuana purchases.

Weedmaps Dispensary Data—As the RAND Marijuana Use in West Coast States Survey was not a representative sample of people who regularly buy marijuana, we decided to augment our analysis with information obtained through the website *Weedmaps.com*, which advertises marijuana products and price menus for medical dispensaries across the country. New dispensaries are invited to list services for free, which ensures that we include information of new dispensaries in the market, with a pay option to continue the listing (Lipperman-Kreda et al., 2014).

We used web scraping techniques in which a web crawler we designed gathered and copied data from pages of the *Weedmaps* website and deposited the data into our central local database for later analysis. The data collected included prices for dispensaries and collectives that listed their products and prices on *Weedmaps* in each of our states.[9] We obtained prices for multiple, retail-level quantity sizes: one gram, an eighth (of an ounce, or 3.5 grams), a fourth (of an ounce, 7 grams), a half (of an ounce, 14 grams), and one ounce (28 grams). We restricted the analysis in this study to dispensaries located in the same states as in the RAND West Coast States Survey data (CO, OR, WA) to assess the extent to which our self-reported prices from the survey data were comparable to other data collected within these states.

In order to be comparable to the survey data, we used daily prices in October 2013 and May 2014, a time period which includes only one state transitioning to a legal recreational market (CO).[10] There were several forms (e.g., edibles, plants) and species (e.g., Indica, Sativa, hybrid) of marijuana in the *Weedmaps* data, and an extremely large number of strains for sale. In order to impose some homogeneity on the sample, we restricted the analysis to flower products of the species Sativa and Indica, including hybrids; we did not include resin (hash) or oil as these represent fundamentally different goods that did not have an easy translation into grams of flower. We focused the analyses on five relatively well-known strains that were frequently referenced in the data and had varying levels of quality. Three of

[8]A study on how to handle missing data focusing on marijuana prices paid using this survey also supports this (Hunt & Miles, 2015).
[9]The NIDA funded project began scraping prices from *Weedmaps* in January of 2012 and continued through 2014, to overlap with the timing of the RAND West Coast States Survey.
[10]Due to a change in how dispensary menus were posted on the web starting in the summer of 2014, the original web scraping techniques being used missed some menus that were posted by dispensaries in all states for several months. This error was not identified until mid-October 2014, making data for that month incomplete and unusable.

the strains-Green Crack, Blue Dream, and Sour Diesel-were typically considered Sativa dominant and were the most commonly found strains in the data. Two strains in our data were considered Indica-dominant, Purple Kush and Bubba Kush. We allowed for variations of these strain names.[11] We removed any product with reference to 'shake.'[12] This yielded a sample of 365,536 price observations.

As the web scrapping program collected prices from websites and could contain technical errors, we examined the price distribution for each purchase amount and dropped values less than the 1st percentile and values greater than at the 99th percentile. In a final step, we collapsed the prices into a dispensary-month-strain-type price by unit weight. This yielded a final analytical sample of 3,802 prices for analyses examining CO and OR. WA was dropped from the dispensary analysis for reasons that become clear in the results section.

The data scraped from *Weedmaps* suffered from two types of missing data that should be kept in mind when interpreting findings from them. The first type of missing data occurred because *Weedmaps* was not a comprehensive list of all dispensaries operating within a state; it only contained those dispensaries that chose to advertise with them. If systematic biases existed in the types of dispensaries that chose to list with *Weedmaps*, and the characteristics of those dispensaries that chose not to list were correlated with price (e.g., small firms with higher prices) then average prices generated from these data would not necessarily reflect the true average price in each market. However, as long as those systematic biases in the type of dispensaries represented in the data were consistent across states and over time, our estimated effects from these data would not be biased. A bigger concern to us, given our analytic approach relied on identification from within state variation in prices, was if legalization itself caused dispensaries to change their willingness to advertise with *Weedmaps* (making them either more or less likely to do so). If legalization caused dispensaries in legalizing states to systematically drop out of the sample or enter the sample, and those dispensaries had systematically different prices (either higher or lower on average) than the dispensaries included before the policy change, then this change in the composition of dispensaries in our post policy period would bias estimated policy effects.

A second source of missing data in *Weedmaps* was due to the fact that not all dispensaries reported a price for every strain offered at each available amount each week. For example, a dispensary might have listed a price for 1/8th ounce of Purple Kush, but not the full ounce in a given week (while it presented prices for both amounts in another week). To deal with this second type of missing data, we used a multivariate normal imputation approach, which substituted estimated values for missing values in the final model using the *Weedmaps* data (Miles & Hunt, 2015). We applied an imputation model of price as a function of the unit weight, strain, time, and dispensary. Each imputed dataset was analyzed separately and the coefficients from the imputed datasets were pooled to generate a single set of estimates. Overall, the number of imputed observations per dataset was 1,548 of the total 3,802 (40.7% of the observations), which ranged by strain type from 39.3% to 44.7% of the total number of observations. Given this rate of missing data and the Monte Carlo error estimate on the

[11]This includes common misspellings and additional text.
[12]Shake refers to the loose leaves, seeds and stems, at the bottom of a bag containing marijuana.

coefficient and *p* value of the legalization variable, our results based on 30 imputed datasets satisfied criterion regarding the stability of our results (Graham et al., 2007; White, et al., 2011).[13]

Analysis: We analyzed self-reported and advertised marijuana prices before and after the opening of retail recreational stores in treated states as compared to a control group. Our treatment group included individuals residing in CO who were exposed to recreational stores in wave 2 (May 2014), five months after the January 2014 implementation in CO, and those residing in WA in wave 3 (October 2014), four months after the July 2014 implementation in WA. The comparison group comprised individuals living in OR. Although OR eventually legalized recreational marijuana in November 2014, it was not legal, nor were stores for recreational marijuana open, in OR during our study period. Given that all three states eventually adopted the legalization policy within two years of each other, our use of OR as a comparison group allowed us to account for any common unobservable characteristics or trends associated with willingness to adopt a recreational marijuana law.

We employed a fixed effect differences-in-differences model that includes state-and month-year fixed effects in all regressions. Using prices and quantity purchased, we constructed our outcome variable (price per bulk gram) as the reported price divided by the unit weight (i.e., amount) purchased. We included in all of our analyses a measure of the quantity amount purchased translated into grams, specifically 1g, 1/8th ounce (=3.5g), 1/4th ounce (=7g), and ½ ounce (=14g) to account for quantity discounting; for the analysis using dispensary list price, we also included prices for an ounce (approximately 28g).

We modeled prices per gram as a function of the state recreational marijuana law, state fixed effects, month-year fixed effects, and a vector of individual-level time-varying characteristics of the marijuana purchased. Given the data were clustered at multiple levels, e.g., individual/dispensary and state-level, our specifications adjusted standard errors for clustering at the highest level (state-level). Consequently, we estimated the following model:

$$p_{ist}=\alpha+\gamma_s+\lambda_t+\theta L_{st}+\beta X_{ist}+\varepsilon_{ist}, \quad (1)$$

where p_{ist} was the reported price per gram paid by individual i living in state s for their last purchase acquired in the past 30 days at wave t (October 2013, May 2014, or October 2014), L_{st} was a treatment indicator for whether an individual purchased in a state s when legal recreational stores were open at time t (=1 for CO in wave 2 and WA in wave 3; missing for CO in wave 3; 0 otherwise), X_{ist} was a vector of individual time-varying characteristics of the marijuana purchased (amount purchased, reported quality, and type of supplier) to control for any differences in the marijuana purchased over time. The error term, ε_{ist}, was *i.i.d.*, normally distributed, and clustered at the state-level. The parameter of interest, θ, was our differences-in-differences estimator capturing the effect of residing in a state with an operating, legal retail market for recreational marijuana on the price per bulk gram. We

[13]We separately calculate the Monte Carlo estimate for the overall model and each strain to determine the number of imputations for each model.

estimated this model separately for marijuana reportedly purchased for recreational purposes and marijuana reportedly purchased for medical purposes, as it was possible for consumers to consume for either or both purposes, and switch their purpose endogenously between waves.

We estimated a model exactly as specified in equation (1) in which all three states were pooled, and L turned on first for CO in wave 2 and then WA in wave 3; CO was missing in wave 3 in order to focus on the early effects of the policy change. This meant that in the pooled estimation, WA responses were in the comparison group in wave 2 since their recreational law had not yet been implemented. Given this heterogeneity of the comparison group and policy heterogeneity in the treated states of CO and WA as described earlier, we then estimated equation (1) separately for CO as the treatment group and then WA as the treatment group, with OR as the comparison group in each estimation. This imposed homogeneity on the comparison group and treatment group in terms of marijuana markets.

For the dispensary analysis, we estimated a model similar to equation (1) in which p_{ist} was the advertised price per gram by individual dispensary i at time t and state s. There were the following changes: $X_{ist}$was a vector controlling for the particular strain of marijuana advertised (Blue Dream, Green Crack, Sour Diesel, Purple Kush, Bubba Kush), the species (Indica, Hybrid, Sativa), and the unit weight; λ_t was a time fixed effect; and $\lambda_s$represented dispensary fixed effects. As we only had data on dispensary prices for two periods (October 2013, May 2014), and because WA and OR were not homogeneous as a comparison group, our dispensary analysis only used data from CO and OR.

Results

We have organized our presentation of the study's results around the key questions that we specified in the introduction.

(1) What were the levels of prices in the medical and (illegal) recreational markets before recreational stores opened and how did they change a few months after stores opened in CO and WA?

Self-reported medical marijuana prices from the RAND West Coast States Survey, shown in the top portion of Table 1, revealed that the average price per gram of medical marijuana varied considerably across these three states during the baseline period (W1). The average price for medical marijuana in WA ($10.65) was more than 20% higher than the average price for medical marijuana in CO ($7.98) and OR ($8.51). The lower baseline prices in CO vis-à-vis WA were not that surprising in light of the structural differences in the medical markets in these two states (as described above). Moreover, home cultivation of recreational marijuana was allowed in CO under the 2012 law, which was not the case in WA. By May 2014 (wave 2, or "W2"), when CO opened legal recreational stores, the average price per gram of medical marijuana fell in all three states, with the largest decline occurring (in percentage terms) in WA state. By October 2014 (the third wave of the survey, referred to as "W3") when WA recreational stores began to open recreational retail stores, the average medical marijuana prices in all three states rose, exceeding the average prices reported at baseline in CO and WA. As the means presented in Table 1 were unadjusted, this common

trend in medical marijuana prices in all three states across the three survey waves might have reflected a number of factors, including a broad increasing trend in the cost of inputs involved in producing marijuana, a change in the typical purchases made by respondents (to high potency and/or smaller purchases resulting in a higher average price per gram), or a compositional shift in the characteristics of respondents represented in the RAND West Coast States Survey.

As shown in the lower portion of Table 1, the average prices for recreational marijuana followed a different pattern over time in each of the three states. At baseline (W1), when the purchase of recreational marijuana from a dispensary was illegal in all three states, the average price per gram of recreational marijuana was once again higher in WA ($10.40) than in CO ($9.94) and OR ($8.63), consistent with findings from the medical marijuana market. Interestingly, the average prices per gram of medical and recreational marijuana at baseline in WA were fairly similar ($10.65 vs. $10.40, respectively). Similarly, OR purchasers reported no difference in the average price paid for medical or recreational marijuana ($8.51 vs. $8.63, respectively). However, CO purchasers reported paying a higher average price for recreational ($9.94) than medical marijuana ($7.98) at baseline.

Similar to what was observed for the medical marijuana market, the recreational marijuana market showed declines in average prices per gram paid across all three states between W1 and W2, including CO which opened its first retail stores for recreational marijuana during this period. Despite declines reported in all three states for the average price per gram of recreational marijuana, these prices were higher at W2 than were prices for medical marijuana at W2, including OR. Trends in unadjusted mean prices of recreational marijuana began to diverge considerably between W2 and W3, when WA opened its first stores. In OR, the average price per gram declined modestly (from $8.02 to $7.70), while in CO, the average price per gram stayed about the same ($9.26 to $9.20). In WA, the average price per gram of recreational marijuana actually rose from $9.04 to $12.21, similar to what was observed in the medical marijuana markets for all three states.

(2) Were there other shifts in the market that might help explain why prices moved in the direction they moved over time or across states?

Prior research showed that the average price per gram of marijuana paid in black markets is influenced by a number of factors, including the amount that is purchased (due to quantity discounting), the average potency (higher potency commands a higher price), and the source of supply (Caulkins & Pacula, 2006; Davenport & Caulkins, 2016; Pacula et al., 2010). Given the consistency in trends reported in average medical and recreational prices between W1 and W2 across all states, followed by diverging trends both within and across states between W2 and W3, we wanted to examine if other aspects of purchase behavior changed between waves in a manner that might help explain these differences. As shown in the top part of Table 1, the average amount of medical marijuana purchased rose in all three states between W1 and W2, although only by a small amount (about 1–2 grams, which translates into about 2–5 joints). Similarly, as shown in the bottom part of Table 1, the average amount of recreational marijuana purchased rose in OR and WA between W1 and W2. CO

recreational markets were the only ones in which the average amount purchased declined between W1 and W2, but this change was fairly small (less than 2 grams on average).

There was far less consistent trends in potency across any of the waves. Respondents in OR reported more frequent high quality (potency) marijuana purchases in the recreational market between W1 and W2 and lower frequency in the medical marijuana, despite the decline in prices in both markets. CO and WA respondents reported the exact opposite. In both states, respondents reported more frequent high potency purchases in the medical market in W2 than in W1, and less frequent high potency purchases in the recreational market. Again, average price per gram in both markets and both states declined during this period. Between W2 and W3, respondents in WA and CO reported modest declines in the share of high quality purchases in the medical marijuana market, but virtually no change in the recreational market. Respondents in OR, on the other hand, reported no substantive change in the share of high quality purchases in the medical market, but large reductions in the recreational market.

To consider whether the observed changes in average price, amount purchased and potency were a function of where the marijuana was purchased, we next examined the source of supply. Generally, we saw a large shift in the source of supply for both medical and recreational marijuana in CO and WA over the three waves, with more people buying from medical dispensaries in wave two and recreational stores in wave three and fewer purchasing from dealers or friends in either of these markets. The movement away from street dealers between W1 and W2 might explain why prices declined while potency moved in varying directions (as potency is not known with certainty when purchased from dealers). Even in OR, where recreational stores did not exist, some individuals reported purchasing from recreational dispensaries by W3, which could be the case if they lived near the WA border. No one in CO reported purchasing marijuana from a recreational dispensary in W2 because, as discussed previously, only existing medical dispensaries could sell marijuana for recreational purposes in the first nine months.

Unadjusted means presented in Table 1 suggest that there may have been some important differences across states in a few of the purchase behaviors at baseline. Since we only had one observation before the intervention, we conducted a two-sample *t* test of the balance of covariates and the outcomes of interest (price per gram for medical or recreational use). As we were initially considering estimating models using OR and WA as a pooled comparison group to CO in W1, we conducted the test twice. We first conducted the test with residents of OR only as the comparison group for CO residents, and then we reran the test using residents of both OR and WA as the comparison group in W1. While test results indicated no significant differences between the treated group and either of the comparisons (due largely to our very small samples which generated large standard errors), the size of the differences in the covariate means was smaller when only OR residents were in the comparison group than when OR *and* WA residents were in the comparison group.[14] We therefore decided to use only OR as a comparison group for CO when assessing the policy change between W1 and W2.

[14]Results are available from authors upon request.

(3) To what extent are descriptive findings about changes in average prices from the self-reported data validated by findings from dispensary data?

As shown in Table 1, the number of people who self-reported purchasing either medical or recreational marijuana in each of the surveys was very small, raising serious doubts about the robustness and generalizability of findings generated from these data. We therefore sought to replicate findings from a secondary and independent data source. *Weedmaps* provided such a data source, although only for self-described "medical" marijuana dispensaries. No comparable data existed for recreational outlets (which were illegal at baseline in all three states) or the other sources of supply. As shown at the bottom of Table 2, there were more observations per state at each wave from *Weedmaps* than was the case of buyers in the RAND Western Coast State Survey, although CO and WA had many more advertised dispensaries in October 2013 than OR, regardless of wave. This might reflect a greater willingness to advertise in these two states, given that both states adopted legalization policies for recreational marijuana in 2012.

As shown in the top of Table 2, the average price per gram of medical marijuana reported on menus from dispensaries appeared to decline between W1 and W2 for the state of WA, but prices in OR and CO either stayed constant or rose. This contradicts what was shown in Table 1. However, Table 2 also shows that the share of the sample representing particular strains of marijuana also changed over this period. In OR, for example, more dispensaries advertised prices for Blue Dream and Sour Diesel in W2, while fewer advertised Bubba Kush. In WA, however, there was no similar increase in advertisements for Blue Dream, and Greek Crack rose slightly. To the extent that different strains of medical marijuana command different market prices, the compositional shift in strains advertised could have easily generated the different trends observed between states that we reported in Table 2. Additional support of compositional shifts in advertised strains is indicated by the species type represented on menus across waves. In OR in particular there were large shifts in the species of marijuana included on the menu, with smaller shifts observed in CO and WA.

As with the survey data, we statistically tested for baseline differences in the sample across states by conducting a two-sample t test of the balance of covariates and price per gram with OR dispensaries as the comparison group and CO dispensaries as the treated group (recall that WA did not open stores until the third wave of data in 2014, but clearly looks different than both CO and OR so was best kept out of the comparison group). Similar to findings in our survey data, we found that the price per gram in the dispensary data was not statistically significant different between the two groups, indicating OR was a viable comparison group.

As discussed previously, we imputed values for missing information in *Weedmaps*. It is therefore important to consider the impact of imputing data on the sample means. Table 3 provides summary statistics of the dispensary advertised prices for the raw and imputed data for the two states used in our dispensary analyses. When missing data were accounted for, imputed prices per gram in OR and CO were greater than the raw data in wave 1. For OR, this could be explained by a greater proportion of hybrids in the imputed dataset, which constituted the most expensive species in the raw data. For CO, this could be explained by the greater proportion of expensive strains (within the same species) represented in the data in W1, as indicated by greater representation of Bubba Kush and Green Crack. In wave 2,

the imputed price per gram was less than the raw data for both states, which are again easily explained by compositional shifts in the representation of strains in the imputed versus the raw data.

(4) To what extent does the legalization of state recreational markets influence either medical or recreational average prices a few months after retail stores opened, holding constant changes in the location and amount purchased?

Table 4 shows the results of models estimating the effect of opening legal recreational stores on prices per gram in both medical and recreational markets using the difference-in-difference model specified in equation (1) on data from the RAND West Coast State Survey. In the columns labelled "Pooled" data from all three waves were pooled together, using WA and OR as the comparison group in wave 2, given that CO opened stores (i.e., "legalized") in wave 2 and then OR as the only comparison group when WA and CO both had legal stored legalized in wave 3. For reasons discussed previously, we felt it was important to assess impacts using OR as the only comparison group for each state, as we did in each of the next two columns for the medicalized and then legalized markets. In the columns labelled "Effect on CO," the effect of "legalizing" was assessed five months after stores opened in CO (wave 2) vis-à-vis changes in prices in OR only. In the columns labelled "Effect on WA," results were assessed for WA vis-à-vis OR in the four months after stores opened (wave 3).

Regardless of specification or market, the findings from models that adjust for the amount purchased, source of supply and the quality of marijuana showed no statistically significant effects of stores opening in CO and WA on average prices per gram of either medical or recreational marijuana. All the results from the medical market specification indicated a statistically insignificant, positive relationship between prices and stores opening to sell recreational marijuana, while results from the recreational market indicated a statistically insignificant and negative relationship in Colorado and a positive relationship in WA. Importantly, however, all models were significantly under-powered to detect anything but a large change in price at traditional levels of statistical significance (e.g., 5% level) because of the small number of observations. Even in the pooled analyses which provided us with the largest sample sizes for each market, the effect size, as measured by Cohen's *d*, needed to be 1.06 standard deviations in the medical market and 1.01 standard deviations in the recreational market for the price effect to be detected at the 5% statistical significance level. In other words, opening a legal recreational market would have had to have very large effects on prices for these survey data to show a result that met criteria for statistical significance. Thus, the null effect may have resulted because our estimation sample was too small to detect it.

Even with the very low power for detecting effects on prices in these models, some results in Table 4 were statistically significant. In particular, we found that individuals who purchased larger quantities paid a lower price on average, suggesting that even within our very narrow range of retail quantity amounts, price discounting occurred. The quantity discounts per gram were similar across medical and recreational markets, ranging from approximately $0.35 to $0.50 per gram on average. We also found that individuals who reported purchasing

marijuana for recreational purposes from a recreational store paid significantly higher prices per gram than those who purchased from a friend.

As the RAND West Coast State Survey generated samples that were too small to be sufficiently powered to identify possibly divergent effects on prices of opening markets in CO and WA, we wanted to look at the effects of stores opening on reported dispensary menu prices. Results using the *Weedmaps* data, shown in Table 5, revealed that opening recreational stores in CO was associated with an overall increase five months later in the advertised prices of medicinal marijuana. Specifically, at a time when prices of marijuana were in general falling (by approximately $0.53 per gram on average), the price per gram listed on dispensary menus was on average $0.28 more in CO than OR as a result of legal recreational markets. Because the model used multiple imputation methods (due to missing values for some dispensary menu items), we needed to make sure that the estimated coefficient on legalization was fairly robust to the variation that could naturally occur because of the random component of our imputed values (what is referred to as the "Monte Carlo error"). As shown near the bottom of Table 5, the Monte Carlo error on the coefficient of our legalization variable was only 0.011, and represented only 8.9% of the value of the standard error of the coefficient on the legalization variable (which was 0.124). The p value for the Monte Carlo error (0.009) also indicated our estimated coefficient of the effect of legalization had low variation due to imputation, suggesting the estimated effect was in fact robust to additional runs of the model on the same imputed data.

Our finding of a positive effect of opening stores in CO on listed medical marijuana prices was not robust across different strains of medical marijuana advertised, as shown in the remaining columns of Table 5. We found no significant effect of opening recreational stores on dispensary prices in CO for Blue Dream, Bubba Kush, or Purple Kush; higher prices on medical marijuana were only observed for Sour Diesel and Green Crack.

Discussion

If medical marijuana markets only serviced patients, than legalization should have increased demand for marijuana, possibly by a lot. If the supply of recreational marijuana was initially constrained in some way, due to regulatory design or inaccurate expectations of new market demand, the increase in demand could have caused prices for marijuana to rise in both the medical and recreational markets, at least in the short run. Over the long run, however, marijuana prices are expected to decline, even precipitously, because the artificial barriers to production and legal risks imposed that raise costs for the suppliers are removed (Caulkins et al., 2010; Caulkins & Reuter, 1998). Market level prices at a given point in time, therefore, are very good indicators of where the markets are in terms of their transition.

Markets prices, which are widely available when markets are legal, can be a useful indicator to researchers and policy analysts for identifying the appropriate time window in which to evaluate the impact of a large policy change like legalization. If markets are not finished transitioning, then evaluations of the effects of legalization on outcomes measured immediately or shortly after markets open will not accurately reflect the total impact of the policy. This important point is frequently forgotten in evaluations considering the immediate

impact of legalization on youth. Even if youth cannot access stores to buy marijuana, consumption of marijuana by youth is very sensitive to changes in its price (Pacula et al., 2001; Pacula & Lundberg, 2014; Williams 2004). If legalization eventually leads to a reduction in the price of marijuana, then we will not know the impact of the policy change until we have data on youth's responses to the full change in price. Short run analyses, which include time periods where the price remains artificially high due to excess demand or federal enforcement against a market, will not be sufficient.

This paper contributes to the literature by addressing the question, "How long is the short run for marijuana markets?" To answer this question, we use a quasi-experimental approach to study the effects of opening legal recreational stores on average marijuana prices in CO and WA four to five months after stores opened. As information on the price of illegal goods is difficult to obtain, we use data from two independent, albeit imperfect sources: (1) self-reported survey data from a state representative household population, and (2) marijuana dispensary price lists. The findings from the two alternative data sources are not consistent, but neither suggests that prices had begun to fall in the four to five months after recreational stores opened. The main implication of these findings is that early evaluations of the effects of legalization using data within months of the store opening will not provide an adequate indication of the total impact of this policy change. More time is needed for the markets to continue the transition, although this paper cannot speak to how much more time might be required..

This study contributes to growing evidence that relaxation of restrictions on marijuana markets does not necessarily reduce prices paid immediately. In one study examining self-reported prices of street marijuana purchased by arrestees in California before and after adoption of medical marijuana policies, the authors find that marijuana prices actually increased by 36% initially (Pacula et al., 2010). In a different study, investigators show that the advertised price of marijuana within a state remained unchanged after medical marijuana laws were adopted until three years later, when they started to decline (Anderson et al., 2013). However, in both instances it is unclear to what extent reductions in legal risks of moving from no markets to medical markets translated into a real reduction in legal risk in light of the federal prohibition. This study's findings suggest that similar barriers existed initially in markets that moved from medical to recreational markets, but it is limited by the very short time period in which these changes are evaluated. There is still a great deal to learn about how they continue to evolve over time.

Our paper highlights a number of additional insights about how these two state markets transitioned. First, while our evidence from the household survey data showed no statistically significant impact of opening stores on the average price per gram of either medical or recreational marijuana due to the analysis being under-powered, coefficient estimates of the legalization effect on average price per gram in medical markets were positive in all the models estimated. The dispensary data models also showed positive effects of legalization on the average price per gram of medical marijuana, and the dispensary analysis was not underpowered. The fact that opening recreational stores affected the price of medical marijuana suggests these two supply chains are in fact related. While this was true by construction in CO, as only medical marijuana dispensaries were initially allowed to

sell marijuana for recreational purposes and dispensaries had to designate how much of their marijuana they would sell to the recreational market, that was not how the market was set up in WA.

Second, the heterogeneity in findings of the effects of legalization across different marijuana strains in the dispensary data shown in Table 5 was also noteworthy for at least two reasons. First, in the pooled regression combining all strains together, Green Crack was the only strain that had significantly higher average prices (relative to the reference group Blue Dream) across both states, so it is clearly one of the more expensive strains. Sour Diesel, on the other hand, was the only strain that had statistically lower average prices than Blue Dream on average across both states. Yet it was these same two strains (one relatively high priced and one relatively low priced) that experienced statistically higher prices with the opening of the recreational market in CO. Second, both of these strains (Green Crack and Sour Diesel) experienced falling prices in OR between October 2013 and May 2014 based on our imputed data shown in Table 3. The raw data for these two strains in OR, however, suggested that prices were not declining. Deviations between trends in the raw and imputed data were generally caused by having many more missing observations for particular strains listed by a dispensary in the raw data. In CO, the trends in average prices for these two same strains are consistent whether you look at the raw or the imputed data, indicative of fewer missing observations in CO for these two strains. Since imputation occurred because suppliers chose not to list the price of a particular quantity-strain mix, these results indicate that sellers changed the composition of their offerings as a result of the opening of recreational markets opening and, as in the case of Green Crack, were more likely to list the product that was the most expensive as well as a low-cost alternative. It would appear that CO dispensaries engaged in product differentiation to maximize profits, consistently offering both a high quality strain (Green Crack) and a lower quality strain (Sour Diesel).

Our study also sheds light on a methodological concern related to the use of price information obtained from both marijuana dispensaries and self-reports. While dispensary menu data may appear to be a more objective measure of prices than the self-reported data, and are clearly better for accounting for unobserved potency, it is also the case that these listings reflect strategic behavior on the part of the sellers. Moreover, it is clear from the heterogeneous effects of legalization on the price of different strains that product differentiation is clearly achievable in this market. In light of this, it is important for researchers and policy makers to understand what product consumers actually purchase, not just what is advertised. Moreover, it is important to understand which commodities are actually purchased, by whom, and in what quantities.

Limitations

The lack of a statistical power to identify significant effects on price in our analysis of the household survey data is an obvious limitation of the study. Moreover, because the RAND West Coast States Survey comprises a very small number of individuals who reported purchasing marijuana, it might not represent the behavior of the population we are most interested in. The *Weedmaps* data, on the other hand, suffers from nonrandom sampling bias that is clearly observable in the pre-policy time period, as is indicated by the fact that

findings from two strains alone dominated the overall pooled results in our regression analysis. Future studies will need to pay close attention to the quality of these data and underlying shifts in what strains are captured in them if they are to be used for policy analyses.

Conclusions

No jurisdiction has maintained a legal, regulated market of marijuana for recreational purposes in well over 50 years. It is thus not surprising that there is immense interest around the world in what happens as markets develop over time in U.S. states that have legalized marijuana. Our study shows limited effects on prices paid in the first four to five months after markets were opened and began operating. Suppliers generally increased the advertised prices for the most common strain types, with certain strain types in particular receiving the focus of these price increases (Green Crack). Given the evidence that prices did not respond immediately downward in these markets, policy makers should not be relieved by early evidence that opening these markets had no effect on consumption by youth or adverse effects from heavy users. The overwhelming empirical evidence is that consumption by both these groups is highly sensitive to changes in price, and that if prices did not change in the short run (or went up and took time to come back down), it is entirely plausible that changes in behavior among these two high risk groups may not emerge until market prices fall below pre-policy levels. In other words, short run evaluations of policy effects on marijuana consumption behavior will not necessarily be indicative of long run effects on consumption. In the case of WA and CO, it is clear that four to five months after the initial stores open is not sufficient time for long run market forces in these markets to dominate. How much more time is needed before we can expect to see impacts on prices? That question cannot be answered by the data we had available for our study. However, what we do know is that studies looking for effects using annualized data comparing behavior in 2013 to behavior in 2014 will not be adequate.

Finally, our findings provide an important caution to government budget managers who are seeking to estimate tax revenues from these emerging markets. If tax revenues are tied to prices, short run tax windfalls associated with initially high prices in these markets will not be maintained. The only way tax revenues can remain stable once high prices eventually fall is for consumption to change by a greater amount (in percentage terms) than the price declines that will naturally occur as the market transitions to its longer run steady state. Thus, understanding who those consumers are in the long run that make up the long run demand is vitally important for governments to understand whether they can expect a net gain or cost associated with the policy. For the reasons discussed in this paper, it is obvious that more time is needed before such a calculation can be made.

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Table 1

Summary Statistics of Prices Paid by Consumers, RAND West Coast States Survey, 2013–2014

	OR			CO			WA		
Medical	**W1**	**W2**	**W3**	**W1**	**W2**	**W3**	**W1**	**W2**	**W3**
Price per gram ($)	8.51	6.88	8.78	7.98	7.19	10.20	10.65	8.81	13.45
Amount (in grams)	7.05	9.20	6.87	5.46	7.79	5.00	4.70	5.23	4.64
Supplier (%)									
Dealer	0.09	0.09	0.06	0.13	0.05	0.00	0.22	0.17	0.17
Friend	0.27	0.27	0.31	0.20	0.10	0.04	0.37	0.26	0.17
Medical Dispensary	0.55	0.55	0.37	0.60	0.80	0.64	0.33	0.56	0.54
Recreational	n/a	0.00	0.06	n/a	0.00	0.32	n/a	0.00	0.12
Dispensary									
Other	0.09	0.09	0.19	0.07	0.05	0.00	0.04	0.00	0.00
High Quality (%)	0.72	0.64	0.62	0.60	0.75	0.68	0.67	0.70	0.58
Number of Observations	10	10	15	14	19	25	27	22	22
Recreational									
Price per gram ($)	8.63	8.02	7.70	9.94	9.26	9.20	10.40	9.04	12.21
Amount (in grams)	6.15	7.37	8.81	6.95	5.45	4.53	5.73	6.20	3.77
Supplier (%)									
Dealer	0.20	0.20	0.06	0.18	0.09	0.00	0.25	0.10	0.14
Friend	0.70	0.73	0.81	0.36	0.38	0.07	0.54	0.65	0.38
Medical Dispensary	0.10	0.07	0.06	0.36	0.48	0.47	0.12	0.20	0.14
Recreational	n/a	0.00	0.06	n/a	0.00	0.47	n/a	0.00	0.24
Dispensary									
Other	0.00	0.00	0.00	0.09	0.05	0.00	0.08	0.05	0.09
High Quality (%)	0.70	0.80	0.62	0.91	0.62	0.60	0.71	0.60	0.57
Number of Observations	10	15	16	11	21	15	24	20	21

Note. W1- wave 1 (October 2013); W2- wave 2 (May 2014); W3- wave 3 (October 2014)

Table 2

Summary Statistics of Dispensary Advertised Price Sample, 2013–2014

	OR		CO		WA	
	W1	W2	W1	W2	W1	W2
Price per gram ($)	8.4	8.77	8.75	9.98	10.09	9.69
Unit (grams)	10.17	10.44	10.78	10.59	10.22	10.32
Strain (%)						
Blue Dream	0.29	0.37	0.34	0.27	0.39	0.36
Sour Diesel	0.22	0.29	0.33	0.32	0.2	0.24
Green Crack	0.16	0.15	0.09	0.13	0.09	0.13
Bubba Kush	0.2	0.11	0.15	0.17	0.18	0.14
Purple Kush	0.12	0.07	0.1	0.1	0.15	0.13
Species (%)						
Indica	0.27	0.15	0.25	0.28	0.29	0.25
Sativa	0.45	0.41	0.54	0.49	0.46	0.52
Hybrid	0.28	0.44	0.21	0.22	0.24	0.23
Number of Observations	192	174	1,042	846	883	1,157

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Table 3

Summary Statistics of Dispensary Advertised Prices with Imputations, 2013–2014

	OR				CO			
	W1		W2		W1		W2	
	Raw data	Imputed data	Raw data	Imputed data	Raw data	Imputed data	Raw data	Imputed data
Price per gram ($)	8.40	8.88	8.77	8.35	8.75	9.52	9.98	9.27
Blue Dream	8.41	8.60	8.32	8.09	8.68	9.42	9.75	9.04
Sour Diesel	8.08	8.96	8.88	8.65	8.43	9.15	10.06	9.28
Green Crack	8.66	8.96	8.67	8.47	9.36	10.29	10.55	10.38
Bubba Kush	8.73	9.51	9.95	8.61	9.07	9.94	10.25	9.26
Purple Kush	8.11	8.29	9.02	7.80	8.97	9.43	9.12	8.76
Amount (grams)	10.17	10.30	10.44	10.30	10.78	10.71	10.59	10.71
Strain (%)								
Blue Dream	0.29	0.32	0.37	0.32	0.34	0.30	0.27	0.30
Sour Diesel	0.22	0.24	0.29	0.24	0.33	0.32	0.32	0.32
Green Crack	0.16	0.17	0.15	0.17	0.09	0.11	0.13	0.11
Bubba Kush	0.20	0.18	0.11	0.18	0.15	0.17	0.17	0.17
Purple Kush	0.12	0.09	0.07	0.09	0.10	0.10	0.10	0.10
Species (%)								
Indica	0.27	0.22	0.15	0.22	0.25	0.28	0.28	0.28
Sativa	0.45	0.43	0.41	0.43	0.54	0.49	0.49	0.49
Hybrid	0.28	0.35	0.44	0.35	0.21	0.23	0.22	0.23
Number of Observations	192	329	174	329	1,042	1,572	846	1,572

Note. W1- wave 1 (October 2013); W2- wave 2 (May 2014).

Table 4

Effect of Recreational Legalization on Consumers

Dependent variable: Price per gram	Medical purposes			Recreational purposes		
	Pooled	Effect on CO	Effect on WA	Pooled	Effect on CO	Effect on WA
Legal recreational market	1.905 (1.874)	2.103 (1.391)	1.771 (3.532)	−0.306 (1.279)	−3.292 (2.623)	1.826 (1.261)
Amount (in grams)	−0.465** (0.108)	−0.335** (0.078)	−0.473** (0.122)	−0.429** (0.064)	−0.503** (0.105)	−0.388** (0.057)
Supplier (omitted “Paid Friend”)						
Medical Dispensary	2.361 (1.597)	−1.711 (1.111)	3.253 (1.776)	−0.213 (1.096)	0.628 (1.903)	−1.008 (0.916)
Dealer	1.037 (1.314)	0.643 (1.111)	0.804 (1.390)	−1.062 (0.808)	−1.562 (1.766)	−0.728 (0.635)
Other	3.821 (1.539)	1.971 (1.403)	0.876 (1.614)	−2.266 (1.287)	−1.633 (2.954)	−3.385 (0.811)
Recreational Store	3.461 (4.329)	.	3.854 (4.459)	8.155** (2.712)	.	8.096** (2.395)
High Quality	0.319 (1.066)	0.345 (0.824)	−0.027 (1.343)	0.696 0.623	1.362 1.197	0.412 (0.512)
Constant	8.517** (1.260)	11.569** (1.095)	10.304** (1.347)	13.542** (2.001)	10.873** (1.433)	11.676** (0.858)
State fixed-effects	Y	Y	Y	Y	Y	Y
Wave fixed-effects	Y	Y	Y	Y	Y	Y
Number of Observations	117	53	106	137	57	105
R^2	0.338	0.544	0.323	0.548	0.419	0.688

Note. Robust standard errors in parentheses. Analysis based on RAND West Coast States Survey data.

** $p<.01$.

Table 5

Effect of Recreational Legalization on Online Advertised Prices

Dependent variable: Price per gram	**All**	**Blue Dream**	**Sour Diesel**	**Green Crack**	**Bubba Kush**	**Purple Kush**
Legal recreational market	0.280 * (0.124)	0.033 (0.185)	0.449 ** (0.203)	0.825 ** (0.305)	−0.185 (0.305)	−0.097 (0.232)
Time	−0.527 ** (0.147)	0.558 * (0.251)	−1.105 ** (0.240)	−0.409 (0.287)	0.306 (1.156)	0.062 (0.211)
Oregon	−1.066 ** (0.303)	−1.454 ** (0.466)	−0.0864 (0.444)	2.032 (2.178)	0.463 (0.443)	−2.782 ** (0.245)
Amount (in grams)	−0.105 ** (0.003)	−0.100 ** (0.004)	−0.100 ** (0.005)	−0.110 ** (0.009)	−0.099 ** (0.005)	−0.107 ** (0.005)
Strain (Blue Dream omitted)						
Sour Diesel	−0.297 ** (0.084)					
Green Crack	0.493 ** (0.145)					
Bubba Kush	0.311 (0.161)					
Purple Kush	−0.195 (0.158)					
Constant	12.77 ** (0.247)	11.86 ** (0.361)	11.97 ** (0.434)	9.58 ** (2.078)	10.10 ** (1.119)	10.86 ** (0.379)
Total Observations	3,802	1,154	1,164	454	648	382
Imputed Observations	1,548	457	458	190	290	153
For Legalization, Monte Carlo error on:						
Coefficient	0.011	0.015	0.017	0.027	0.041	0.011
p value	0.009	0.064	0.008	0.002	0.093	0.035
F stat †	62.96	32.61	46.57	33.60	7.09	42.46
Prob>*F*	0.000	0.000	0.000	0.000	0.000	0.000

Note. Dispensary clustered standard errors in parentheses. All analyses also include dispensary-fixed effects and controls for species (Hybrid, Indica, Sativa). Missing data handled using multivariate normal imputation (30 imputations). Analysis based on *Weedmaps* data.

† F-stat degrees of freedom vary by strain as follows: All F(183,3404.1); Blue Dream F (116,991.7), Sour Diesel F (114,1020.2), Green Crack F (50,391.9), Bubba Kush F (69, 443.6), Purple Kush F (43, 333.4).

* $p<.05$.

** $p<.01$.