Enforcement & Prices
An Empirical Asessment

by

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(Under the Direction of James Monogan III)

Abstract

The prohibition of marijuana and the "war on drugs" more generally is intended to raise drug prices, which, if demand is elastic, would result in a decrease in consumption. How much does prohibition raise the retail price of marijuana? The effectiveness of prohibition at elevating prices has been difficult to assess due to poor data and a lack of variation in the legality of marijuana. I leverage a large, user-submitted database of marijuana purchases in the continental United States, variation in the legality of marijuana, and a spatio-temporal generalized additive model to assess the effectiveness of prohibition. I find that state-level quasi-legalization, decriminalization, and legalization of medical marijuana have substantively small effects, suggesting that active enforcement is ineffective at raising marijuana prices and that passively imposed market inefficiencies are what keeps the unit price of marijuana high relative to its commercial farm-gate price. Thus, federal, state, and local spending on marijuana prohibition could be put to better use.

Index words: policy, marijuana, spatio-temporal modeling, generalized additive models

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B.A., Georgia Southern University, 2009

A Thesis Submitted to the Graduate Faculty
of The University of Georgia in Partial Fulfillment
of the
Requirements for the Degree

Master of Arts

Athens, Georgia

2013

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July 9, 2013

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Chapter 1

Introduction

As of early 2013, marijuana remains a Schedule I substance in the United States, the federal government's highest level of prohibition. Various states, however, have pursued more liberal policies with regards to marijuana prohibition. A number of states have passed laws allowing for marijuana to be used for medical purposes and some states have decriminalized possession of the drug. Washington and Colorado, as of December 6th and 10th, 2012, were the first states to legalize marijuana possession, constituting a form of quasi-legalization, since provisions allowing the sale and growth of marijuana are not yet in place. Despite these steps toward legalization, marijuana remains completely prohibited in most states. Marijuana prohibition cost federal, state, and local governments approximately $10.8 billion in 2008 (Miron 2010).[1] Additionally, prohibition has had a high social cost. There is evidence to suggest that black and Latino males are arrested and incarcerated for marijuana related offenses at significantly higher rates than are whites, despite similar levels of consumption (Ramchand, Pacula and Iguchi 2006). Arrest and incarceration have substantial economic costs (Bushway 1998; Pager 2003). Between 1996 and 2011, there have been 10,769,582 arrests for the possession of marijuana and 1,457,508 arrests for the trafficking or sale of

[1] This number is estimated and is subject to some disagreement. Nevertheless annual expenditures are clearly in the billions.

marijuana.[2] Figure 1.1 shows the number of arrests for possession and trafficking by year from 1995–2011.

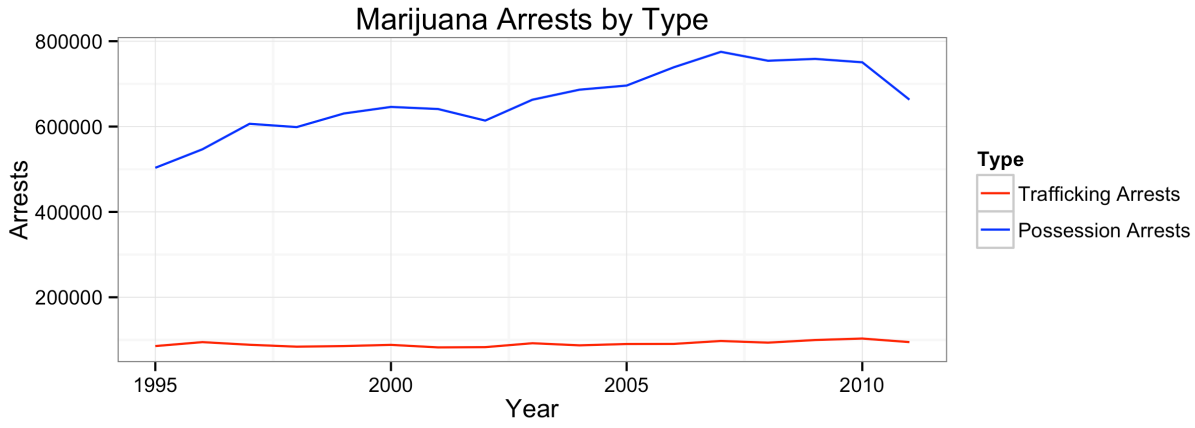

Figure 1.1: Number of arrests by year for possession or trafficking. Taken from the Federal Bureau of Investigation's Uniform Crime Reports.

Although the justifications for marijuana prohibition in particular and the "war on drugs" more generally are varied, the primary motivation identified in the literature is simple (Scherlen 2012). Enforcement is intended to increase drug prices, which, if demand for targeted drugs is elastic, would decrease consumption, thus dampening the social and medical costs of drug use. Enforcement is presumed to increase prices by increasing traffickers' material costs via interdiction, by increasing their risk of arrest and incarceration (which translates to higher labor costs), by preventing economies of scale, and by imposing other market inefficiencies (Reuter and Kleiman 1986; Caulkins and Reuter 1998). These increased costs, which are imposed on drug retailers (dealers), transporters (smugglers), and manufacturers (domestic and international) are then presumably passed on to consumers, since it may be reasonably assumed that those involved in the drug trade are profit seeking. Successful seizure of drugs or the arrest of dealers may also increase scarcity, increase user search-time, or make producing the drug in question more difficult (Clements 2006; Dobkin

[2]These data were obtained from the Federal Bureau of Investigation's Uniform Crime Reports, which are available online at http://www.fbi.gov/about-us/cjis/ucr.

and Nicosia 2009; Reuter and Kleiman 1986). Additionally, enforcement may affect demand directly by increasing users' expectation of arrest and incarceration.

To my knowledge, there has been no systematic attempt to estimate the effects of different forms of legality on marijuana prices in the United States. Policymakers lack empirical evidence that marijuana prohibition substantially increases prices when compared to quasi-legal markets, and, if such a difference does exist, which policies are responsible for it. Specifically, what are the effects of quasi-legalization, decriminalization, and the legalization of medical marijuana on the price of marijuana? The comparison of these forms of marijuana legality to fully illegal markets is useful because it may identify the effect of retail level enforcement, given some assumptions about the mechanism by which enforcement affects prices, and the degree to which marijuana prohibition is enforced across different states. Estimating the effect of legalization on marijuana prices has been difficult because of insufficiently detailed data on marijuana prices, which is to be expected given its illicit nature. Additionally, since the data used in previous research has been primarily collected from federal and state agencies making undercover purchases there are no data (or significantly less) collected in states that have made marijuana "more" legal (Horowitz 2001).

I exploit a unique source of data, an online database: http://www.priceofweed.com, which contains more than 112,000 user-submitted transactions which record characteristics of marijuana purchases: price, quantity, quality, date, and location. Though these data are biased towards higher quality types of marijuana, they are of considerably higher resolution than anything previously available, they cover a substantial temporal window (September 2010 to June 2013), and they avoid some of the problems with other data sources (Horowitz 2001).[3] I use these data, information on the legal status of marijuana in the continental United States, estimates of demand for marijuana from the National Survey of Drug use and Health (NSDUH), and a spatio-temporal generalized additive model to estimate the

[3]Data have continued to be submitted; June 26, 2013 was when the data scraping program was last run.

effect of quasi-legalization, decriminalization, and the legalization of medical marijuana on the retail price of marijuana. In Chapters 2 and 3 I detail the legal status of marijuana in the continental United States and the expected effects of different levels of legality on drug prices based on theoretical and empirical models of drug pricing. In Chapter 4 I describe my data and statistical model, in Chapter 5 I discuss my results, and in Chapter 6 I conclude with policy recommendations.

Chapter 2

Marijuana Legality

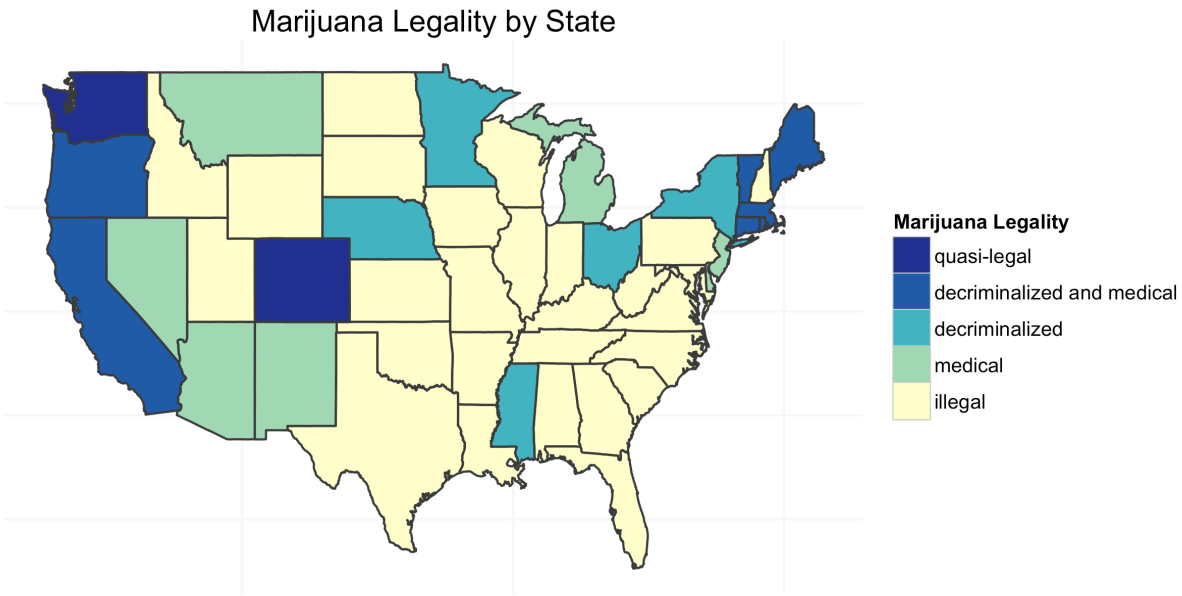

Figure 2.1: Marijuana legality by state, as of July 2013. Data are coded from the National Organization for the Reform of Marijuana Laws (NORML). States are coded as having quasi-legal marijuana if there is no state-imposed penalty associated with possession of some (possibly limited) amount of marijuana. States are coded as having decriminalized marijuana if they do not consider possession (under a certain amount typically) a felony or misdemeanor, though it may be subject to a fine or confiscation. States are coded as having legalized medical marijuana if there is a state-sanctioned way for people that qualify (typically by being approved by a doctor) to legally purchase (or grow) marijuana for personal use.

Marijuana has been illegal in most of the United States since the early 20th century. The *Controlled Substances Act* of 1970, passed under Richard Nixon, classified marijuana as a Schedule I drug, meaning that it has a high potential for abuse and no legitimate medical use. Presidents Reagan, H.W. Bush, Clinton, and W. Bush have similarly passed legislation that reinforces the prohibition regime (Scherlen 2012). Supreme Court cases *United States v. Oakland Marijuana Buyer's Club* (2001) and *Gonzales v. Raich* (2005) have further reinforced the federal government's right to prohibit the possession, sale, and cultivation of marijuana, for both recreational and medical purposes. Despite this, several states have passed laws decriminalizing the possession of marijuana, though typically only in low quantities. As of 2013, 12 states have passed laws removing all criminal penalties for marijuana possession (though it may be subject to a fine or confiscation).[1] A significant number of states have also passed laws allowing for marijuana to be used for medical purposes, which has resulted in the establishment of medical marijuana dispensaries where those prescribed marijuana can make purchases. Some of these states also allow patients with prescriptions to cultivate their own marijuana. Five states have decriminalized and legalized medical marijuana but have not legalized possession, sale, or commercial production for non-medical purposes. Figure 2.1 shows the legal status of marijuana in the United States. As previously mentioned, both Colorado and Washington have established a form of quasi-legality, which involves no penalties at the retail level (civil or criminal). Provisions which allow the sale and production of marijuana are currently in progress and are not yet implemented. If Colorado and Washington allow commercial scale production, the fact that marijuana is still completely prohibited by the federal government would render the establishment of large-scale cultivation risky, since a non-clandestine cultivation operation would be visible and

[1]Information on the legality of marijuana is available from http://norml.org/states. Citizens in these states may have little knowledge of the legal status of marijuana, though it is reasonable to expect knowledge about the legal status of marijuana to be dependent upon whether (and how much) one uses marijuana (MacCoun et al. 2009).

show a flagrant disregard for federal law. The legal regimes in Colorado and Washington are both in flux but it is clear that there is little to no enforcement pressure on consumers and small scale retailers, which is an ideal legal status for the purpose of identifying the effect of retail-level enforcement on price.

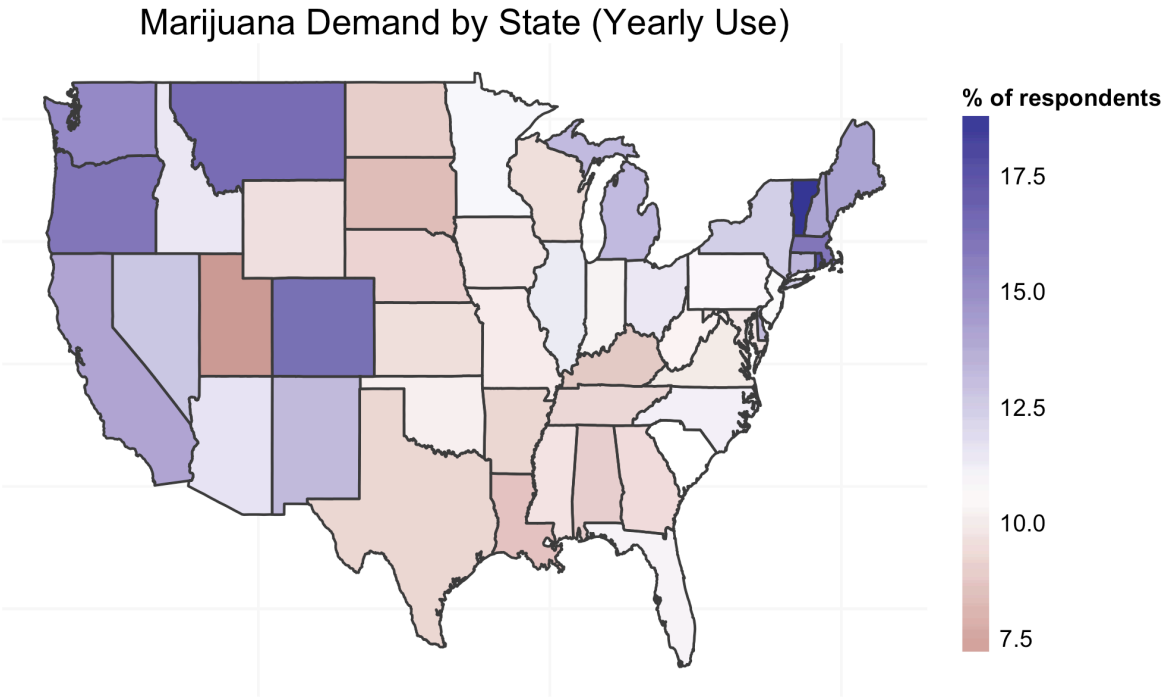

Figure 2.2: Demand is coded from the 2010 and 2011 National Surveys of Drug Use and Health (NSDUH). The data represent the proportion of respondents aged 12 and above that answered that they had used marijuana within the past year. This measure is intended to account for cultural differences in demand between states that could affect both marijuana's legal status and price.

The legal status of marijuana is, of course, not randomly assigned, complicating inference. More permissive marijuana laws have been passed only with public support. Thus, cultural differences in demand may confound estimates of the effect of marijuana legal status on the price of marijuana, since higher aggregate demand would make it more likely for a state to have a more permissive legal regime, as well as affecting price directly. Higher levels of demand could have different effects, depending on the supply schedule, which is likely to

vary substantially across time and space. Figure 2.2 shows the results from the NSDUH, which asks respondents whether they have used marijuana within the past year, allowing me to directly model cultural differences in demand. These estimated levels of demand comport with intuition, since many of the states with high levels of demand are also states that have permissive forms of marijuana legality, and have a "liberal" state ideology.

What is the motivation behind marijuana prohibition? Why is this a public policy issue of importance? The motivations behind the initial push for prohibition are debatable and likely differ substantially from the factors that influence its maintenance. The primary reason for the policy's maintenance is path dependence (Scherlen 2012). Since prohibition has been in place for some time, with a large bureaucratic apparatus supporting it, removing the policy is more difficult than maintaining the status quo. According to the estimate by Miron (2010), in 2008 the U.S. spent around $10.4 billion on marijuana prohibition. This estimate takes into account the expenditure of police resources on arrests, judicial resources expended on prosecutions, and costs associated with incarceration that are explicitly marijuana related.

Enforcement is targeted at all levels of the marijuana supply chain. Retail-level enforcement involves more focus on consumers and those that deal directly with the consumers. Enforcement at the retail level is responsible for the vast majority of prohibition-related spending, since the majority of marijuana prohibition-related spending is devoted to costs associated with arrest and incarceration, and marijuana retailers and consumers greatly outnumber large-scale cultivators and traffickers as well as being much more susceptible to arrest. This is supported by the raw number of arrests for possession versus trafficking as shown in Figure 1.1.

However, it is likely that marijuana users and traffickers have a lower risk of incarceration than do users and traffickers of cocaine, heroin, and methamphetamine (Caulkins and Chandler 2006; Sevigny and Caulkins 2004; Caulkins and Reuter 2010). Despite this, the number of arrests of traffickers and users is still high in absolute terms and costly from a so-

cial and budgetary perspective (Miron 2010). Additionally, even absent a significant period of incarceration associated with arrest for possession or distribution of marijuana, there is evidence to suggest that arrest itself (assuming the arrestee's record is not expunged) results in employment problems; incarceration induces more significant problems (Bushway 1998; Pager 2003).

As previously mentioned, prohibition has had a disproportionate effect on black and Latino communities, who are arrested and incarcerated at significantly higher rates, despite evidence that marijuana consumption is similar amongst whites (Golub, Johnson and Dunlap 2007; Geller and Fagan 2010; Engel, Smith and Cullen 2012; Room et al. 2010; Nguyen and Reuter 2012; Ramchand, Pacula and Iguchi 2006). Given the high recidivism rate of former prisoners in the United States and the lack of economic opportunities available after incarceration, it is likely that the negative effects of prohibition are more consequential than arrest and expenditure figures might suggest. That the negative effects of prohibition are well known increases the importance of accurately evaluating whether or not prohibition has achieved its proximate policy goal: elevated prices. If it is the case that retail-level enforcement substantially raises prices and that demand is elastic enough that a significant number of people are deterred from using marijuana due to its high price then perhaps continuing prohibition is the best policy. If, however, retail-level enforcement does not have substantively large effects, then this is evidence that the current policy has primarily negative social and economic effects, and is a policy issue that should be revisited.

Chapter 3

Markets & Pricing

How is marijuana priced and how does government action affect that price? First, consider drug sources and the mode of distribution. Unlike cocaine and heroin, a significant portion of the marijuana consumed in the United States is grown domestically by individuals for personal consumption and by small, medium, and large-scale distributors (National Drug Intelligence Center 2011). Trafficking from Mexico and Canada also introduces a significant amount of marijuana into the country (National Drug Intelligence Center 2011). Cocaine and heroin are primarily purchased from professional retailers–individuals that derive their primary source of income from the sale of drugs (Caulkins and Pacula 2006). Evidence suggests that marijuana is distributed primarily within social networks, where sale of the drug does not constitute the seller's primary source of income (Caulkins and Pacula 2006; Belackova and Vaccaro 2013). Additionally, markets for cocaine and heroin seem to be relatively hierarchical: drugs are primarily shipped to major cities, and then distributed to smaller municipalities from there rather than shipping drugs to markets along the shortest path, forming an "urban hierarchy" (Caulkins 1995). The empirical implications of this are that cocaine and heroin prices increase as a function of distance from the nearest major city (Caulkins 1995).

It seems unlikely that marijuana price would follow a similar pattern since a significant portion of marijuana is produced domestically, and production in urban areas is undesirable (Caulkins and Bond 2012). Analysis from the National Drug Intelligence Center suggests that marijuana originates from Mexico, entering the U.S. through southern Texas, Arizona, and California, from British Columbia, entering Washington, Michigan, New York, and Vermont, and from domestic sites in Tennessee, Kentucky, West Virginia, and surrounding areas (National Drug Intelligence Center 2011). As Caulkins and Bond (2012) note, California is also a large-scale producer of high quality marijuana, despite the fact that marijuana is not legalized. How smoothly marijuana price varies across space may be a function of smuggling costs as well as how costly lateral transactions are. If smuggling and lateral transaction costs are low, the price of marijuana should vary as a function of demand only. It seems more likely, however, that lateral transaction costs are non-trivial, and vary from place to place. Similarly, smuggling costs are also not likely to be trivial, which would mean that price would increase as a function of the distance from the source and how much enforcement pressure is expected along the smuggling route. Caulkins and Bond (2012), for example, find a price gradient extending from California.

How does prohibition affect prices? Reuter and Kleiman (1986) suggest that there are several mechanisms by which enforcement could affect prices, all of which are driven by the presumed goal of those involved in the drug trade: profits. First, the seizure of drugs while in transit requires that a larger amount be shipped than is desired to be delivered. Seizures close to the source, while often impressive in size, are unlikely to have large effects on retail prices, since replacement costs closer to the source are much lower than at retail (Reuter and Kleiman 1986). Second, as employees of drug trafficking organizations expectations' about their probability of arrest and incarceration go up, the utility of continuing to work for said drug trafficking organization goes down, *ceteris paribus*, relative to the value of an outside option, such as pursing licit employment. Thus, labor costs would go up as enforcement

pressure increases, especially given the relatively low earnings of retail-level dealers relative to other forms of illegal activity (Thompson and Uggen 2012).

Enforcement may, however, have perverse or null effects on drug prices. Tsebelis (1990), for example, suggests that increases in the penalty for a crime may not decrease crime, but may instead affect police behavior, leading to a decrease in enforcement pressure in equilibrium, a claim which generated some controversy (Bianco, Ordeshook and Tsebelis 1990; Tsebelis 1993, 1989). While it may be the case that the amount of marijuana market activity (e.g. sellers entering the market, aggregate demand, etc.) is invariant to the harshness of the statutory penalties imposed for possession or trafficking, it is unlikely that it is invariant to the probability of arrest and incarceration, which is minimal to non-existent in states with permissive legal regimes. Another possible effect that is perverse from the perspective of policymakers is that high levels of enforcement may benefit traffickers that manage to avoid arrest and incarceration. If high levels of enforcement affect supply by deterring potential suppliers from entering the market and demand remains constant or increases, then a shortage would result, which would result in higher profits for the remaining suppliers. The lure of high profits could then result in new or former sellers re-entering, or attempting to re-enter, the market. Lastly, given that enforcement pressure differs by state, this generates opportunities for arbitrage, resulting in marijuana exporting states, such as California.

Increased enforcement pressure may also increase competition between drug trafficking organizations. As enforcement pressure increases, the probability that an employee gets arrested and induced to inform on his former employers increases, requiring, if the organization is to survive, a strong incentive for arrested employees to stay silent. These incentives involve both the threat of violence and additional economic enticements (see the above-mentioned increase in labor costs). The risk of theft by competing organizations or opportunistic individuals is also present. In a licit market, the risk of theft is mitigated by the contract enforcement carried out by the government. In an illicit market, the government does not

guarantee contracts, thus increasing the risk of possibly violent theft, which can increase costs to traffickers by requiring extra security precautions, making lateral transactions more costly, and by further increasing labor costs. These risks raise the cost of labor (dealers) at the retail level, costs which are passed on to users in the form of higher retail prices.

In addition to the increase in risk of product seizure, arrest, and incarceration associated with enforcement, prohibition may increase prices by preventing economies of scale and by imposing other market inefficiencies. Domestic cultivation must be clandestine, which means the scale of cultivation must be smaller than it otherwise could be. If marijuana could be cultivated at a commercial scale, it could be as cheap as other similarly produced goods, such as tobacco or coffee. An example of this is Israel's state controlled medical marijuana farms, which can produce a pound of high quality marijuana at around $0.79 a gram, compared to the average retail per-gram price of high quality marijuana in these data of $12.20 (Caulkins, Kilmer, MacCoun, Pacula and Reuter 2012).[1] Marijuana is packaged and distributed by hand, whereas it could be packaged by machines much more efficiently. The risk of seizure makes investment in such fixed assets unattractive (Clements 2006). In this sense, enforcement induces this inefficient behavior, preventing economies of scale and increasing the retail price of marijuana compared to what it would be, *ceteris paribus*, if prohibition were not in place. The prevention of economies of scale and other market inefficiencies imposed by prohibition are often referred to as the structural consequences of product illegality.

Empirical evidence of the price-raising effects of various enforcement actions has been difficult to attain, particularly for marijuana. Dobkin and Nicosia (2009) have examined the effect of a large shock to the methamphetamine market (two large seizures of methamphetamine precursors in California) on subsequent prices and purity, levels of consumption

[1]There would, of course, be differences in the farm-gate price of marijuana between countries even given similar legal regimes, but Israel's farm-gate price allows for a illustrative comparison between the raw cost of marijuana grown at a large scale and the retail black market price.

(as measured by hospitalizations related to methamphetamine), and various forms of crime, especially property crime. They find that although there was a large short term spike in price and concomitant decrease in purity, the market returned to normal rather quickly, suggesting that even very large enforcement successes have little long-run effect. Caulkins and Reuter (2010) note that, despite increasing enforcement, cocaine and heroin prices have fallen substantially over time, which is paradoxical given the large increase in enforcement-related expenditures. Caulkins and Reuter suggest that drug markets have multiple equilibria and that the static "risks and prices" model of Reuter and Kleiman (1986) (and its derivatives) may be improved by considering the dynamics of market development. Their model shows that enforcement is likely to be most effective at preventing small or emerging drug markets from tipping to a low price, high volume equilibrium rather than tipping a large market back to a low volume, high price equilibrium. This has implications for the likely effects of prohibition on the market for marijuana. Since the marijuana market is the largest of any illicit drugs, worldwide and in the United States, it should be more difficult to tip it back to a low volume equilibrium than it would be for drugs with smaller markets (Caulkins and Reuter 2010). Additionally, since, as previously noted, marijuana is not purchased primarily through professional dealers, but rather through social networks, arresting and incarcerating dealers would be expected to have less of an effect on end-user search time than it would for other drugs, meaning that artificial scarcity is difficult to impose. Additionally, meta-analysis of marijuana's elasticity of demand suggests that it is relatively *inelastic* in absolute terms, and *less* elastic than demand for "harder" drugs such as cocaine and heroin, a counter-intuitive finding (Gallet 2013). This could be because marijuana is highly addictive, which is not supported by the extant literature on the psycho-pharmacology of marijuana, or because marijuana users spend relatively little of their disposable incomes on the drug and therefore are less responsive to changes in price (Gallet 2013; Budney et al. 1998; Haney et al. 1999; Budney et al. 2007).

At the transaction level there are a number of important determinants of price, specifically quantity discounts and differences in quality. Clements (2006) examines quantity discounts for marijuana using panel data on price and quantity (as well as "type") in Australia. The conversion from larger quantities of marijuana to smaller quantities is not costless, in that it implies an increase in risk–a retail-level dealer that has more buyers should be more likely to be caught, since each buyer could conceivably be arrested and induced to turn on his or her dealer. This same logic would apply further up the supply chain as well. Thus, the price per gram should increase as the size of the marijuana package decreases. This is referred to as size elasticity, which is the percent reduction in per gram price for a 1% increase in package size. In addition to size elasticity, there are transportation and packaging costs at each level of the supply chain. Thus, in general, more steps in the supply chain should result in a higher price. Lateral transaction costs may also be affected by these factors. If the cost of splitting a parcel into smaller pieces, repackaging them, and increasing exposure to new customers is greater than the expected value of selling to new customers, arbitrage is unlikely to occur. This would imply that there is a price gradient that extends from the source.

There is evidence to suggest that, at least for cocaine and heroin, purity is not an important predictor of transaction cost at retail (Caulkins 1994; Weatherburn and Lind 1997). Caulkins and Reuter (1998) suggests that this may be due to retail buyers' inability to distinguish levels of purity at the time of the transaction. If this is the case, and quality is assessed visually, then marijuana quality should be a more important determinant of price, since different qualities of marijuana are more readily visually distinguishable than are cocaine or heroin. Although some authors normalize price by Tetrahydrocannabinol (THC), content in a similar way in which you would normalize heroin, cocaine, and methamphetamine prices by purity, it is not clear that THC content normalization is appropriate for marijuana, in the same manner that higher alcohol content does not necessarily imply a higher price per

unit.[2] Grain alcohol, for example, costs less than many designer liquors.

[2]Although THC is commonly considered *the* active ingredient in marijuana, there are a number of other cannabinoids that have been shown to be important, such as Cannabidiol (CBD) (Caulkins, Hawken, Kilmer and Kleiman 2012, 6-9)

Chapter 4

Methods

4.1 Data

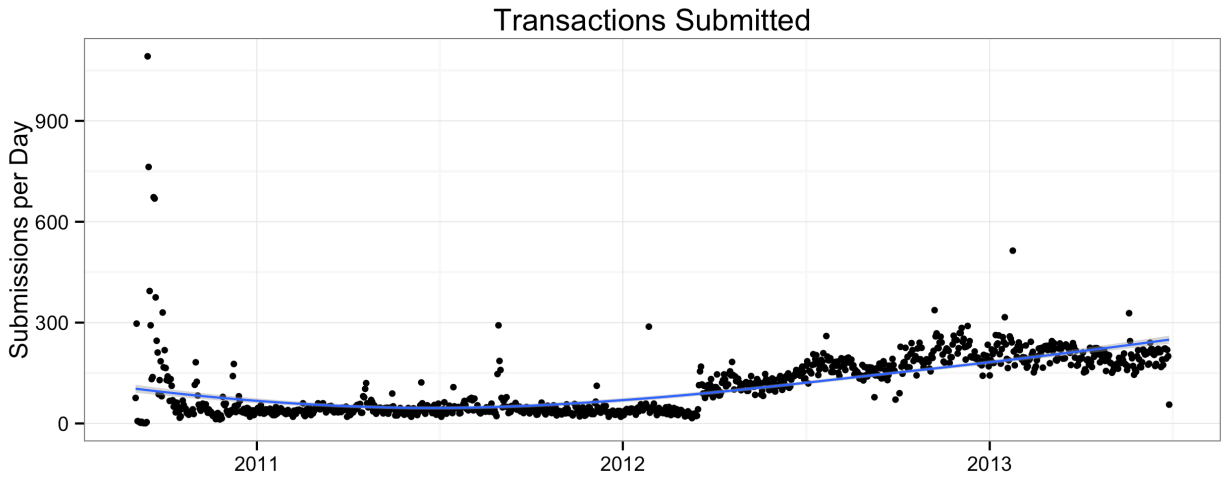

Figure 4.1: The number of transactions submitted by date. There appear to be a few days at the beginning of the covered time period with a very large number of submissions. In general there is an increase in the number of submissions, with a large jump around April 2012. The smooth is a local regression (LOESS) with a span of 1.5.

The data are scraped from an online database of user-submitted marijuana purchases: priceofweed.com.[1] Users submitting transactions record marijuana quality (low, medium

[1]The python script used to obtain these data is available online at http://github.com/zmjones/

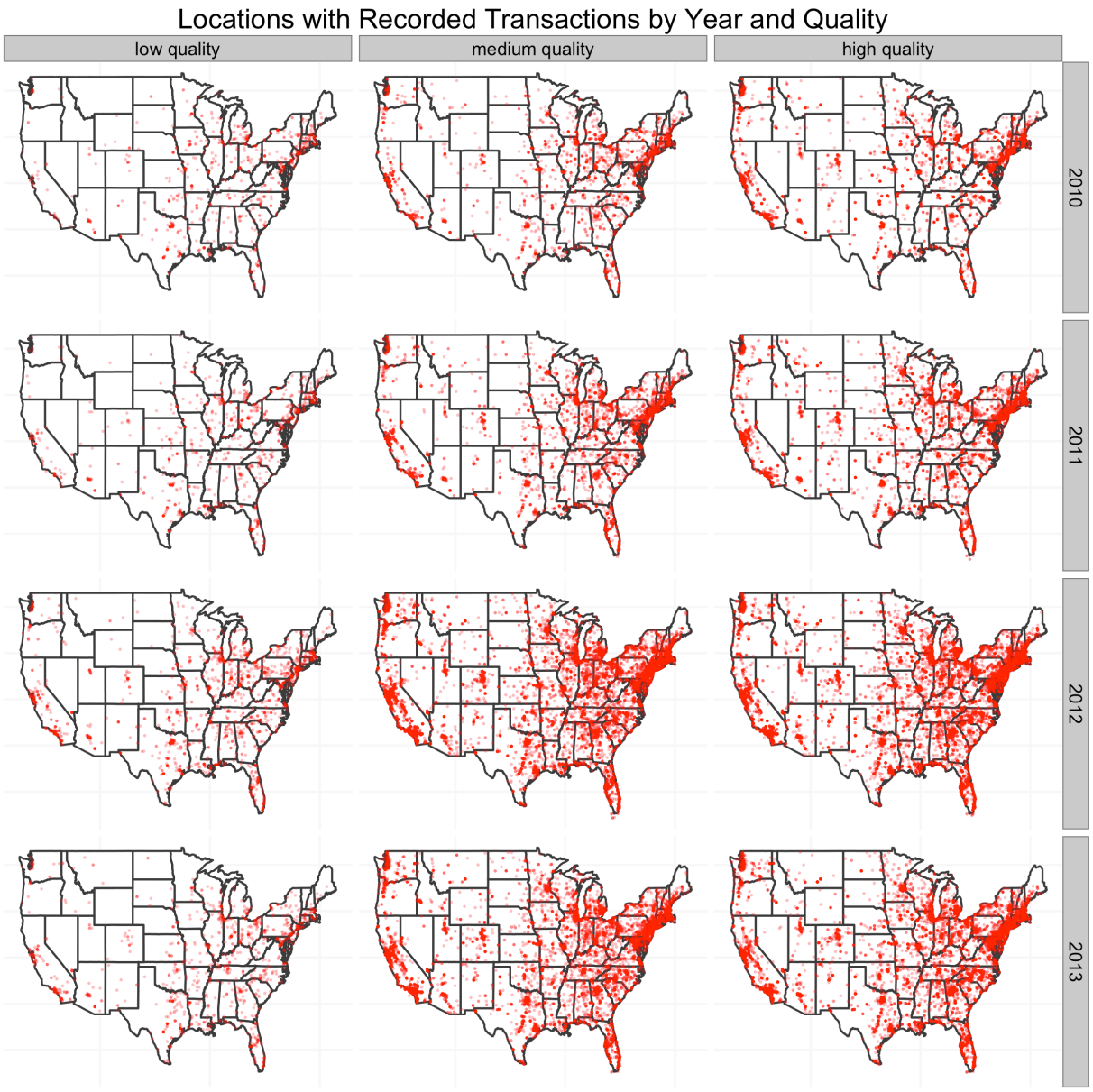

Figure 4.2: Locations in which transactions were recorded between September 2010 and June 2013, shown by year and by quality. Data at the same location are jittered and semi-transparent. Given population density, there appear to be no areas which are grossly under-represented in the data. There are substantially more medium and high quality transactions recorded.

high), quantity purchased (one gram, an eighth of an ounce, five grams, a quarter of an ounce, 10 grams, half an ounce, 20 grams, 25 grams, and an ounce), and price paid. The user may also submit the strain of marijuana purchased but these data are not accessible. Location is automatically coded from by using the user's IP address and the date is recorded automatically as well. The data are recorded from September 2010 to June 2013. Since these data are collected via the web, the amount of traffic the website receives varies over time and results in different numbers of submissions each day. Figure 4.1 shows the number of submitted transactions over time. It could be the case that these data do not have good spatial or temporal coverage. Figure 4.2 shows the locations of transactions by year and marijuana quality. The distribution of transaction locations over (aggregated) time looks reasonable given population density. There is evidence that submitter error or the transaction submission process has resulted in some measurement error. In some cases users report implausible prices, such as $25 for an ounce in a location where an ounce typically costs more than $250, or by recording a price per gram less than $1. In many of these cases a more reasonable price would have been recorded had the user submitted an extra digit, suggesting that at least some of these implausible seeming submissions are input error. It may also be the case that these data are accurate and these transactions record actual outliers. Measurement error is also likely induced by the discrete categories for quantity purchased. Since, as previously noted, packaging marijuana is not costless, it is likely that most marijuana sales are made at a fixed set of discrete quantities. However, the available choices may not reflect the full spectrum of possible package sizes. It is clear, in any case, that these quantities restrict submissions to the retail-level, as the highest quantity purchased that users can submit is one ounce. Lastly, the fact that the recorded strain of the marijuana purchased is not available renders the coding of quality fairly rough. To deal with the aforementioned error in the measurement of price I use a simple rule (for the purposes of

`legalization`.

reproducibility). I drop transactions in which the price per gram is above $35 or below $1. The results are robust to variations in these cut points and including all the recorded data.

To discern whether active enforcement increases marijuana price above what it would be in more legal settings where retail-level enforcement is absent, I code whether the state in which the transaction takes place has quasi-legalized, decriminalized, or allowed medical marijuana, using data from the National Organization for the Reform of Marijuana Laws (NORML), with reference to the text of each state's legislation. If retail-level enforcement increases price by increasing traffickers' probability of arrest and incarceration, then I would expect that decriminalization and quasi-legalization would precipitate a substantial decrease in price, since retail-level enforcement is absent in these legal regimes. If this is the case I also expect that the legalization of medical marijuana gives legal "cover" to recreational users, which would decrease the risk to traffickers as well, also inducing a decrease in price. If, however, retail-level enforcement has little effect on the price of marijuana, then the difference in price per gram of marijuana in illicit or semi-licit markets and the commercial farm-gate price of marijuana is attributable to the structural consequences of prohibition, i.e. the inefficient means of production. If the effects of quasi-legalization, decriminalization, and medical marijuana legalization are substantively small then this provides evidence that prohibition has failed at its presumed goal and that quasi-legalization or decriminalization would be more socially just and economically sound policies.

4.2 Model

The data considered have several features that make the use of common spatial econometric models difficult. As previously mentioned, the transaction data contain the location (municipality, state) and date of each purchase. However, there are many locations that appear at least once in the data, but have relatively few or no recorded transactions on most days. As

would be expected, smaller municipalities in the data have relatively few recorded transactions, whereas major cities in some cases have several hundred in a single day. As a result, treating the data as a time-series of spatial processes is less than ideal, as it would require several steps of data aggregation, making it difficult to include transaction-level predictors of price. Instead I estimate a Generalized Additive Model (GAM) of the form:

$$\log Y_i|\mathbf{T}_i, \mathbf{X}_i, \mathbf{L}_i, Q_i, D_i \sim \mathcal{N}(\alpha_0(\mathbf{L}_i|\mathbf{X}_i) + \alpha_1(Q_i) + \alpha_2(D_i) + \mathbf{T}_i^T\beta + \mathbf{X}_i^T\Gamma + S_i, \nu^2)$$

Y_i is the response variable, price paid per gram of marijuana. The natural logarithm of the dependent variable is used due to positive skew. $\mathbf{T}_i$ is the set of dummy variables which describe marijuana legality within the state in which the transaction takes place and $\mathbf{X}_i$ are binary indicators of marijuana quality, with the associated vector of fixed-effects Γ and β, respectively. α_0 is the intercept, smoothed over the location in time and space, $\mathbf{L}_i$ (latitude, longitude, and time in days), for each level of marijuana quality, X_i.[2] α_1 is the smoothed coefficient on the quantity purchased, Q_i. S_i is a random effect for each state.[3] Lastly, ν^2 is the variance, which is assumed to be constant. The use of a GAM allows me to model the price of marijuana using transaction level variables, avoid aggregation, and smooth over time and space as appropriate.

Quantity purchased is smoothed using univariate cubic regression splines with evenly spaced knots across the variable's range. Latitude, longitude, and time are smoothed using a tensor product of low-rank thin-plate splines, as described in Wood (2003). I also consider models with a smooth over space for each type of marijuana quality with an additive smooth over time and random effects, a model with a smooth over latitude, longitude, and time (but

[2]The specification of the smoothed intercept differs across models, as indicated in Table 5.1.

[3]Random effects are present only in the models indicated in Table 5.1 (the two models furthest to the right).

not separate smooths by quality or random effects), a model without a smooth over latitude and longitude by marijuana quality with an additive smooth over time and no random effects, a model with a smooth over latitude and longitude (but not separate smooths by marijuana quality or random effects), a model with no smooth over space and an additive smooth over time, and a generalized linear model with a log-normal link function. I compare the fit of these models, shown at the bottom of Table 5.1, using the Akaike information criteria (AIC), the restricted maximum likelihood score (REML score), and mean squared error (MSE).[4] Across all metrics the GAM which has a three dimensional smooth over latitude, longitude, and time for each type of marijuana quality performs the best, balancing the number of included parameters against the risk of over-fitting based on the aforementioned loss functions.

[4] MSE is defined as $\frac{1}{N}\sum_{i=1}^{n}(\hat{Y}_i - Y_i)^2$, where Y is the log transformation of the per gram price of marijuana recorded for each transaction.

Chapter 5

Findings

The findings indicate that the effects of quasi-legalization, decriminalization, and medical legalization are substantively small, which suggests that retail-level enforcement has not been effective at substantially raising prices. Thus, the discrepancy between the price of marijuana grown at industrial scale, i.e. the commercial farm-gate price and marijuana purchased in illicit retail markets in the United States is primarily due to the market inefficiencies imposed by prohibition *not* retail-level enforcement. These effects are imposed without the costly enforcement apparatus now in place, since it is relatively easy to prevent large-scale marijuana cultivation. The model with the best fit, labeled "sp-tp-re-qual gam" in Table 5.1, suggests that decriminalization has a small negative effect, around 2%, and that quasi-legalization and the legalization of medical marijuana have indiscernible effects. The more simple, less realistic models suggest somewhat larger effects. The model that smooths over space by marijuana quality but has an additive smooth over time suggests that quasi-legalization is associated with a 2.9% decrease in price, that decriminalization is associated with a 4% decrease in price, and that medical marijuana has a conditional effect when the state in question has also decriminalized possession, resulting in a further 3.7% decrease in price. However, since the fit of the most complex model is noticeably better when compared

Table 5.1: Coefficients from all estimated models. Since the link used in all models is log-normal, the marginal effect can be interpreted as the $\beta * 100$ change in the price per gram for a one unit change in the explanatory variable. Standard errors are in parenthesis. The non-spatial models ("glm" and "no-sp gam") overstate the effects of legality and medical marijuana legality in comparison to the spatial GAMs. All of the smooth terms (amount purchased, longitude, latitude, and time, for all models, are approximately significant, with $p \leq 0.0000001$ for all smooth terms. DF indicates the effective number of parameters estimated by each model, rounded to the nearest integer. AIC is the Akaike information criterion, MSE is the the mean squared error and REML score is the score function.

	glm	non-sp gam	sp gam	sp-qual gam	sp-tp gam	sp-qual-re gam	sp-tp-qual-re gam
low quality	2.272***	1.886***	1.874***	1.925***	1.880***	1.921***	1.935***
	(0.015)	(0.010)	(0.010)	(0.011)	(0.010)	(0.015)	(0.015)
medium quality	2.658***	2.267***	2.254***	2.254***	2.258***	2.248***	2.237***
	(0.011)	(0.003)	(0.004)	(0.004)	(0.004)	(0.011)	(0.012)
high quality	2.892***	2.491***	2.479***	2.478***	2.482***	2.472***	2.462***
	(0.011)	(0.003)	(0.004)	(0.004)	(0.004)	(0.011)	(0.012)
quasi-legal	−0.077***	−0.074***	0.002	−0.010	−0.021	−0.009	−0.015
	(0.014)	(0.014)	(0.015)	(0.015)	(0.019)	(0.018)	(0.022)
decrim.	0.019***	0.032***	−0.054***	−0.050***	−0.071***	−0.021	−0.013
	(0.004)	(0.005)	(0.007)	(0.007)	(0.007)	(0.013)	(0.015)
medical	−0.058***	−0.052***	0.006	0.002	−0.003	0.0002	0.007
	(0.005)	(0.005)	(0.007)	(0.007)	(0.007)	(0.018)	(0.019)
decrim. and medical	−0.152***	−0.125***	−0.029***	−0.030***	−0.003	−0.028	−0.006
	(0.006)	(0.008)	(0.010)	(0.010)	(0.011)	(0.019)	(0.022)
amount purchased	−0.020***						
	(0.0001)						
time	−0.00004***						
	(0.00000)						
demand	−0.004***						
	(0.001)						
N	113,412	113,412	113,412	113,412	113,412	113,412	113,412
DF	11	32	57	101	91	129	216
Adjusted R^2		0.315	0.335	0.342	0.337	0.344	0.353
AIC	677059	672614	669156	668051	668964	667743	666335
MSE	22.92	22.03	21.36	21.13	21.31	21.06	20.77
REML Score		336394.6	334706.7	334199.6	334642.7	334066.9	333442.2

*p < .1; **p < .05; ***p < .01, "sp" = spatial, "tp" = temporal, "qual" = quality, "re" = random effects

to the other models, the data are numerous enough to allow estimation of a very complex model, and it seems substantively plausible that supply changes over time and space within each quality strata, it is likely that parameter estimates from the most complex model are most reliable. Since the origin of domestically grown marijuana, marijuana's legal status, and demand are inter-related and have independent effects on marijuana prices, not accounting for any one of these factors may bias the estimated effects of the legality variables, as can be seen in the non-spatial models, which suggest substantial price decreases in states that have decriminalized and legalized medical marijuana.

The smoothed intercept term $\alpha_0(\mathbf{L_i}|\mathbf{X_i})$ is shown in Figure 5.1. This provides insight into to where different types of marijuana originate as well as how sources have changed over time.[1] The spatial patterning for high quality marijuana comports with the findings of Caulkins and Bond (2012) and suggests that most of the high quality marijuana purchased in the continental United States originates in the Pacific northwest, particularly northern California. The slope of this price gradient appears to have increased over time. Medium quality marijuana is cheapest in the southeast, particularly in Tennessee and Arkansas. This price gradient appears have dissipated substantially over time, however. Low quality marijuana is cheapest by a large margin in southern Texas, suggesting that Mexico is a major supplier. As was the case with medium quality marijuana, the slope of the price gradient has decreased substantially over time, though, as with medium quality marijuana, the area with the highest marginal effect remains the same over time. In general, the relatively steep price gradients suggest that arbitrage is difficult because of high lateral transaction costs, thus providing support for Caulkins and Bond (2012), who suggest that price would increase with distance from the source. To date, there is little evidence that either Colorado or Washington's quasi-legalization has resulted in substantial marijuana exports to neighboring

[1] Due to the limitations of this 2-D medium, I display the spatial smooth over aggregated time without measures of uncertainty.

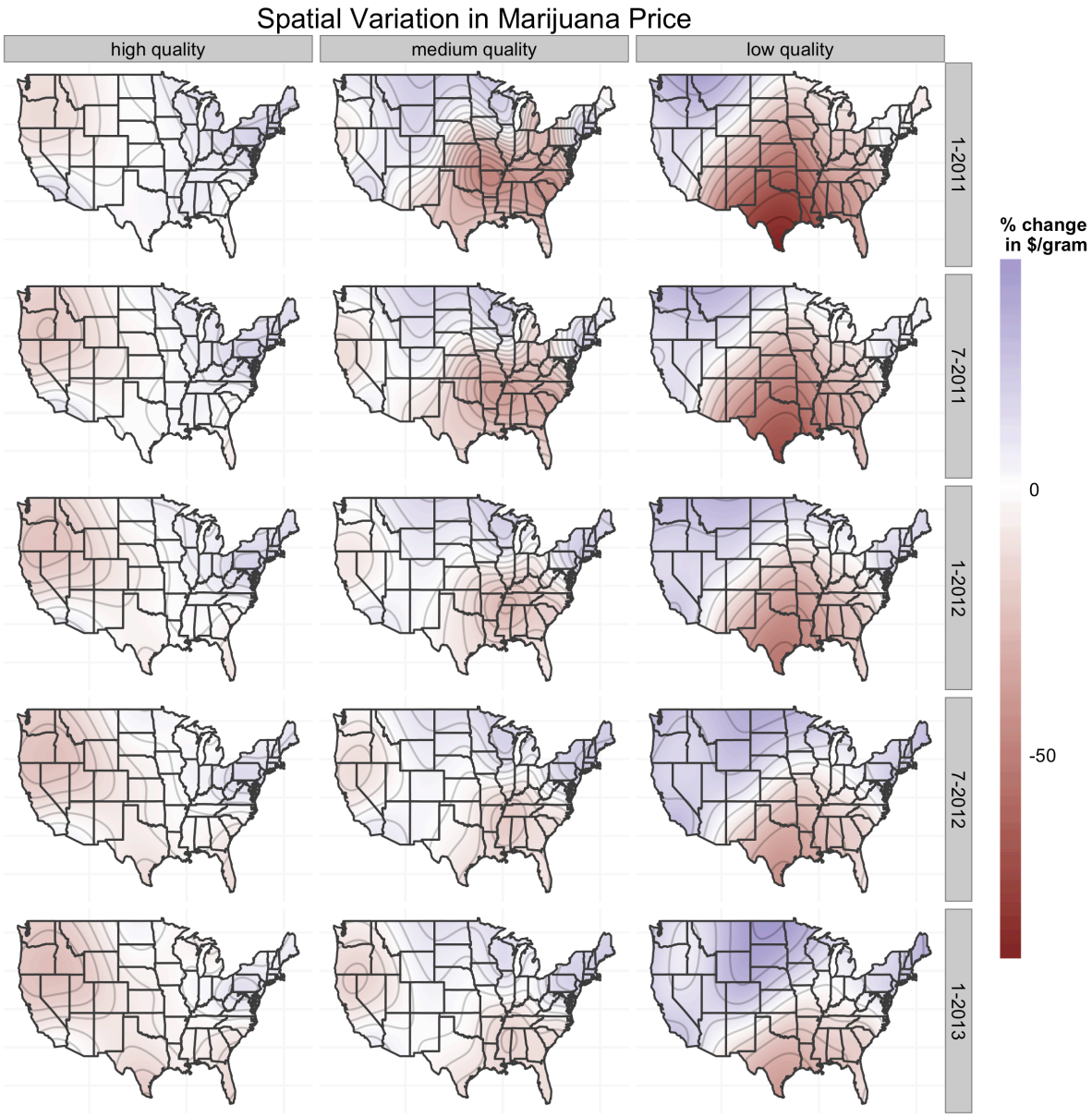

Figure 5.1: Smoothed spatial intercept, by marijuana quality. High quality and medium quality marijuana is on average 247 and 224% more expensive than low quality marijuana, respectively. The gradient goes from black (lowest price) to white (highest price).

states, though, with the legalization of trafficking and growing still in progress, it is too early to determine whether Colorado and Washington will export large quantities of marijuana to states where marijuana remains more illegal. It is, however, clear that marijuana is being exported from California.

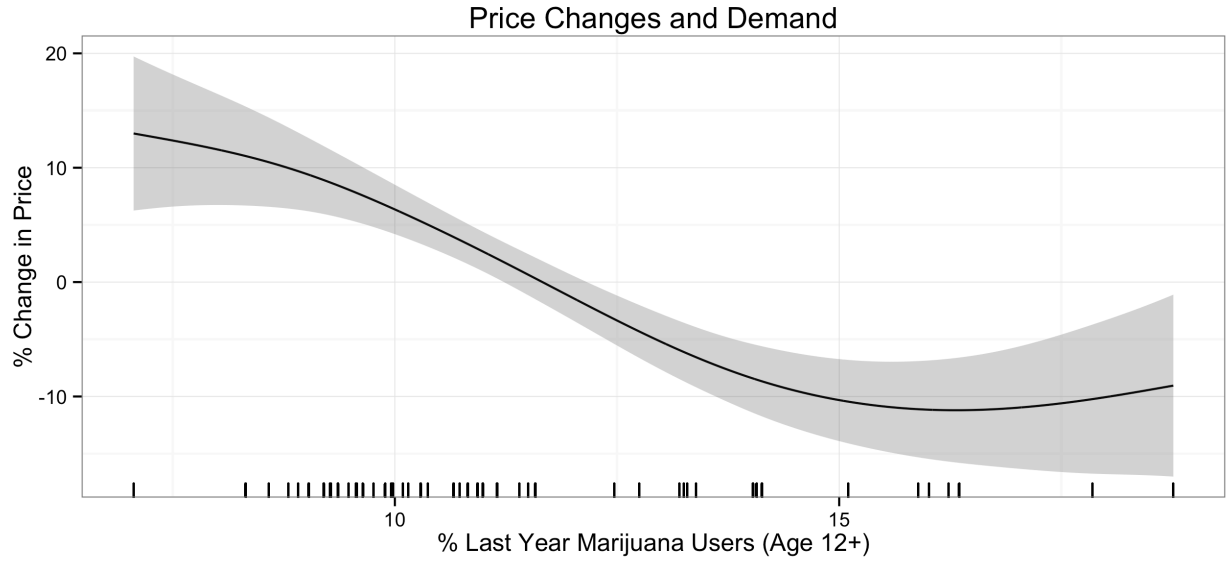

Figure 5.2: The marginal effect of demand, e.g., the percentage of respondents that had used marijuana in the previous year. The tick marks at the bottom of the plot show the distribution of demand by state. The shaded gray area shows a point-wise 95% confidence interval.

State-level differences in demand, as shown in Figure 2.2, may result in state-level variation in price. State-level differences in demand might also affect marijuana's legal status as well, which would bias the estimated effects of legal status. Figure 5.2 shows the marginal effect of demand for marijuana, as measured by the proportion of respondents aged 12 and older that had used marijuana within the last 12 months. The estimated smooth suggests that marijuana is around 10% more expensive in states with the lowest demand for marijuana, and around 10% cheaper in states with the highest demand for marijuana.

It could be the case that the legal status of marijuana in a particular state poorly proxies for the amount of enforcement activity within said state, which could confound the estimated

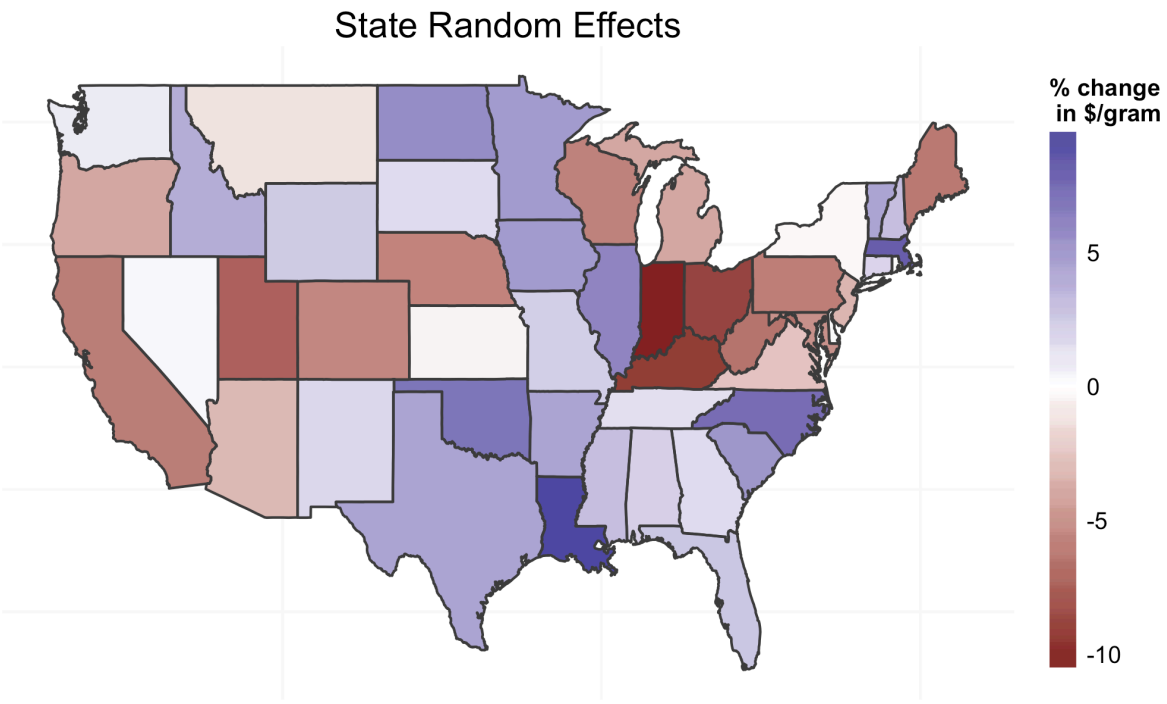

Figure 5.3: Random effects by state. This could represent unobserved heterogeneity in enforcement levels, measurement error in the included variables, or other, ommitted, variables.

effects of the legal status variables. If, for example, marijuana is completely illegal in a state, but the law is not enforced, there is de-facto decriminalization. The unobserved level of enforcement activity could have both supply and demand-side effects. Ideally, a measure of the likelihood of arrest and incarceration for possession of a particular amount of marijuana would be used, however, such data is, as far as I am aware, unavailable.[2] To control for unobserved state-level variation I estimate random-effects for each state, shown in Figure 5.3. There is substantial variation in the random effects, which may reflect unobserved state-level differences in enforcement, measurement error in other variables, or other omitted variables. Southern states appear to slightly more expensive than the model would otherwise predict, along with some states in the Midwest, Massachusetts, and Vermont. Marijuana is cheaper in Indiana, Pennsylvania, and several other states in the northeast than the model would otherwise suggest. If these results reflect unobserved differences in retail-level enforcement, then the estimated effects of marijuana legality, which proxy for the level of enforcement, could be biased in an unknown direction. The size of these random effects suggest that this possible error is not so substantial as to invalidate the conclusion that the substantive effect of retail-level enforcement on price is small.

The size elasticity, i.e. the percent decrease in price for a 1% increase in the quantity purchased is shown in Figure 5.4. There is a decline in price as the package size increases, with the exception of prices at around 14-15 grams, and at one ounce. It could be the case that 14.15 grams and 15 grams reflect the same quantity purchased in most transactions, and that this non-monotonicity is induced by rounding up from 14.15 grams to 15. While there are a few states which consider possession under half an ounce to be a misdemeanor and above half an ounce to be a felony (Virginia, West Virginia, and Tennessee), there is

[2] I estimated all of the models reported in Table 5.1 with a set of binary variables which indicate the severity of penalties for the possession of marijuana. None of these variables had a discernible impact on the fit of the model or the size or certainty with which the other parameters were estimated. However, since this variable is coded from statutory laws, it may still miss heterogeneity in enforcement pressure.

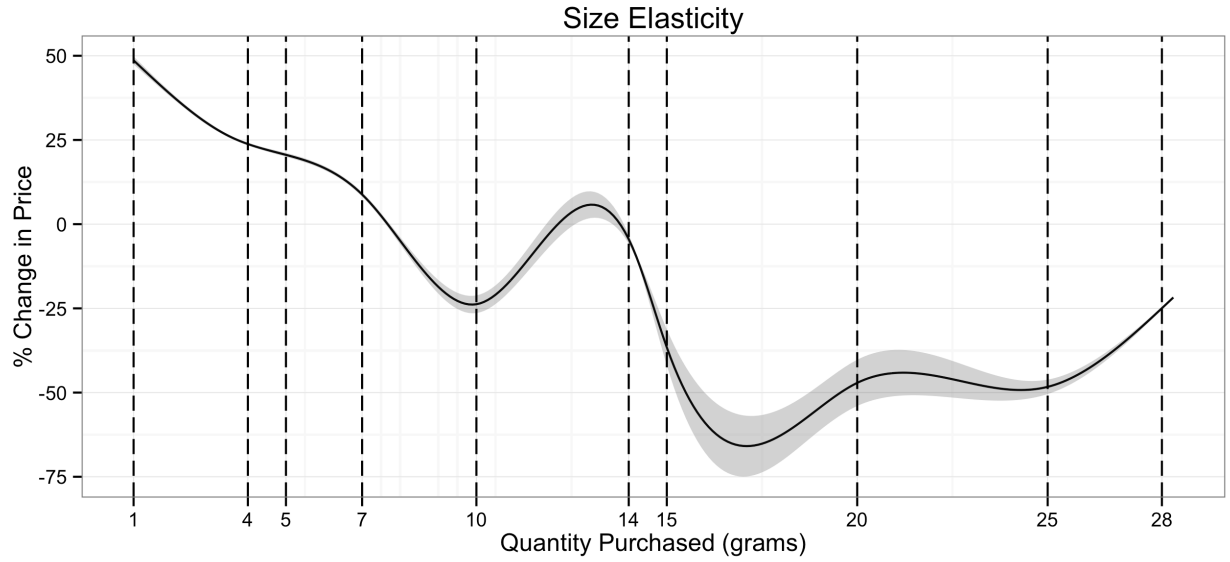

Figure 5.4: The marginal effect of the quantity purchased (in grams) on the natural log of price per gram, smoothed with a cubic regression spline with 3 degrees of freedom. Since the dependent variable is logged, the marginal effect can be interpreted as size elasticity, i.e., a $\beta * 100$ decrease or increase in the price per gram as the quantity purchased increases or decreases, which is shown on the y-axis. Marijuana is commonly purchased at discrete quantities, which are indicated by the dashed lines (1 gram, an eighth of an ounce, 5 grams, a quarter of an ounce, 10 grams, half an ounce, 20 grams, 25 grams, and an ounce.)

no evidence to suggest that this felony cutoff induces this non-monotonicity.[3] The increase in price per gram for amounts in excess of 20 grams could be due to the increased risk incurred by sellers carrying larger amounts of marijuana, since, presumably, sellers (even non-professional sellers) likely serve more than one consumer.

As previously mentioned, meta-analysis of studies which estimate the demand elasticity of marijuana suggest that demand for marijuana is relatively *inelastic*, at least in comparison to cocaine and heroin (Gallet 2013; Jacobi and Sovinsky 2012). This goes against the intuition that more addictive drugs (such as cocaine, heroin and methamphetamine) should be less elastic than "softer" less addictive drugs such as marijuana. This may be due to the fact that marijuana purchases represent less of an individual's income than do purchases of heroin, cocaine, or methamphetamine, reflecting disparities in per unit price as well as addictiveness between marijuana and "harder" drugs such as cocaine and heroin. Specifically, the price elasticity of demand appears to be between -.15 and -.31, meaning that for a 1% increase in price we would expect demand to decrease by between 15 to 31%. Gallet (2013) also finds that price has the greatest impact on the decision to use drugs in the first place (the extensive margin) rather than on the amount demanded (the intensive margin). Combined with the substantively small marginal effects shown in Table 5.1, this suggests that quasi-legalization, decriminalization, and the legalization of medical marijuana would have little effect on the number of marijuana consumers, at least relative to the size of the market, which, according to the NSDUH, includes around 2.6 million Americans.[4] Although the estimates of marijuana expenditure at the federal, state, and local levels are likely unreliable, it seems reasonable to suggest that the cost of driving demand down is extremely high in per capita terms. This leaves aside the intangible social and economic costs incurred by marijuana prohibition.

[3]The inclusion of binary indicators of whether felony cutoffs for possession are non-existent, high, medium, or low did not change the estimated size elasticity or any other parameters in the model.

[4]The 2011 NSDUH is the most recent survey available.

Chapter 6

Conclusion

These findings have substantial implications for public policy, which has heretofore relied on largely speculative estimates of price changes induced by different levels of legalization, or research that has focused on other illicit drugs. The evidence suggests that the marijuana market is not substantially affected by the absence of retail-level enforcement, which in turn suggests that imposing costs on retail-level traffickers and consumers, the most expensive component of the marijuana prohibition regime, has been ineffective at decreasing consumption, a fact further supported by the increase in reported marijuana consumption over time (National Drug Intelligence Center 2011). More passive enforcement which restricts large-scale cultivation but does not involve the aggressive pursuit of retail-level traffickers and consumers is responsible for the majority of the price difference between the commercial price of marijuana (i.e. how much marijuana would cost to produce at scale) and the black market price that we observe. In summary, there is strong evidence to suggest that decriminalization, or the legalization of possession (i.e. quasi-legalization), do not have substantial effects on price. Since demand for marijuana is less responsive to price changes than intuition would suggest and the observed price shifts are small, decriminalization or quasi-legalization are not likely to result in large (in relative terms) changes in consumption.

Despite this, it could be the case that national decriminalization or quasi-legalization would result in interactive effects that would decrease the price of marijuana below the price decreases that have occurred in the wake of state-level decriminalization and quasi-legalization, or have other unknown consequences. However, at this time, there is no current evidence to suggest that this will occur. The effects of commercial legalization (i.e. legalization that allows large-scale marijuana production) remain unknown and inestimable, since no country has fully legalized marijuana. The commercial farm-gate price, i.e. the production cost of marijuana grown at scale, suggests that commercial legalization would result in a dramatic drop in price, which would have an unknown effect on demand. Additionally, it remains unclear whether marijuana consumption is a substitute for other intoxicating substances. Many other substances, including alcohol, are associated with significant amounts of social and individual problems. If marijuana would act as a substitute for more destructive drugs in a legal market, this would strengthen the case for commercial legalization, since even heavy marijuana use is relatively inconsequential, personally and socially, in comparison to heavy use of other (even legal) drugs. Conversely, if marijuana is a complement for other drugs, possibly increasing their consumption, this may outweigh the negative social and economic costs of continued marijuana prohibition. The status quo in most states remains full illegality, with its high social and economic price and paltry results. The evidence presented herein suggests that maintaining the status-quo in these states does more harm than good and that decriminalization or quasi-legalization would be better policy choices.

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