Marijuana pricing structure

and state-level price determinants

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Honors thesis submitted in partial fulfillment of the requirements for Graduation with Distinction in Economics in Trinity College of Duke University.

Duke University

Durham, North Carolina

2014

Acknowledgements

This thesis would not be complete without acknowledging the many people who made it possible. My deepest gratitude to Professor Philip Cook and Professor Mike Munger for their indispensable advice and wisdom, to Professor Michelle Connolly for three semesters of patient guidance, to the students of ECON 495S and 496S for their input, to Professor David Banks for his support, and to Professor Clifford Thies of Shenandoah University for sharing the price data set used in this analysis. Such generosity provides clear evidence that, contrary to popular belief, economists are indeed capable of kind and selfless acts, although further empirical research is required to determine whether such findings are robust to statistical scrutiny.

Abstract

This study uses the PriceofWeed.com data set first examined in Thies (2012) to analyze the price-quantity relationship for marijuana transactions and to determine the effect of various state-level factors on marijuana prices. By applying the cost-based full fixed cost recovery pricing model developed by Britney, Kuzdrall, and Fartuch (1983), this paper finds support for an inverse price-quantity relationship for marijuana rather than a logarithmic or linear relationship. User-rated quality is robust and significant across all models, and price-quantity discount elasticity of -0.220 is observed empirically. An analysis of state-level legal, demand-side, and supply-side determinants of marijuana price demonstrates that medical marijuana has a negative relationship with price, perhaps due to the reduction in risk faced by suppliers when medical marijuana is legalized.

JEL Classification: D40, K42, I18

Keywords: Marijuana; price; quality; transaction size

I. Introduction

Marijuana is the most widely used illegal drug in the United States, and has been since drug usage survey data first became available in the 1970s. In 2011, the National Survey on Drug Use and Health (NSDUH) found more than 30 million Americans reported using marijuana in the past year, and according to a recent Gallup poll, 38 percent of adults in the U.S. admit to having tried marijuana over their lifetimes (Saad, 2013). Although there is no country in the world where marijuana is fully legal and regulated for both production and consumption, research shows that marijuana usage more closely resembles the behavioral pattern for alcohol rather than for other illegal drugs like cocaine or methamphetamines. Most marijuana users are not frequent or heavy users – about a third of those who used marijuana in the past year used it only 10 times or less, and the 20 percent of users who use marijuana on a daily or almost-daily basis account for 80 percent of all marijuana consumed. Even frequent marijuana usage is not a clear indication of abuse or dependency. Only about 30 percent of those who use marijuana at least every other day are medically classified as dependent on the drug, while the corresponding figure for cocaine is 88 percent (Caulkins et al., 2012).[1]

Under U.S. federal law, marijuana is grouped with heroin, LSD, and ecstasy as a Schedule I substance, meaning it has "no currently accepted medical use and a high potential for abuse […] with potentially severe psychological or physical dependence" (U.S. Drug Enforcement Administration, 2013). This strict federal classification of marijuana is at odds not only with the observed marijuana usage patterns described above, but also with some state-level policies on

[1] According to the American Psychiatric Association, dependence is defined as meeting three or more of the following conditions: tolerance, withdrawal, using more than intended, wanting to cut down on use, considerable time spent obtaining and using the substance, interference with work or other important activities, and continued use despite knowledge of adverse consequences (Caulkins et al., 2012; American Psychiatric Association, 2000).

marijuana use.[2] Recent calls for marijuana policy reform in the United States are, in some ways, an attempt to reconcile these ambiguous and conflicting public perceptions of marijuana. Proponents of reform argue that an outright ban creates a black market that encourages criminal activity and cartel trafficking. Lowering the criminal penalties for marijuana will reduce the cost of enforcement and keep otherwise law-abiding citizens from facing criminal charges, which have a high cost both to the individual and to the justice system. Legalization would also subject a large and currently unregulated industry to taxation – Caulkins et al. (2012) estimate that marijuana is among the top 15 cash crops in the U.S., comparable to potatoes or grapes.[3] Opponents of reform fear that by lowering the potential social and legal costs of marijuana usage, the number of users will increase, and marijuana could have a "gateway" effect that may subsequently increase the number of users of more addictive and more harmful drugs.

State-level policies regarding marijuana typically fall into two categories: decriminalization of marijuana usage and legalization of medical marijuana. Decriminalization refers to the elimination of criminal penalties for the first-time possession of small amounts of marijuana (typically less than one ounce) for personal use. Although marijuana possession is still technically illegal under decriminalized policy, the offense is classified as a civil charge rather than a criminal one, and in most cases offenders are required to pay a fine rather than serve jail time. However, it is important to note that state decriminalization laws apply to marijuana users only, not to suppliers, and therefore selling or cultivating marijuana remains a felony. Legalization of medical marijuana means that with doctor approval, it is legal to grow marijuana or purchase it from a state dispensary for

[2] A recent instance of controversy between state and federal marijuana laws was the *Gonzalez v. Raich* Supreme Court case in 2005. Raich was a California resident who grew marijuana for medicinal purposes with the recommendation of a doctor and had his cannabis plants seized and destroyed by federal Drug Enforcement Administration (DEA) agents. Despite California's state law allowing the use of medical marijuana and Raich's claim that his marijuana was intended for intrastate, noncommercial cultivation only, the U.S. Supreme Court upheld the DEA's actions under the Commerce Clause (Cornell Legal Information Institute, 2005).

[3] Rumors that marijuana in the U.S. generates $35 billion in revenue, however, are almost certainly apocryphal and grossly exaggerated (Caulkins et al., 2012).

personal medical purposes. Unlike decriminalization, medical marijuana legalization has the potential to affect supply if in-state growers can benefit from increased ambiguity regarding the sourcing of marijuana that is dispensed legally.[4]

Despite the economic significance of marijuana and the ongoing debate about marijuana policy, much is still unknown about the dynamics of the marijuana market and its response to decriminalization and medical marijuana. This paper seeks to better understand the market for marijuana in a few important ways: first, by investigating the pricing structure of marijuana transactions by quantity, and second, by exploring the impact of state legislation, supply-side, and demand-side factors on marijuana price. Section II provides an overview of the existing literature on marijuana price and policy; sections III and IV present theoretical and empirical models, respectively; section V describes the data used in the analysis; section VI explains the findings of this paper; section VII concludes with a summary of the results and the possible implications of this research.

II. Literature review

Because policymakers are most concerned with the end effect of legislation on social welfare, most studies focus on the impact of marijuana policy on usage rather than on price. In their meta-analysis of the marijuana decriminalization literature, Damrongplasit and Hsiao (2009) find the results of such studies to be mixed and sometimes contradictory. Aside from the typical discrepancies in the data, time period, and population under analysis, one major problem may be omitted variable bias due to the lack of accurate data for the monetary and non-monetary price of marijuana. Clearly, a better understanding of marijuana price and market dynamics is necessary to conduct a more complete analysis of the factors that affect policy results like usage.

[4] Although medical marijuana laws differ by state, California is one frequently-cited example where the legalization of medical marijuana has created a semi-licit gray market for growers, whose products may be considered legal depending on the size of the crop, the town where it was grown, and the inclinations of the judge hearing the case (Samuels, 2009).

One obvious reason the literature on marijuana price is so limited is that accurate price data for a black market good like marijuana is hard to come by. Most studies use data from the System to Retrieve Information from Drug Evidence (STRIDE) compiled by the DEA – however, because the DEA tends to focus on heroin and cocaine trafficking, and because it only publishes price information for 19 cities, many researchers believe that its marijuana price database contains insufficient information to construct reliable price estimates (DeSimone and Farrelly, 2003). To further complicate the issue, STRIDE data represents information from drug seizures and therefore is not representative of all retail transactions, especially given that the market level at which marijuana is seized can greatly affect its valuation. As an alternative price measure, Pacula et al. (2010) use marijuana transaction information from the Arrestee Drug Abuse Monitoring (ADAM) Program. While these data have the advantage of including information about a wide range of transaction dimensions (like indoor or outdoor, regular or occasional dealer, public or private property), the sample is inherently biased because the survey only includes people who have already been arrested. Thies (2012) is the first and only published study to use the PriceofWeed.com data set that will serve as the source of price data for this paper. His research looks at price and drug policy enforcement on a global level based on online and user-reported enforcement ratings to demonstrate that stricter enforcement of marijuana prohibition has a positive impact on prices.

Price data imperfections aside, there are a few facts about the marijuana market that can be known with relative certainty. First, marijuana price varies greatly by location. Because marijuana has a strong and distinctive odor and a low value-to-weight ratio relative to other drugs like cocaine, it is difficult to transport in bulk, and therefore transportation costs are expected to increase with distance from source. Caulkins et al. (2012) estimate that about two-thirds of the marijuana currently consumed in the United States is imported from Mexico, and the majority of the remaining marijuana in the U.S. is cultivated domestically. Spatial variation of drug prices may also follow an "urban hierarchy" in which major cities act as points of import through which drugs diffuse to smaller surrounding communities (Caulkins and Reuter, 1998); larger markets also reduce the search costs for users seeking to purchase marijuana. Pacula et al. (2010) demonstrate this empirically, finding that price is lower in larger markets as measured by county-level population. Another reason for the regional variation in marijuana prices is local differences in attitudes and policies towards marijuana. As mentioned earlier, state laws regarding decriminalization and medical marijuana can considerably change the legal risks faced by users and sellers of marijuana. In their analysis of user risk and price, Pacula et al. (2010) find that decriminalization and medical marijuana both have a positive and significant effect on price, supporting their hypothesis that price changes are affected by changes in user risk rather than seller risk.

Second, transaction quantity and the market level at which the transaction occurs are usually the single largest determinant of marijuana prices. Raw material costs tend to be very low, with extremely high markups between farm gate and final sale (Reuter and Kleiman, 1986; Caulkins and Reuter, 1998). For example, Caulkins et al. (2012) estimate that commercial-grade marijuana sells for $35-40 per pound in Mexico and $200-500 per pound once it crosses the Mexico border, with further markups as marijuana is repackaged at the street level. DeSimone (2006) finds that such markups correspond to an additive rather than a multiplicative model in that price increases between wholesale and retail levels correspond to a fixed amount rather than a fixed percentage of the original price. In addition to transportation and storage costs, sellers at the retail level must be compensated for the non-monetary risks that they incur, such as risk of imprisonment and risk of physical injury. For example, Caulkins and Reuter (1998) estimate 50 percent of the cost of cocaine can be attributed to risk compensation, although that figure is likely to be lower for marijuana because the marijuana market is subject to less internal violence and law enforcement pressure.

Lastly, although several studies have examined the relationship between marijuana and alcohol due to the aforementioned similarities in the usage patterns for these goods, the results are conflicting. Looking at legal enforcement and usage, DiNardo and Lemieux (2001) find that a higher legal minimum drinking age increases the prevalence of marijuana consumption, suggesting a substitute effect. On the other hand, Pacula (1998) estimates individual-level demand equations and finds that the price of beer (as represented by the beer tax) has a negative effect on demand for both alcohol and marijuana, implying a complementary relationship. Several factors could explain these mixed results, including possible endogeneity when "enforcement" or "social climate" variables are used to predict usage, potential omitted variable bias due to the lack of accurate marijuana price data, and different effects across specific time periods, age groups, or cohorts. More recent studies that attempt to address some of these issues have generally found support for a complementary relationship. For example, Williams et al. (2004) find that marijuana price and stricter campus bans on marijuana ("enforcement") both have a negative effect on marijuana and alcohol usage among college students. Nevertheless, any relationship between marijuana and alcohol does have important implications since the inclusion or exclusion of other drugs' prices is a potential source of omitted variable bias that could affect the interpretation of the current marijuana literature (Damrongplasit and Hsiao, 2009).

III. Theoretical model

Price-quantity relationship in marijuana markets

In any market, suppliers can base their pricing decisions either on market conditions or on cost. However, because the flow of information is so restricted in illegal markets, a cost-based pricing model for marijuana seems more likely. More specifically, this paper will assume the full fixed cost recovery pricing model developed by Britney, Kuzdrall, and Fartuch (1983). This type of pricing occurs when a vendor is compelled to recover some fixed cost component per order regardless of the purchase size – in this case, the fixed component (*F*) is to compensate the seller for the monetary and non-monetary risk of engaging in an illegal transaction. There is also a variable cost component (*v*) proportional to quantity (*q*) that is equal to the unit cost of producing and transporting marijuana. Total cost (*TC*) can therefore be represented by:

$$TC = F + v * q \tag{1.1}$$

Marijuana is typically sold in pre-packaged fixed quantities without a scale in order to reduce the time it takes to complete a transaction and therefore minimize the risk of arrest (Pen, 2012). Therefore, the marijuana price schedule is characterized by quantity intervals, and full quantity pricing is in effect such that a quoted price applies to a quantity on the schedule and all quantities below that price for which no price is stated. In order for the model to hold, the intervals must be fairly narrow and the variable cost must be small relative to the total cost, which seems to be the case for marijuana. The interval price schedule can be visually represented as a stepwise function; this is what Britney, Kuzdrall, and Fartuch refer to as a "second degree" price-quantity relationship. Applying a least squares technique can reveal the underlying "first degree" price-quantity relationship, which is represented as follows:

$$P = F + v * q \tag{1.2}$$

Where P is the full quantity price equal to unit price p times quantity q, and $F + v*q$ represents total cost as described above. Dividing both sides by quantity (q), we find:

$$p = F\left(\frac{1}{q}\right) + v \tag{1.3}$$

This implies that the price schedule for marijuana exhibits an inverse relationship between unit price and quantity.

Discount elasticity

Following Caulkins and Padman (1993) and Pen (2012), the proportionate discount for bulk purchases (hereafter referred to as "discount elasticity") illustrates the following relationship between price (*p*) and package size (*q*):

$$logp(q) = \alpha + \beta_1 logq \tag{2.1}$$

Where a is an intercept and β_1 is size elasticity of the unit price. This model assumes a distribution network in which a dealer buys a given quantity of drugs and repackages that quantity into sale units of equal size φ priced at multiple δ of the original price:

$$\varphi * p\left(\frac{q}{\varphi}\right) = \delta * p(q) \tag{2.2}$$

And: [5]

$$p(q) = \alpha * q^{1-ln\delta/ln\varphi} \tag{2.3}$$

Therefore, we can state the discount elasticity as $\beta_1 = 1 - \ln\delta/\ln\varphi$, where φ represents the branching factor and δ is the markup factor. As an illustrative example, let $\varphi = 28$ (the unit conversion from ounces to grams) and $\delta = -0.20$ as found empirically in Pen (2012). Then $\delta = \exp(-(-0.20)\log 28) = 1.95$, indicating a 95 percent price markup for 28 purchases of 1 gram versus 1 purchase of 28 grams. As the absolute value of β_1 increases, so does the markup factor, implying a less competitive market or a market with less availability of information.

IV. Empirical model

Assume that marijuana price (*Y*) is affected by two distinct sets of factors, transaction-specific factors (*Q*) and state-specific factors (*X*), such that:

[5] See Pen (2012) for a more detailed mathematical proof.

$$Y_i = \alpha + \beta_1 Q_{Ti} + \beta_2 Q_{Li} + \sum_{j=1}^{51} \omega_{ij} X_{ij} + u_i$$

Where Q_T represents the quantity of the transaction, Q_L represents the user-rated quality of the marijuana purchased, $X_{1\ldots51}$ represent dummies for all 50 states plus the District of Columbia, and u represents the error term.

State-specific factors can be further broken down into legislative, supply-side, and demand-side factors in the market for marijuana. Legislative factors (L) represent laws that regulate marijuana usage and distribution, like decriminalization and medical marijuana. Demand-side factors (D) may include risk, enforcement, and other considerations for recreational users of marijuana. Supply-side factors (S) may include marijuana cultivation and the enforcement of criminal sanctions against producers and sellers of marijuana. Additional control variables (Z) account for variation in demographics and income between states.

$$Y_i = \alpha + \beta_1 Q_{Ti} + \beta_2 Q_{Li} + \sum_{j=1}^{k} \rho_{ij} L_{ij} + \sum_{j=1}^{m} \gamma_{ij} D_{ij} + \sum_{j=1}^{n} \varphi_{ij} S_{ij} + \sum_{j=1}^{p} \vartheta_{ij} Z_{ij} + u_i$$

V. Data

Price

The price data used in this study are from PriceofWeed.com, an online website and forum that compiles user-submitted price and transaction data for marijuana purchases around the world. Each data point includes transaction information about price, quantity, location, date, and user-rated quality (low, medium, or high). These data are from September 2010 through June 2011, and were obtained courtesy of Professor Clifford Thies of Shenandoah University.

Given the general paucity of accurate marijuana price data, the data used in this analysis have a few significant advantages over other price data sets. First, because price reflects transaction price rather than price from drug seizures, these data do not suffer from the same sampling bias that affects other commonly-used data like STRIDE. Second, quality information reflects user-rated quality rather than potency. This is an important distinction because marijuana usage is a subjective experience that can be affected by user preference for certain strains of marijuana,[6] and therefore potency may not be a complete measure of quality as it corresponds to price.

Although it is common for marijuana transactions in the United States to be conducted in ounces, all volumes in this study have been converted to grams for the sake of unit consistency. Since "one ounce" and "an eighth ounce" are by far the most common volume of transaction, the data are heavily clustered around certain transaction sizes. In addition, the self-reported nature of the data is likely the cause of some inaccuracy, as can be seen in the wide range and high standard deviation for both the full global sample and the U.S. sample (Table 1).

Table 1: Summary of price data

Price per gram	N	Mean	SD
Global sample	25,579	10.89	9.17
U.S. sample	20,208	11.32	8.39
U.S. sample (trimmed)	17,061	11.17	4.66
Price per gram by quality (trimmed sample)			
Low	1,073	5.16	3.11
Medium	5,591	8.77	4.65
High	10,397	13.09	3.54
Price per gram by transaction quantity (trimmed sample)			
An eighth	6,237	14.41	3.42
5 grams	792	9.44	4.09
A quarter	2,245	11.02	4.79
10 grams	105	8.29	4.02
A half	1,163	9.41	4.52
15 grams	36	8.44	4.12
20 grams	17	7.85	4.32
25 grams	6	9.17	4.88
An ounce	6,460	8.96	4.17

[6] For example, there are two major species of marijuana, *Cannabis indica* and *Cannabis sativa*, that each induces a different type of user experience independent of potency – the former causes a "body high" while the latter is associated with more of a "mental high." Most strains of marijuana are a hybrid cross of these two types of plants, with a corresponding blend of their psychoactive effects.

To improve the accuracy of the analysis, a 10 percent upper and lower trim has been applied to the data for each state, resulting in a loss of about 3,000 data points but narrowing the range and reducing the variance of the final data set.

State marijuana policies

This paper will formally define state marijuana policies as follows. Decriminalized states are those that impose no criminal penalties for first-time possession of small amounts of marijuana for personal use.[7] Medical marijuana states are those that make it legal to grow marijuana or purchase it from a state dispensary for personal medical purposes with doctor approval in the form of a letter or license.

Some debate remains as to whether decriminalization as a binary is meaningful as a legislative distinction, as has been traditionally assumed in the literature. Pacula et al. (2003) examine the validity of the "decriminalized state" dummy compared to a finer gradation of state penalties regarding fines and jail time. They find that the wide variation in penalties even among non-decriminalized states demonstrates that decriminalized states are not uniquely identifiable based on statutory law alone, but formal decriminalization remains statistically important, perhaps because it reflects social acceptance of marijuana or because it indicates greater public knowledge of reduced penalties associated with marijuana possession. To test this relationship, this paper uses dummies for decriminalization and medical marijuana states, as well as state-level variables indicating the maximum fine and maximum jail time for possession of a small amount of marijuana for personal use (half ounce or less). These variables are based on data from the website for the National Organization for the Reform of Marijuana Laws (NORML), a nonprofit lobbying organization.[8]

[7] Recall that even in states that have decriminalized marijuana possession, the production, sale, and distribution of marijuana remain felonies under both state and federal law.

[8] Unfortunately, NORML only provides current information on marijuana laws, not historic information. Therefore, these variables reflect state policies as of April 2014 and are not contemporaneous with the rest of the data, which is

Demand-side factors

To distinguish between *de jure* and *de facto* state marijuana policies, a user enforcement index has been created via principal components analysis to reflect state-specific enforcement levels for recreational users. The index is based on the probability of arrest for recreational drug possession (represented by number of user arrests divided by number of users), the number of marijuana possession arrests per capita, and respondents per capita who perceive "great risk" associated with marijuana use (see Appendix for factor loadings). These three variables capture 63.04 percent of the underlying variance, and their eigenvectors are used to construct the index variable. Because all of the eigenvectors are positive, a higher enforcement index number indicates a stricter degree of enforcement, although the index value itself is not meaningful except as a relative point of comparison between states. Arrest data comes from the FBI Crime Reporting Program 2010 report. Risk perception data is taken from the 2010-2011 National Survey on Drug Use and Health (NSDUH), an annual survey of about 70,000 respondents nationally sponsored by the U.S. Department of Health and Human Services. The NSDUH provides estimates of tobacco, alcohol, and illegal drug usage, and it is published bi-annually at the state level.

Although this study aims to examine marijuana price rather than demand, the excise tax on beer is included as a measure of the relationship between marijuana and alcohol in order to eliminate any potential omitted variable bias from a substitute or complement effect. Past studies also show that the effect of price on demand for alcohol similar regardless of whether price is represented by beer prices, the tax on beer, or a weighted price index of beer, wine, and spirits (Pacula, 1998). Because beer prices vary greatly by brand, quantity purchased, and venue of purchase, it is difficult

from 2010-2011. While there have certainly been major policy changes in the interim period, most notably the full legalization of marijuana in Washington state and Colorado and decriminalization in Connecticut, these changes reflect gradual shifts in rather than unexpected reversals of public attitude towards marijuana. Therefore, the direction of these variables is expected to remain consistent. Empirical results excluding the Washington, Colorado, and Connecticut data can be found in the Appendix; they are largely consistent with the full model.

to obtain accurate local measurements for beer prices. Furthermore, Grossman et al. (1987) find that the tax on beer is fully passed on to the end consumer, lending further validity to the use of beer tax as a measure of relative alcohol prices by state. Beer excise tax is obtained from the Distilled Spirits Council of the United State and The Tax Foundation, an independent tax research think tank based in Washington, DC.

Supply-side factors

A final set of explanatory variables reflects the production and sale of marijuana by state. Marijuana sales arrests is used to represent legal enforcement against suppliers, stated on a "per user" basis to adjust for the size of the state marijuana market. Sales arrest data is taken from the FBI Crime Reporting Program 2011 and the usage data is based on the NSDUH survey for the number of people over the age of 12 who report having used marijuana in the past year. Note that this usage measure represents total number of users and does not reflect frequency of usage.

Two variables are included to reflect marijuana imports and domestic production. To represent the transportation and smuggling costs of imported marijuana, distance from Mexico is a dummy (1-7) that groups states by distance from Mexico using a 300-mile radius such that 1 represents states within 300 miles of Mexico, 2 represents states within a 300-600 mile radius, etc.[9] To represent domestic cultivation, the cultivation state dummy is set to equal 1 if more than 100,000 cultivated marijuana plants (both indoor and outdoor) were seized in the state in 2010 based on public data from the DEA. Although 100,000 is an arbitrary cutoff, this variable is meant to indicate whether or not a state is a major domestic producer of marijuana. Nine states qualify under this specification: California, Kentucky, North Carolina, Ohio, Oregon, Tennessee, Utah, Washington, and West Virginia. Because this variable is constructed from drug seizures rather than total amount cultivated, there may be a bias towards regions and climates where marijuana is commonly grown

[9] Based on the seven-stage mileage strata proposed by Cunningham et al., 2010.

outdoors and therefore more visible to law enforcement officials. It is worth keeping in mind that due to advances in hydroponic growing techniques, marijuana cultivated indoors domestically tends to be of higher potency than marijuana cultivated outdoors or imported from Mexico (10-18 percent THC content for indoor-cultivated sinsemilla versus 4-6 percent for commercial-grade marijuana).[10] However, because the quality measure associated with the PriceofWeed.com data set is a self-reported subjective measure rather than an indication of THC content, this distinction cannot be directly accounted for in the analysis.

Control variables

Several additional variables for racial composition and median income are included to account for demographic differences between states. Percent urban population is used to proxy the size of the marijuana market within each state. All control variables are taken from the 2010 and 2011 U.S. Census data.

VI. Results

Price-quantity relationship

The first two models (Table 2) test whether an inverse relationship between price and quantity exists. Quality and state dummies are included as controls (coefficients for state dummies not shown).

[10] Delta-9-tetrahydrocannabinol (THC) is the main psychoactive ingredient in marijuana, and percent THC content is a measure of potency. Because unpollinated plants have higher cannabinoid content due to the greater amount of resin that their flowers produce, sinsemilla from unpollinated female plants is much more potent than commercial-grade marijuana from pollinated plants (Caulkins et al., 2012).

Table 2: Linear v. inverse price-quantity relationship		
	Price per g	
	(1a)	**(1b)**
Transaction size	-0.159***	-
	(0.00213)	-
Inverse transaction size	-	18.22***
	-	(0.214)
Medium quality dummy	-4.365***	-4.190***
	(0.0607)	(0.0585)
Low quality dummy	-7.506***	-7.279***
	(0.0914)	(0.0886)
State dummies	Y	Y
R^2	0.5182	0.5492
N	17,061	17,061
MSE	3.2392	3.1333
Robust standard errors in parentheses		
*** p<0.01, ** p<0.05, * p<0.1		

First, it is clear that transaction characteristics like quantity and quality are highly significant in the regression. Even though a lot of information about other dimensions of the transaction was not available (e.g. whether the sale was conducted indoors or outdoors, frequent versus occasional customer, etc.), just these two characteristics plus the state dummies result in fairly high R^2 values that explain a large amount of the variance. Quality has a positive sign and a relatively large coefficient that remains consistent across all of the models. A simple interpretation is that high-quality marijuana would cost on average at least $4 more per gram than medium-quality marijuana and at least $7 more than low-quality marijuana. Given that the mean price per gram in the sample is $11.17, this implies quite a substantial markup for quality, but this is roughly in line with the summary statistics for price by quality seen in Table 1, where average price for high-quality marijuana is $3.61 and $7.93 more than the average price for medium- and low-quality, respectively.

Notice that quality discounts seem to exhibit a greater tendency towards linearity than quantity discounts.

To test the relationship between price and quantity, Box-Cox tests were performed on both the dependent and independent variables to determine the best-fit transformation.[11] A left-hand-side Box-Cox on the price variable on price gives a parameter theta (θ) of 0.966, indicating a linear fit for the dependent variable in this model. A right-hand-side Box-Cox on quantity, holding other explanatory variables constant, produces a parameter lambda (λ) of -1.198, which further supports the inverse price-quantity relationship. Finally, a two-sided joint Box-Cox allowing different parameters gives θ = 0.983 and λ = -1.196, supporting both of the one-sided models and soundly rejecting any of the contemporaneous $\theta = \lambda$ transformations. As a note of caution, while these results are highly encouraging, the Box-Cox test is not robust to heteroskedasticity and therefore further analysis is required to better substantiate these findings. Nevertheless, it can be seen in Table 2 that the inverse transformation does give a higher R^2 (0.5492) and lower root mean squared error (3.1333) than the linear regression (0.5182 and 3.2392, respectively), indicating that the inverse transformation has more predictive and explanatory power than the linear model and therefore is likely to provide a better fit for the data.

Discount elasticity

The second set of models represents a log-log relationship between price and transaction size as a measure of elasticity. 2a uses model 1 with state dummies, while 2b includes the full model with state-level variables (Table 3).

[11] Box-Cox transformations are used to correct for normality, and can also test different transformations of a variable x in order to determine the best fit model. Algebraically, the relationship between x and the tested parameter λ is

$$x'_\lambda = \frac{x^\lambda - 1}{\lambda}$$

Therefore, λ = 1 would indicate an inverse transformation, λ = 0 would indicate a log transformation, and λ = 1 would indicate a linear transformation or no transformation. The parameter for a right-hand-side (independent variable) transformation is represented by λ, and the parameter for a left-hand-side (dependent variable) transformation is represented by θ. A two-sided Box-Cox tests for transformations that fit both sides contemporaneously.

Table 3: Discount elasticity		
	Log price per g	
	(2a)	**(2b)**
Log transaction size	-0.220***	-0.222***
	(0.00304)	(0.00323)
Medium quality dummy	-0.497***	-0.500***
	(0.00708)	(0.00747)
Low quality dummy	-0.934***	-0.940***
	(0.0130)	(0.0137)
Maximum fine (0.5 oz possession)	-	-1.65e-05***
	-	(5.07e-06)
Maximum jail time (0.5 oz possession)	-	2.71e-05
	-	(3.32e-05)
Medical marijuana (Y=1)	-	-0.0167**
	-	(0.00842)
User enforcement index	-	0.807***
	-	(0.159)
Beer excise tax	-	-0.0549***
	-	(0.0196)
Distance from Mexico	-	0.0524***
	-	(0.00260)
Cultivation state dummy	-	-0.0506***
	-	(0.00942)
Seller enforcement index	-	4.894***
	-	(1.755)
State dummies	Y	N
R^2	0.5280	0.5254
N	17,061	15,242
Robust standard errors in parentheses		
*** p<0.01, ** p<0.05, * p<0.1		

A discount elasticity of about -0.220 seems to be consistent between price and quantity in both of the log-log models (2a and 2b). In other words, a 2.2 percent increase in quantity corresponds to a 10 percent decrease in price. This matches the findings of Pen (2012), which found a similar discount elasticity of -0.204 for marijuana prices in Australia. Table 4 presents a set of predicted markup values using a discount elasticity of -0.220 compared to the empirically observed markups from the price data set.

Table 4: Predicted v. empirical markup values

	N	Average price per oz	Actual markup	Predicted markup
An eighth	6,237	400.88	57.76%	58.01%
A quarter	2,245	312.52	22.99%	35.66%
A half	1,163	266.90	5.03%	16.47%
An ounce	6,460	254.11	0.00%	0.00%

The predicted markup for an eighth (58.01 percent) almost perfectly matches the observed markup in the data set (57.76 percent). However, the predicted markups for a quarter and a half ounce are about 1.5 and 3 times the observed markups, suggesting that a transaction quantity-markup relationship other than the one proposed in the theoretical framework might be a better fit for the observed prices. Data skewness may be partially responsible as well, given that the number of observations for a quarter and a half ounce is much lower than for an eighth or one ounce.

State-level explanatory factors

The final set of regressions drops the state dummies and approximates state-level marijuana market characteristics by including various supply- and demand-side factors, building a full model that captures the impact of state legislation, enforcement, and culture on marijuana prices. The first model (3a) includes formal marijuana legislation only, with dummies for whether a state has decriminalized marijuana usage and legalized medical marijuana. In the second model (3b), maximum fine and maximum jail time for marijuana possession for recreational use are included to test whether decriminalization status is a meaningful distinction. The third model (3c) adds to the previous one with explanatory variables that capture demand-side factors, including beer excise tax and user enforcement index. The full model (3d) adds explanatory variables that capture supply-side factors, including marijuana cultivation, distance from Mexico, and seller enforcement.

		Price per g			
		(3a)	(3b)	(3c)	(3d)
	Inverse transaction size	18.41***	18.40***	18.29***	18.14***
		(0.221)	(0.221)	(0.232)	(0.228)
	Medium quality dummy	-4.216***	-4.212***	-4.260***	-4.234***
		(0.0595)	(0.0594)	(0.0622)	(0.0617)
	Low quality dummy	-7.230***	-7.230***	-7.295***	-7.239***
		(0.0880)	(0.0879)	(0.0924)	(0.0908)
Legal	Decriminalization (Y=1)	-0.303***	-	-	-
		(0.0591)	-	-	-
	Maximum fine (0.5 oz possession)	-	-0.000121***	-3.90e-05	-7.25e-05*
		-	(3.19e-05)	(3.48e-05)	(3.99e-05)
	Maximum jail time (0.5 oz possession)	-	0.00164***	0.000976***	0.000835***
		-	(0.000196)	(0.000230)	(0.000246)
	Medical marijuana (Y=1)	-1.338***	-1.390***	-1.273***	-0.703***
		(0.0686)	(0.0684)	(0.0694)	(0.0725)
Demand	User enforcement index	-	-	8.873***	13.92***
		-	-	(1.335)	(1.420)
	Beer excise tax	-	-	-1.200***	-0.513***
		-	-	(0.155)	(0.168)
Supply	Distance from Mexico	-	-	-	0.388***
		-	-	-	(0.0212)
	Cultivation state dummy	-	-	-	-0.742***
		-	-	-	(0.0801)
	Sales arrests per user, 2011	-	-	-	55.48***
		-	-	-	(14.88)
	R^2	0.5155	0.5167	0.5239	0.5416
	N	17,060	17,060	15,364	15,241

Table 5: State-level explanatory factors

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Medical marijuana is highly significant with a consistently negative coefficient across all of the models. Note that the coefficient for medical marijuana decreases by about one-fourth when supply-side factors are included in the regression; cultivation factors and seller enforcement may be absorbing some of the change in risk that marijuana producers face. This supports the idea that in states where medical marijuana is legalized, legal ambiguity regarding the sourcing of medical marijuana creates a gray market that increases the *de facto* legitimacy of marijuana producers. This could decrease the level of risk that sellers face, thereby lowering marijuana prices.

While decriminalization is significant in 3a, the coefficient for decriminalization is notably smaller than the coefficient for medical marijuana (although still negative). Interestingly, decriminalization becomes insignificant when maximum fine and maximum jail time are added, although the latter two variables are both significant at $p < 0.01$. A Wald test demonstrates that decriminalization does not improve the fit of the model with the inclusion of formal legal penalties (reject at $Prob > F = 0.5404$), and therefore the decriminalization dummy is dropped from the model in 2b. This supports the findings of Pacula et al. (2003) that the wide variation in penalties by state renders decriminalization status less meaningful in practice. However, while maximum fine and maximum jail time are significant, the coefficients are too small to have a practical interpretation, and maximum fine has an unexpectedly negative relationship with price. One explanation may be that maximum penalties are not always fully enforced, and actual penalties may be more lenient; detailed information on expected fines and jail times rather than statutory maximums would be helpful in this regard, but is not readily available. All of the other variables remain highly significant with little change in coefficient between 3a and 3b, confirming the robustness of this basic model.

User enforcement is positive and significant at the 0.01 level, which fits the intuition that stricter enforcement of marijuana policy increases price. Both domestic and imported supply of marijuana, as represented by distance from Mexico and the cultivation state dummy, are significant as well, with the expected signs – price increases with distance from the cultivation source. The seller enforcement variable, marijuana sales arrests, is positive and significant, with a large coefficient due to the relative infrequency of seller arrests compared to user arrests. Notice that the user enforcement index remains significant and increases with the inclusion of supply-side factors, which seems to indicate that demand-side and supply-side enforcement capture separate policy dimensions and do not cancel each other out.

If beer excise tax is a proxy for beer prices, then the third model (3c) indicates that marijuana has a lower price per gram in states where beer is more expensive. While it is not within the scope of this analysis to determine the precise nature of the relationship between marijuana and alcohol, the beer excise tax coefficient does allow for some speculation. If the marijuana price decrease is more driven by a change in demand than in supply, then equilibrium quantity will decrease and the goods will be complementary; vice versa if the goods are substitutes. Therefore, the reduction in magnitude of the beer tax coefficient when supply-side factors are included suggests more support for a substitute relationship, but given the limitations of this analysis it is not possible to draw a definitive conclusion.

VII. Conclusion

This paper uses the PriceofWeed.com data set first studied in Thies (2012) to determine the price-quantity relationship for marijuana transactions and to examine the effect of various state-level factors on marijuana prices. Applying the cost-based full fixed cost recovery pricing model developed by Britney, Kuzdrall, and Fartuch (1983), the analysis finds support for an inverse price-quantity relationship rather than a logarithmic or linear relationship. A price-quantity discount elasticity of -0.220 is observed empirically, which matches the discount elasticity of -0.200 found in Pen (2012). This indicates an ounce-to-eighth markup value of 58 percent, which almost exactly corresponds to the actual markup observed in the data, although the markup values for a quarter and half ounce are not as closely matched.

An analysis of state-level legal, demand-side, and supply-side price determinants demonstrates that the coefficients for the quality dummies are very robust across all of the models, with a medium-quality discount of about $4 and a low-quality discount of about $7 on a per-gram basis. Decriminalization is insignificant with the inclusion of actual legal penalties like maximum fine and maximum jail time, supporting the findings of Pacula et al. (2003) that decriminalization may not be meaningful as a binary dummy. Medical marijuana has a negative relationship with price and is highly significant across all of the models, although the coefficient decreases by about half with the inclusion of supply-side factors, implying that any price change due to medical marijuana is affected more by changes in supply than by changes in demand. All of the demand- and supply-side variables are highly significant and display the expected signs, confirming the fundamental intuition behind this price model.

This paper expands on the current literature in a few notable ways. First, it explores a relatively new marijuana price data set that offers certain advantages over more well-studied data sets like STRIDE and ADAM. Since so few studies to date have looked at the pricing of marijuana transactions due to the lack of availability of accurate price data at the retail level, the unique nature of the PriceofWeed.com data set opens many possibilities for further research, especially regarding seldom-available transaction characteristics like user-reported quality. Second, this paper proposes a new framework for the price-quantity relationship for marijuana transactions, which has broad implications for policymakers aiming to size the marijuana market and to price marijuana in a way that maximizes tax revenue in states where it is legal. Third, the analysis of discount elasticity and state-level factors provides results that support some findings from past research. Hopefully, these findings on the transaction- and state-level determinants of marijuana price will improve the understanding of the market for marijuana in a way that benefits researchers and policymakers alike.

Appendix

Appendix Table 1: Data summary by state (trimmed)

State	Observations	Mean price	SD price	Decrim	Medical marijuana	Maximum fine (half oz)	Maximum jail time (half oz)
Alabama	122	10.05	5.787	0	0	6,000	365
Alaska	57	11.72	2.011	1	1	2,000	90
Arizona	292	10.10	5.136	1	0	750	730
Arkansas	95	9.86	5.606	0	0	2,500	365
California	2,112	10.57	3.515	1	1	100	0
Colorado	374	10.42	2.475	1	1	0	0
Connecticut	225	12.99	4.517	0	1	150	0
Delaware	52	10.51	5.308	1	0	1,150	180
District of Columbia	94	15.67	3.858	1	0	1,000	180
Florida	1,004	10.76	4.392	0	0	1,000	365
Georgia	408	10.02	5.545	0	0	1,000	365
Hawaii	57	13.13	3.739	1	0	1,000	30
Idaho	82	11.14	2.624	0	0	1,000	365
Illinois	693	12.84	4.497	0	0	0	365
Indiana	309	9.78	5.319	0	0	5,000	365
Iowa	184	11.36	5.147	0	0	1,000	180
Kansas	237	11.49	5.275	0	0	2,500	365
Kentucky	185	9.10	4.851	0	0	250	45
Louisiana	164	10.75	6.515	0	0	500	180
Maine	130	10.99	3.508	1	1	600	0
Maryland	294	11.46	5.247	0	0	500	90
Massachusetts	635	13.01	3.622	0	1	100	0
Michigan	626	10.44	4.433	1	0	2,000	365
Minnesota	305	13.44	4.066	0	1	200	0
Mississippi	74	9.66	6.247	0	1	250	0
Missouri	353	10.56	5.668	0	0	1,000	365
Montana	149	10.63	1.897	1	0	500	180
Nebraska	121	10.57	4.956	0	1	300	0
Nevada	102	10.39	4.227	1	1	600	0
New Hampshire	114	11.71	3.790	0	0	2,000	365
New Jersey	385	12.88	4.735	1	0	1,000	180
New Mexico	93	10.95	4.763	1	0	100	15
New York	1,408	12.91	4.195	0	1	100	0
North Carolina	436	11.27	5.254	0	1	200	0
North Dakota	42	14.77	3.192	0	0	1,000	30
Ohio	655	9.16	4.825	0	1	150	0
Oklahoma	125	9.61	6.264	0	0	0	365
Oregon	434	9.10	1.915	1	1	650	0
Pennsylvania	731	11.37	4.787	0	0	500	30
Rhode Island	98	12.71	3.736	1	1	150	0
South Carolina	206	9.58	5.485	0	0	200	30
South Dakota	37	14.52	3.181	0	0	2,000	365
Tennessee	220	10.80	5.615	0	0	250	365
Texas	921	10.42	6.091	0	0	2,000	180
Utah	116	11.22	2.972	0	0	1,000	180
Vermont	94	13.02	3.020	1	1	200	0
Virginia	416	11.66	5.019	0	0	500	30
Washington	559	10.16	2.003	1	1	100	0
West Virginia	77	10.55	4.489	0	0	1,000	180
Wisconsin	325	13.47	3.699	0	0	1,000	180
Wyoming	34	13.52	3.594	0	0	1,000	365

Appendix Table 2: User enforcement index	
Total variance: 63.04%	
Eigenvector	**Variable**
0.6914	Marijuana possession arrests per capita, FBI Crime Reporting Program 2010
0.7108	Probability of arrest for drug possession, FBI Crime Reporting Program 2010
0.1294	Respondents per capita who perceived "great risk" associated with marijuana use, NSDUH 2010-2011

Appendix Table 3: Select summary statistics				
	Mean	**SD**	**Min**	**Max**
Maximum fine (half oz), $	723	979	0	6,000
Maximum jail time (half oz), days	139	171	0	730
User enforcement index	0.0605	0.0208	0.0315	0.2026
Beer excise tax, 2010	0.2513	0.2309	0.0190	1.0700
Marijuana sales arrests per user, 2011	0.0028	0.0020	0.0000	0.0099
Percent black, 2011	0.1227	0.0809	0.0054	0.5066
Percent Native American, 2011	0.0121	0.0156	0.0022	0.1487
Percent Asian-Pacific Islander, 2011	0.0534	0.0463	0.0075	0.4861
Percent mixed race, 2011	0.0237	0.0144	0.0107	0.2294
Median income, 2010	0.0237	0.0144	0.0107	0.2294
Percent urban population, 2010	81.31	11.76	38.66	100.00

Appendix Table 4: State-level model (excl. CO, CT, and WA)

		Price per g			
		(4a)	(4b)	(4c)	(4d)
	Inverse transaction size	18.79***	18.78***	18.70***	18.55***
		(0.233)	(0.233)	(0.245)	(0.241)
	Medium quality dummy	-4.409***	-4.404***	-4.479***	-4.445***
		(0.0619)	(0.0618)	(0.0649)	(0.0643)
	Low quality dummy	-7.333***	-7.333***	-7.410***	-7.350***
		(0.0886)	(0.0885)	(0.0930)	(0.0915)
Legal	Decriminalization (Y=1)	-0.195***	-	-	-
		(0.0616)	-	-	-
	Maximum fine (0.5 oz possession)	-	-0.000136***	-4.79e-05	-8.25e-05**
		-	(3.16e-05)	(3.46e-05)	(4.09e-05)
	Maximum jail time (0.5 oz possession)	-	0.00138***	0.000768***	0.000753***
		-	(0.000199)	(0.000232)	(0.000252)
	Medical marijuana (Y=1)	-1.165***	-1.205***	-1.120***	-0.675***
		(0.0728)	(0.0737)	(0.0744)	(0.0758)
Demand	User enforcement index	-	-	8.494***	13.70***
		-	-	(1.358)	(1.481)
	Beer excise tax	-	-	-1.126***	-0.517***
		-	-	(0.156)	(0.169)
Supply	Distance from Mexico	-	-	-	0.369***
		-	-	-	(0.0241)
	Cultivation state dummy	-	-	-	-0.825***
		-	-	-	(0.0898)
	Sales arrests per user, 2011	-	-	-	55.28***
		-	-	-	(15.28)
	R^2	0.5268	0.5280	0.5366	0.5537
	N	15,902	15,902	14,205	14,083
	Control variable:				
	Black	3.709***	3.713***	5.776***	2.095***
		(0.404)	(0.403)	(0.478)	(0.524)
	Native American	10.59***	8.740***	12.90***	16.66***
		(1.917)	(1.960)	(2.102)	(2.235)
	Asian-Pacific Islander	6.033***	7.417***	6.821***	14.45***
		(1.319)	(1.357)	(1.414)	(1.442)
	Mixed race	-17.14***	-18.28***	-10.62***	-28.64***
		(3.572)	(3.574)	(3.626)	(3.503)
	Median income	8.94e-05***	9.57e-05***	8.80e-05***	1.83e-05***
		(4.99e-06)	(5.10e-06)	(5.25e-06)	(5.84e-06)
	Percent urban population	-0.00807***	-0.0149***	-0.0171***	0.0116***
		(0.00294)	(0.00311)	(0.00372)	(0.00402)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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