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Estimating the Price Elasticity of Demand for Cannabis: A Geographical and Crowdsourced Approach

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ABSTRACT

Recent legalizations of cannabis at the state level in the United States have given rise to renewed interest in the price elasticity of demand for cannabis and implications for likely state excise and sales tax revenues. We use crowdsourced data on prices, qualities, and consumption of cannabis across regional markets in the United States to estimate the price elasticity of demand for cannabis. We use distances from growing areas to the major markets as a proxy for cost variations. We obtain an estimate of the price elasticity of demand for cannabis of -0.418, which suggests that legalizing and taxing recreational cannabis use would be lucrative for government treasuries.

Keywords: Cannabis; price elasticity; demand.
JEL classification: D12; H71; E26.
MSC2010: 91C99; 62P20.

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La estimación de la elasticidad en los precios de la demanda de cannabis: un enfoque geográfico y basado en la colaboración abierta distribuida

RESUMEN

Las recientes legalizaciones del cannabis a nivel estatal en los Estados Unidos han dado lugar a un renovado interés en la elasticidad en los precios de la demanda de cannabis y sus implicaciones en los ingresos por impuestos estatales y sobre ingresos por ventas. Utilizamos datos en colaboración abierta sobre precios, calidades y consumo de cannabis en los mercados regionales de los Estados Unidos para estimar la elasticidad en los precios de la demanda de cannabis. Utilizamos distancias desde las zonas de cultivo hasta los principales mercados como sustituto de las variaciones de los costos. Se obtiene una estimación de la elasticidad en los precios de la demanda de cannabis de -0,418, lo que sugiere que la legalización y el gravamen del cannabis para uso recreativo sería lucrativo para los erarios públicos.

Palabras claves: cannabis; elasticidad en los precios; demanda.
Clasificación JEL: D12; H71; E26.
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1. Introduction

Changes in the U.S. legal regime governing the production and sale of cannabis have gained momentum in recent years. Starting in 1996, the sale of cannabis for medical use was legalized in California and thereafter in 22 other states and in the District of Columbia, with the number of states expected to reach almost 30 in the next year (*Economist*, 2016, p. 18). Possession of cannabis in small quantities has been decriminalized in several states, starting with Oregon in 1973 and now extending to 16 states including California and New York (Norml.org, 2013). Decriminalization means no prison time or criminal record for first-time possession of a small amount of cannabis for personal consumption (Norml.org, 2013). Although the sale and possession of cannabis for recreational purposes is still illegal under federal law, ballot measures providing for legalization passed in Colorado and Washington state in November 2012. Colorado voters approved Amendment 64 to the state constitution, which allows persons aged twenty-one and older to purchase up to one ounce of cannabis at specially regulated retail stores. Possession is legal, but not public use. Adults are allowed to grow up to six cannabis plants in their homes (Gurman, 2012). Similarly, Washington state's Initiative 502 removes criminal sanctions for anyone aged twenty-one and older possessing one ounce or less of cannabis, although it also does not permit public consumption (Myers, 2012). Colorado and Washington commenced legal sales in 2014; Oregon followed suit in October 2015 and Alaska will soon join them (*Economist*, 2016, p. 18).

The Obama administration has indicated that as long as "strong and effective regulatory and enforcement systems" are maintained at the state level, the U.S. Department of Justice will not seek to overturn state laws or enforce federal prohibition (Dennis, 2013; Wing, 2013; *Economist*, 2013, p. 61). In the meantime, efforts are under way to place legalization measures on the ballot in several additional states, including Arizona and California (Wing, 2013). Canada is expected, in 2017, to become the first G7 country to legalize recreational cannabis use (*Economist*, 2016, p. 18).

The impetus for legalization stems in large part from the expected tax revenue generated from the legal sale of cannabis, especially in states confronting severe budget pressures, and from the widespread belief that legalization will mitigate drug-related crime and relieve crowding of state penal systems overburdened by minor drug offenders. Some Democratic strategists might be motivated to place cannabis legalization measures on state ballots by the hope that such measures will mobilize electoral turnout of young and liberal voters (Wing, 2013). There is also considerable public support for legalization. According to a Gallup poll, in 2013, for the first time, a majority of Americans – 58 percent – favored legalization (NBC News, 2013).

The Washington state initiative legalizing cannabis applies a 25 percent excise tax and, according to official estimates, could generate as much as $1.9 billion in state tax revenue over five years (State of Washington, 2015). In November 2013, voters in Colorado approved a 15 percent excise tax and a 10 percent sales tax on cannabis, which are in addition to a 2.9 percent sales tax applied to cannabis stores (9news.com, 2013). Colorado collected $44 million in cannabis taxes in 2014 and $72.5 million in the first eight months of 2015, with a total of $109 million anticipated for the year (*Economist*, 2015, p. 34). Nationally, the tax base is potentially significant: $1.43 billion of legal cannabis is estimated to have been sold in the United States in 2013 and this figure was expected to grow by 64 percent, to $2.34 billion, in 2014. Fourteen more states are predicted to legalize cannabis for adult recreational use in the next five years, creating a potential $10.2 billion cannabis market by 2018 (ArcView, 2013; Schwartz, 2013). One study estimates that nationwide legalization of cannabis could ultimately generate $8.7 billion of tax revenue annually (Miron and Waldock, 2010). An earlier estimate is $2.55 billion to $9.09 billion (Caputo and Ostrom, 1994). Legalization in California alone is expected to produce $1 billion per year in tax revenue (*Economist*, 2016, p. 19).

The trend toward decriminalization and legalization has raised important questions about the market for cannabis and specifically the determinants of demand for the drug and the price elasticity of demand. Estimates of price elasticity may be expected to inform the debate about the magnitude of government tax receipts in markets in which cannabis has been legalized (Caputo and Ostrom, 1994). Several efforts have recently been made in the economics literature to estimate the price elasticity of demand for cannabis. Such efforts are necessarily premised on an empirical identification of the demand equation for cannabis, which can be difficult in the case of a product that, until recently, has been traded only in illegal markets. We approach this problem by using a hedonic method of estimating the relationship between prices and quantities in the market which gives us an estimate of the price elasticity of demand for cannabis. Our method utilizes a novel dataset consisting of distances from the primary Mexican growing areas to all of the major markets in the United States. These distances are then used as proxies to capture variation in costs of production and distribution across markets. We estimate a price elasticity of demand for cannabis of -0.418. This estimate is sufficiently inelastic that it is reasonable to believe that the tax revenues from an excise tax on legalized cannabis would be substantial.

In the next section we outline the various approaches that have been used in the literature to identify the demand for cannabis and other drugs, and to estimate the price elasticity of demand. Section 3 describes the data and model used in our study, with empirical results presented in section 4 and implications and conclusions in section 5.

2. Studies of the Market for Cannabis

Empirical estimation of demand and supply equations for illegal goods, or for goods traded in informal markets, confront unique challenges, not least of which being a lack of reliable data on prices, quantities, costs, and consumption (Bohme and Thiele, 2012). Thus for example, due to the unavailability of cannabis price data, many studies have focused on estimating cross-price elasticities of demand, rather than own-price elasticities for cannabis (Pacula *et al.*, 2000). Much of the existing literature on cannabis, cocaine, heroin and other illegal drugs uses interview or survey data (Chaloupka *et al.*, 1998; Saffer and Chaloupka, 1999a, 1999b; Dave, 2008; Pacula *et al.*, 2010) or enforcement data such as arrests and fines (Dave, 2008; Pacula *et al.*, 2010). A notable exception is Olmstead *et al.* (2015), who use actual daily price and quantity data for a sample of heroin users, as well as experimental data obtained by confronting the same heroin users with alternative hypothetical prices in a laboratory setting. Both empirical strategies yield an estimated conditional price elasticity of demand for heroin of approximately -0.80.

One of the problems of relying on individual consumer-level data is that, particularly with addictive drugs such as cocaine and cannabis, tastes may be endogenous in the sense that current consumption is partly determined by past consumption (van Ours, 1995). This endogeneity becomes especially problematic in estimating the demand equation, which requires tracing out the effects of supply shifts and resulting price changes on the quantity demanded. Habitual drug users' consumption will not vary significantly in response to such shifts whereas casual users are likely to be more sensitive to supply-induced price changes (Pacula *et al.*, 2010). The dependence of present consumption of addictive drugs on past consumption may produce nonlinear estimates of price elasticity, with high elasticity at both low and high prices and low elasticity in the middle range of prices (Bretteville-Jensen and Biørn, 2004).

A major parameter that is used in much of the literature to identify demand for cannabis is decriminalization or the passage of so-called "medical marijuana" laws (Saffer and Chaloupka, 1999a, 1999b). Such policy changes may be associated with lower costs or risks of acquiring the drug, a supply-side shift which can be used to identify the demand equation. Thus for example, Saffer and Chaloupka (1999a, 1999b) find that cannabis decriminalization increased the probability of participation in cannabis use among high school seniors by roughly 8 percent. However, Chaloupka *et al.* (1998, p. 20) show that the elasticity of youths' cannabis use with respect to fines for possession is very small, in the range of -0.007 to -0.008. Wen *et al.* (2014) examine the effects of medical marijuana laws in seven states between 2004 and 2011, and find that the adoption of such laws increased the probability of cannabis use by 16 percent among those aged twenty-one or older and by 5 to 6 percent among those aged twelve to twenty years.[1] A contrary result is that of Anderson *et al.* (2014) who use national and state Youth Risk Behavior Surveys, the 1997 National Longitudinal Survey of Youth and the Treatment Episode Data Set to show that legalization of medical marijuana does not in fact produce an increase in cannabis consumption among teenagers. But in a study of cannabis possession arrests across cities from 1988 to 2008, Chu (2014) finds that the enactment of medical marijuana laws increased arrests among adult males by about 15 to 20 percent and increased treatment admissions to rehabilitation facilities by 10 to 20 percent.

Pacula *et al.* (2000) use survey data on high school seniors' cannabis participation to estimate time-series and cross-sectional models of demand for the drug. In order to account for the endogeneity of the price variable and identify the demand equation in the time-series model, these authors use variations in the amount of resources allocated to apprehension and conviction of cannabis dealers as an instrument for exogenous shifts of the supply curve. The supply function is assumed to be infinitely elastic, since high school seniors are price takers if they represent a small fraction of the cannabis market. The study finds that the estimated price elasticity of annual cannabis participation ranges from -0.06 to -0.47.

Davis *et al.* (2016) study the cannabis demand function in a cross-section of U.S. states, cities and counties. They use electricity prices, the legal status of medical marijuana and

[1] For expanded findings, see Wen *et al.* (2015).

distance to Mexico City as instrumental variables to identify the cannabis demand function, these three variables being treated as exogenous supply-side factors which affect the price of cannabis. The authors argue that, although medical marijuana legislation might be expected to reduce the risk of use and increase social acceptance, thereby influencing demand, this variable is likely to have a stronger impact on the supply side, as it allows for home cultivation. Electricity prices are argued to be the largest single component of production cost for domestic producers, since most domestic production takes place indoors and requires electricity for high-intensity lighting, dehumidification, space heating, and carbon dioxide generation. The authors use distance to Mexico City to capture the cost of imported cannabis (Davis *et al.*, 2016). Using these variables as instruments, Davis *et al.* (2016) estimate that the price elasticity of demand for cannabis ranges from -0.67 to -0.79. These findings are broadly consistent with earlier estimates of the price elasticity, ranging from -0.40 to -1.51, cited by Caputo and Ostrom (1994, p. 486).

Like Davis *et al.* (2016), we use crowdsourced transaction data on prices and quantities for high-, medium- and low-quality grades of cannabis in a cross-section of market areas, obtained from the priceofweed.com website, in order to estimate the price elasticity of demand. The validity of crowdsourced data is attested to in a study by Lutz (2016) which shows that crowdsourced samples produce results similar to those in the laboratory. Also, following the method established by Davis *et al.* (2016), we incorporate a measure of spatial distances from primary growing areas to the major markets in the United States. The distance from growing area to market is a meaningful indicator of cost differences across markets and therefore can be used as a proxy for production costs in a hedonic model. However, whereas these latter authors use the distance from each state's geographic center to Mexico City, we take the average of the distance from the center of each county in the United States to the three states in Mexico which account for the majority of Mexican cannabis production. According to the 2009 United Nations World Drug Report, the Mexican states of Sinaloa, Chihuahua, and Durango accounted for 76 percent of cannabis crop eradication in Mexico. This implies that these states, located in the north of the country, are the major growers of cannabis.[2] In the next section we discuss the data and model used in our study in more detail.

[2] The 2009 United Nations World Drug Report can be found at: http://www.unodc.org/unodc/en/data-and-analysis/WDR-2009.html.

3. Data and Model

In order to evaluate the potential for state governments to raise revenue by legalizing and taxing recreational cannabis use, it would be useful to have an estimate of the price elasticity of demand for cannabis in the United States, but transactions data for illegal markets can be difficult to acquire. We address this potential stumbling block by using data for individual market transactions that were collected by priceofweed.com, a site that describes its function in the following manner: "We crowdsource the street value of marijuana from the most accurate source possible: you, the consumer. Help by anonymously submitting data on the latest transaction you've made."[3] Each transaction entered by a consumer contains the city in which the transaction occurred, the total price of the transaction, the weight of the cannabis involved, the quality of the product (low, medium, or high), and the date. There were 29,472 transactions that were entered onto the site from September 2010 through March 2012. County level data were also used to allow additional control variables and instruments to be implemented that were not available at the city level.

We use Full Information Maximum Likelihood (FIML) to estimate a semi-log model. The logarithm of price and logarithm of quantity of cannabis bought and sold are endogenous variables. The logarithms are appropriate to capture the non-linear aspect of cannabis demand as well as facilitating the interpretation of slope estimates as elasticities. Gallet and List (2003, p. 825), in a metastudy, report that out of 523 estimated cigarette price elasticities, 292 come from a double or semi log model. Exogenous demand parameters include the total number of arrests for possession or sale of cannabis in each county, median household income in each county, and dummies measuring the quality of cannabis. To represent supply costs, we use a measure of the distance that imported cannabis was transported to each of the market areas in our dataset. These variables are given more precise definitions below.

The model is estimated using each transaction in the dataset as a separate observation, giving 29,461 observations (eleven of the 29,472 observations that were originally collected from the priceofweed.com site were either incomplete or were omitted because the price was recorded as zero, so that 29,461 observations are available).

[3] See the front page of www.priceofweed.com.

The model to be estimated with full information maximum likelihood is as follows:

$$Ln(Q_i) = B_0 + B_1. Ln(P_i) + B_2. QUALITY1_i + B_3. QUALITY3_i + B_4. Ln(INCOME_i) + B_5.ARRESTS_i + B_6. Ln(DISTANCE_i) + e_i$$

where

$Ln(Q_i)$ = the natural logarithm of the quantity, in grams, of cannabis for transaction i. Each quantity observation is rounded to the nearest whole integer. The data are from priceofweed.com for 29,461 transactions submitted to the website from September 2010 through March 2012.

$Ln(P_i)$ = the natural logarithm of the price, in U.S. dollars, per gram of cannabis for transaction i. As in the case of the quantity data, the price data are from priceofweed.com for 29,461 transactions submitted to the website from September 2010 through March 2012.

$QUALITY1_i$ = 1 if the quality of the cannabis in the transaction is rated as low (out of low, medium, and high); $QUALITY1_i$ = 0 otherwise. Quality ratings are submitted by the consumers and correspond to the same 29,461 transactions submitted to priceofweed.com from September 2010 through March 2012 mentioned above for the price and quantity data.

$QUALITY3_i$ = 1 if the quality of the cannabis in the transaction is rated as high; $QUALITY3_i$ = 0 otherwise. As above, quality ratings are submitted by the consumers and correspond to the same 29,461 transactions submitted to priceofweed.com from September 2010 through March 2012. Note that the middle quality rating is represented by the intercept in the model.

$Ln(INCOME_i)$ = the natural logarithm of median household income, in thousands of dollars, for the county in which transaction i occurred. Data are from the United States Census Bureau, “Small Area Income and Poverty Estimates for 2011”. They can be found at http://www.census.gov//did/www/saipe/ (accessed October 2, 2015).

$ARRESTS_i$ = the number of arrests for sale or possession of cannabis per 100,000 residents for the county in which transaction i occurred. These data are from the

Federal Bureau of Investigation's "Uniform Crime Reports", http://www.drugscience.org/States/US/US_home.htm (accessed October 2, 2015). Data are for 2007, except for Wyoming counties and the Missouri counties of Adair, Audrain, and Boone, which are for 2006. There are 12 counties in total for which there were no arrests, so the natural logarithm cannot be used in those cases.

Ln($DISTANCE_i$) = the natural logarithm of the average distances, in miles, between the county of transaction i and the Mexican states of Sinaloa, Chihuahua, and Durango, which are the major North American growing regions for cannabis. For each U.S. county, three distances are calculated, namely, the straight line distance from the center of the county to the geographic center of each of the three Mexican states. These three distances are then averaged for each U.S. county in the dataset. It should be noted that this measure does not consider differences in the ease of crossing borders at different points or in the characteristics of distribution networks.

4. Empirical Results

Table 1 shows descriptive statistics for Q, P, QUALITY1, QUALITY3, INCOME, ARRESTS, and DISTANCE. Table 2 gives the FIML results. As part of the FIML estimation process, an additional instrument was used. In addition to DISTANCE as defined above, a domestic version of DISTANCE was used as an instrument where weighted distances from all other states were calculated, using cannabis crop eradication data as the weights. The eradication data were used to represent the prominence of each state as a growing area. These eradication data are from a United States Department of Justice website which is no longer active; however, the data can be obtained from the authors on request. Note that this variable is used as an additional instrument in the FIML process to represent supply costs along with DISTANCE; it is not a variable in the regression.

The main variable of interest, the logarithm of P, has a slope estimate that is statistically significant at a 1% level. The -0.418 coefficient estimate for the log of P indicates a relatively inelastic demand for cannabis in the United States. This estimate falls within the range of values for the price elasticity of demand for cannabis found in previous work (see Caputo and Ostrom, 1994, and Davis *et al.*, 2016), and bodes well for state governments that hope to raise revenue by legalizing and taxing recreational cannabis use.

Table 1. Descriptive Statistics for Variables Used in FIML Model, for 29,461 transactions conducted from September 2010 to March 2012.

Variable	Mean (Standard Deviation)	Minimum	Maximum
Q (Quantity in grams)	14.70 (10.97)	4.0	28.0
P (Price in dollars)	10.81 (8.76)	0.036	249.75
QUALITY1 (Low quality rating)	0.067 (0.250)	0	1
QUALITY3 (High quality rating)	0.347 (0.476)	0	1
INCOME (Median household income in thousands of U.S. dollars, by county, for 2011)	54.403 (13.596)	21.865	119.525
ARRESTS (For sale or possession of cannabis per 100,000 residents by county)	297.25 (175.38)	0	3411
DISTANCE (Average distance in miles between county and major growing areas of Sinaloa, Chihuahua, and Durango)	1506.99 (497.99)	283.17	3375.46

Table 2. FIML Results for Cannabis Market for 29,461 transactions conducted from September 2010 to March 2012.

Left-Hand-Side Variable: Ln(Q)
(Natural logarithm of quantity in grams)

Variable	Coefficient (Standard Error)	Z-statistic	p-value
Intercept	3.190 (0. 223)	14.33	0. 000
Ln(P) (Natural logarithm of price in dollars)	-0.418 (0.007)	-60.12	0.000
QUALITY1 (Low quality rating)	0.133 (0.021)	6.281	0.000
QUALITY3 (High quality rating)	0.187 (0.011)	17.43	0.000
Ln(INCOME) (Natural logarithm of median household income in thousands of U.S. dollars, by county, for 2011)	-0.012 (0.021)	-0.600	0.548
ARRESTS (For sale or possession of cannabis per 100,000 residents by county)	0.0000683 (0.0000270)	2.53	0.011
Ln(DISTANCE) (Natural logarithm of the average distance in miles between county and major growing areas of Sinaloa, Chihuahua, and Durango)	0.0000239 (0.0000095)	2.51	0.012

R-squared: 0.161

Adjusted R-squared: 0.161

The coefficient estimate for QUALITY1 is positive and significant at a 1% level, indicating that, holding other independent variables constant, lower quality cannabis (which presumably would cost less) is bought in larger quantities than "medium" quality cannabis (note, however, that consumers themselves determine the quality of the cannabis when they submit the transaction data). Likewise, QUALITY3 has a positive coefficient estimate that is significant at 1%, indicating that high quality cannabis is also purchased in larger quantities than medium quality cannabis (even though it would likely cost more). The coefficient estimate for the logarithm of INCOME is insignificant. The coefficient estimates for ARRESTS and the logarithm of DISTANCE are also positive and significant, in this case at 5%, suggesting that increased levels of law enforcement and increased distances from growing areas are both positively correlated with quantity consumed, although the effect is not large. The positive relationship between quantity and DISTANCE might reflect the Alchian-Allen effect, according to which the higher quality product, which, as we have seen, is purchased in larger quantities than medium quality, is also more likely to be shipped over longer distances. This is because the addition of a per-unit transportation cost lowers the relative price of the higher quality product (see Borcherding and Silberberg, 1978).

The adjusted R-squared of 0.161 indicates a relatively weak fit for the model. This is a symptom of the illegality of the market, as a result of which information is not as reliable and transaction costs are higher than in a comparable legal market, such as that for cigarettes. An examination of the correlation matrices for the data used in Table 2 does not suggest any evidence of multicollinearity.

5. Implications and Conclusions

Although the market for cannabis has existed in the United States for longer than anyone alive can remember, a lack of good data concerning this market makes it difficult for empirical economists to contribute to the current debate concerning the legalization of cannabis. The relatively recent phenomenon of "crowdsourcing", or obtaining data from a large number of market participants through the internet, gives rise to the hope that researchers will no longer be dependent on traditional sources of information that ignore illegal or underground markets. Our study uses transaction data collected from individual purchasers of cannabis, reported at priceofweed.com, to estimate the price elasticity of demand for cannabis. Of course, as cannabis is legalized in more states, and probably eventually nationwide, more reliable sales and price data will ultimately become available.

Following Davis *et al.* (2016), we use the spatial distance from major growing areas of imported cannabis to markets within the United States as a measure of variation across markets in the cost of supplying cannabis. In our approach, the distance measure focuses on the actual areas within Mexico where most of the cannabis is grown. For each U.S. county, we calculate the average of the distance from the county's geographic center to each of the three major cannabis growing states in Mexico. This distance variable enters in our regression model as a production cost parameter.

The market for cigarettes is a reasonable proxy for that of a legalized and taxed cannabis market. In a metastudy, Gallet and List (2003) report that the median short-run price elasticity of demand for cigarettes is -0.40 (out of 368 estimates) and that the long-run price elasticity of demand is -0.44 (out of 155 estimates). Recent research also indicates that the absolute value of the price elasticity of demand for cigarettes increases monotonically with price (Tauras *et al.*, 2016). The price elasticities reported in the cigarette literature are comparable to our estimate of the price elasticity of demand for cannabis of -0.418. Goolsbee *et al.* (2010) estimate excise tax rate elasticities for cigarettes to study the effect of internet cigarettes sales on tax elasticities. They find that internet cigarette sales have increased excise tax elasticities for cigarettes, however, the elasticity values are still low, as their results yield a range of excise tax rate elasticities from -0.189 to -0.267, even with internet sales accounted for.

State and local governments collected over $4 billion in tax revenues from cigarettes in 2013, with state and local governments in California collecting over $280 million. These data are from the United States Census Bureau, "Annual Survey of State and Local Government Finances," Government Finances, Volume 4, and the Census of Governments (1977-2011), "State and Local Government Finance Data Query System," http://slfdqs.taxpolicycenter.org/pages.cfm (accessed January 2, 2016), and can be found at the Tax Policy Center, http://www.taxpolicycenter.org/taxfacts/displayafact.cfm?Docid=403 (accessed January 2, 2016). If the price elasticities of demand for cannabis and cigarettes are both in the same range, as suggested by our results for cannabis, then there is every reason to expect that legalizing and taxing recreational cannabis use will yield similarly large state excise tax revenues to those collected from the taxation of cigarettes.

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