Taxation and Welfare in the Cannabis Industry: 
Evidence from Colorado Edibles 2014-2016 

Jacob Kirsch* 

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Abstract 

Legalization of medical and adult-use (recreational) cannabis products in Colorado has lead to an expansive industry with sales of $1.31 billion in 2016. These sales generate significant tax revenue for the state. I estimate the optimal sales tax rate using data on sales of cannabis edibles for the adult-use market in Colorado between 2014 and 2016. I use a discrete choice model to estimate demand parameters that provide marginal costs, equilibrium prices, and welfare. This allows for the simulation of different rates to determine the optimal sales tax rate. I find that tax revenue is maximized at a rate of 65.8%.

JEL Classification Codes: H21, H30, H71, K34, L66 

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1 Introduction 

Legalization of cannabis has expanded considerably in recent years. Twenty-nine states have legalized medical cannabis use. Eight of these states, along with Washington DC, have

*University of Colorado at Boulder, jacob.kirsch@colorado.edu. Thank you Scott Savage for advising on this project. I am grateful to Roy Bingham at BDS Analytics for providing the data. I thank Greg Shoenfeld and Tom Jones at BDS Analytics, Adam Orens and Brian Lewandowski at The Marijuana Policy Group, James Kelley at Terrapin Care Station, and Adam Weiss at Bolder Cannabis for their helpful discussions.
legalized adult-use (recreational) cannabis for individuals 21 and older. Legal cannabis sales in the United States are estimated to have reached $5.4 billion in 2015 and $6.7 billion in 2016 (Huddleston Jr. 2016). The expansion to California, Nevada, Massachusetts, and Maine means that over one fifth of the US population lives in a state which permits legal adult-use cannabis (Borchardt 2017).

Colorado contributes a large share to total US sales. Figure 1 displays total sales in Colorado for 2014-2016. Sales in medical and adult-use cannabis totaled approximately $996 million in 2015 and $1.31 billion in 2016. Growth in sales are largely driven by the adult-use industry, with sales of $588 million and $875 million in 2015 and 2016 respectively. The rapid growth of this industry provides the opportunity to generate significant tax revenue. Sales of adult-use cannabis in Colorado faced a 10% special sales tax rate in addition to the 2.9% state sales tax between 2014 and 2016. Cultivators of cannabis additionally face a 15% excise tax on the value of unprocessed cannabis when their product is first transferred to a cannabis product manufacturer, retailer, or other cultivator. The tax rate on retail cannabis was changed effective July 2017. The special sales tax rate was raised from 10% to 15%, while retail cannabis was made exempt from the state sales tax. Revenue is also generated through application and licensing fees. Employment in a cannabis facility requires an occupational license. A “support employee” who does not make operational decisions faces a $75 application fee, while a managerial “key employee” faces a $250 fee. Operating a cannabis facility additionally requires a business license. The application fee for a retail marijuana store is $4,500 as of May 2017. The medical cannabis industry also generates tax revenue and licensing fees, though medical cannabis is exempt from the special sales and excise taxes levied on adult-use cannabis. Figure 2 provides a breakdown of the monthly tax revenue provided by each source from cannabis between 2014 and 2016. The revenue generated by medical and adult-use cannabis totalled $193,604,810 in 2016. A majority of this revenue is generated by the adult-use cannabis industry. Tax revenue from cannabis is allocated to a variety of state programs and services. The first $40 million of annual revenue generated by the excise tax is allocated to the Public School Capital Construction Assistance Fund to pay for local K-12 school construction projects. Revenue from excise taxes in excess of $40 million are credited to the Public School Fund which provides income to K-12 schools.

\[\text{CO Rev Stat } \S \ 39-26-106\]
\[\text{CO Rev Stat } \S \ 39-28.8-202\]
\[\text{CO Rev Stat } \S \ 39-28.8-302\]
A total of $69.4 million has been allocated to these funds between fiscal years 13-14 and 15-16, including $2.4 million in excess revenue allocated to the Public School Fund. The special sales tax revenue is allocated between the state and local governments. Local governments receive 15% of this revenue while the remainder is allocated to the state’s Marijuana Tax Cash Fund (MTCF). This distribution has been modified effective July 2017. Local governments are now allocated 10% of the special sales tax revenue, with the remainder transferred to the MTCF. The MTCF faces limitations on the timing, amount, and allocation of revenues. Funding is provided for services in agriculture, education, administration, health care, substance abuse treatment, and law enforcement. A detailed table of the MTCF appropriations for fiscal years 2016-17 and 2017-18 can be found in pages 593-595 of the Colorado Joint Budget Committee’s *Appropriations Report Fiscal Year 2017-18*.

Revenue generated from the state sales tax along with licensing and fees are also allocated to the MTCF. Revenue from these sources are subject to limitations under the Taxpayer’s Bill of Rights (TABOR) of the Colorado state constitution. TABOR restricts growth in fiscal spending by the sum of inflation in the CPI and population growth. Growth in fiscal spending includes both increases in expenditure and increases in reserves. Any revenues collected by the state which are not specifically exempt are subject to TABOR. Revenues in excess of this limit must be refunded in the next fiscal year unless voters approve revenue changes. Revenue from these sources totaled $49 million in fiscal year 2015-2016, with $31.6 million generated from state sales taxes and $17.4 million from licensing and fees (Colorado General Assembly).

I investigate the welfare implications of taxation in the cannabis industry. Consumption of cannabis is potentially associated with adverse health and safety effects that may impose external costs on society. I conduct my estimation independent of this consideration and consider the case when external costs are zero. Cannabis products exhibit significant heterogeneity. I utilize a discrete choice model in which consumers demand products based on their characteristics in order to estimate substitution patterns between the numerous products in the industry (Hansen 1982; Hausman and Wise 1978; McFadden et al. 1973; S. T. Berry 1994). I follow closely the estimation strategy of S. Berry, Levinsohn, and Pakes 1995 (BLP). Consumer utility depends on both observable characteristics and unobservable (to the econometrician) characteristics or demand shocks. Consumers have heterogeneous preferences for product characteristics. It is likely that unobserved characteristics will be
correlated with prices and induce a bias in the estimation of price coefficients. I utilize BLP instrumental variables consisting of own and competing product characteristics to address this endogeneity. I use the parameters of my estimation to conduct a counterfactual simulation of the impact on consumer and producer welfare for different tax rates. This simulation results in a tax revenue maximizing rate of 65.8% in total sales tax applied to cannabis sales.

I use data provided by BDS Analytics, a cannabis market data and consumer insight service provider, which provide daily product-level average price and sales data for cannabis products sold in the state of Colorado from 2014-2016. The data provide significant advantage over previous studies which have had to rely on survey information to infer cannabis purchases and use. The use of product-level sales data will allow for estimation of the substitution patterns between many cannabis products, and provide credible analysis of tax impacts in the industry. I am the first to use the data to estimate a structural model of consumer demand. Estimation of structural parameters allows for simulation of a range of policy experiments which evaluate consumer and producer welfare in an equilibrium setting.

This paper is part of a growing literature on cannabis use. Researchers have investigated its negative impacts through its potential function as a gateway drug that induces individuals to consumer harder drugs (DeSimone 1998; Van Ours 2003; Bretteville-Jensen and Jacobi 2011). Others have investigated the impact of cannabis legalization or decriminalization on its use. These include Miron and Zwiebel 1995; Pacula, Grossman, et al. 2000; Clements and Zhao 2009; Pacula, Kilmer, et al. 2010; Pudney 2010; Caulkins et al. 2012; Donohue III, Ewing, and Pelopquin 2010; Williams, Van Ours, and Grossman 2011; Jacobi and Sovinsky 2013. Research has also focused on the substitution patterns between cannabis and other substances in order to investigate the impact of policy that seeks to reduce the use of these substances (Cameron and Williams 2001; Farrelly et al. 2001; Saffer and Chaloupka 1999). These studies have provided some insight into the demand patterns for cannabis. However, these studies have focused on the impact of policies which change access to or seek to reduce the use of cannabis and have not focused on the impact of policies within a legal cannabis industry.
2 Background

2.1 Legal History

Cannabis products were not federally prohibited in the United States prior to the twentieth century. Cannabis and its extracts were available at drug stores and suggested for a variety of ailments in states which permitted its sale. Cannabis extracts were first recognized in the US Pharmacopeia in 1851 as a part of the effort to set standards on the production and use of medicines. Federal regulation of cannabis began with the Federal Food and Drugs Act of 1906. The act required that substances included in the US Pharmacopeia be labeled to identify their contents. A number of states chose to draft their own laws prohibiting or restricting the sale of cannabis over the next decades. The Federal Bureau of Narcotics (FBN) drafted the Uniform State Narcotic Drug Act in 1931. The act allowed states to include cannabis among substances which faced restrictions on their sale and use. Only ten states had adopted the act by the end of 1934. The FBN undertook an effort to expand the act by publicizing cannabis as a drug which lead to insanity and violent crime. All but two states adopted the Uniform State Narcotic Drug Act by the end of 1936. Efforts warning individuals of the dangers of cannabis and the need for state laws lead to further support for federal legislation. Cannabis policy expanded to the federal level with the Marijuana Tax Act of 1937. The act did not explicitly prohibit the sale and use of cannabis. Instead, cannabis was to be taxed at a rate of $1 per transfer of one ounce by a registered physician. Large fines and penalties were imposed for violating the tax act. Individuals in violation could be fined up to $2,000 and face five years in prison (Meier 1994). The tremendous risk associated with prescribing cannabis made the substance effectively illegal in the United States. The Marijuana Tax Act was replaced by the Controlled Substances Act (CSA) of 1970. The CSA classified cannabis as a Schedule I controlled substance. This made it illegal for any individual to manufacture, distribute, or possess cannabis in the United States.

Many states have begun legalizing cannabis use in spite of its Schedule I classification. California became the first state to legalize medical cannabis with the Compassionate Use act of 1996. This provided individuals the ability to obtain and use cannabis when recommended

\footnote{21 U.S.C. § 812}
by a physician to treat serious medical conditions. A number of states enacted similar laws in
the following years. Colorado approved medical marijuana with the passage of Amendment
20 on November 7th, 2000[4].

Amendment 20 allowed physicians to prescribe cannabis to individuals with debilitating
medical conditions. Patients are limited to two ounces of usable cannabis, and are permitted
to grow up to six cannabis plants with a maximum of three plants which are mature and able
to produce usable cannabis. Patients and primary care-givers must apply for and receive
a registry identification card from the state of Colorado authorizing their involvement with
medical cannabis. Primary care-givers are individuals who are responsible for the well-being
of patients with debilitating medical conditions. Primary care-givers are subject to the same
quantity limitations as patients and are responsible for controlling the acquisition of cannabis
by their patients.

Amendment 20 did not regulate the commercial distribution of medical cannabis. Regis-
tered caregivers began serving many patients and operating medical cannabis retail centers
in the 2000’s. Concerns with the lack of regulation of medical cannabis providers lead to
the passage of HB 10-1284 in June of 2010. This created the Medical Marijuana Licens-
ing Authority operated by the executive director of the Department of Revenue with the
responsibility of regulating and controlling the licensing, cultivation, distribution, and sale
of medical cannabis. The bill restricts primary caregivers to a maximum of five patients to
whom they can provide medical cannabis. In addition, the bill allows for the licensing and
operation of medical cannabis centers which are allowed to possess 2 ounces of cannabis and
six cannabis plants for each patient who is registered at the cannabis center. Authoriza-
tion of retail medical cannabis facilities laid the foundation for the future of retail adult use
cannabis facilities.

The process of legalizing adult-use cannabis in Colorado began on November 6th, 2012
with the passage of Amendment 64 by approximately 55% of the vote. The amendment
was added to the state constitution as article XVIII sec. 16 by executive order of Governor
John W. Hickenlooper on December 10th, 2012. The article states that cannabis should be
taxed and regulated in a manner similar to alcohol “in the interest of the efficient use of
law enforcement resources, enhancing revenue for public purposes, and individual freedom.”

Individuals twenty-one and older are allowed to possess, use, and grow restricted quantities of cannabis. Licensed individuals are allowed to operate cultivation, manufacturing, testing, and retail cannabis facilities. The article mandates the adoption of certain regulations for the industry. This includes requirements and qualifications to receive a cannabis license, security requirements, product labeling requirements, health and safety standards, and advertising restrictions. The first licensed retail cannabis stores opened their doors on January 1st, 2014 (Ingold 2013).

2.2 Production

Licensing is required for producers of cannabis. Colorado created the Marijuana Enforcement Division (MED) for the purpose of regulating the industry. The MED issues retail, cultivation, product manufacturing, testing, transportation, occupational, and business operator licences. Retail licenses permit the operation of a store to sell cannabis to individuals twenty-one and older. Cultivation licenses permit the operation of a facility which grows cannabis for sale to other licensed organizations. Product manufacturing licenses permit the operation of a facility which manufactures products with extracts of cannabis such as edibles and concentrates. Testing licenses permit the operation of a facility which tests products to determine their potency and quality. Transportation licenses permit the transportation of cannabis products between licensed organizations. Occupational and business operator licenses permit ownership and employment within licensed cannabis facilities. Producers are required to track every cannabis product from its cultivation to its retail sale.

Production of cannabis products begins with the cultivation of the cannabis plant. Cultivators operate both indoor and outdoor facilities for growing cannabis. Plants are generated either from seeds or from cloning a mature plant. Cloning involves cutting a section from the stem of a plant. The resulting cut can be treated with rooting hormones and placed in soil or other growing medium where it will form into a mature plant. Plants are treated with different cycles of nutrients, light, and water over the course of a few weeks. The plants are then harvested and hung to dry before being trimmed of leaves and stems to produce the dried flower of the cannabis plant. Cultivators pay an excise tax equal to 15% of the aver-
age wholesale price of their cannabis before transporting their product to a licensed retail, manufacturing, or additional cultivating facility.

Product manufacturers extract cannabinoids from cannabis flower to produce concentrates and edibles. Extraction may be water, food, or solvent based. Water-based methods use only water, ice, or dried ice. Food-based methods use propylene glycol, glycerin, butter, olive oil or other cooking fats. And solvent-based methods use butane, propane, $CO_2$, ethanol, isopropanol, acetone, or heptane to extract cannabinoids. Extracts are used to produce a variety of products. Extraction using solvents such as butane and $CO_2$ leave behind a high potency substance that may be vaporized and inhaled for consumption. These extracts are sold in retail stores as concentrates. Examples of concentrates include oil, wax, and shatter. Extracts are also infused into food and beverages to produce edibles. Additional ingestible goods such as capsules and tinctures are also sold as edibles.

Products require testing prior to being transferred from a cultivator or manufacturer. Products are tested to determine the presence of contaminants and the potency of cannabinoids in the product. Testing is conducted to determine the presence of microbials such as Salmonella, E. Coli., yeast, and mold as well as residual solvents such as butane. Contamination testing is conducted on every batch of cannabis products until the production process is validated. This requires passing all contamination tests over a period of six to twelve weeks for flower or over a period of four to eight weeks for concentrates and edibles. Validation of a production process remains in effect for one year.

Potency testing is required for every cannabis strain sold by a cultivator. A strain of cannabis refers to the unique genetic varieties of the plant. A cultivator is required to test four separate harvest batches collected a minimum one week apart. A strain is then tested once every six months after the initial four tests. A cultivator may transfer cannabis to a product manufacturer following the first potency test. Manufacturers of edibles are required to test the potency of their product as well as the homogeneity of cannabinoids distributed through the product until the production process is validated for every type of edible. The process is validated when every production batch that is produced in a four to eight week period passes potency tests.

Concerns over misuse of edible products encouraged restrictions on

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1 CCR 212-2-R 103
1 CCR 212-2-R 605(A)(2)
1 CCR 212-2-R 1501
1 CCR 212-2-R 1503
the strength of cannabinoids. Edibles must be clearly divided into single servings consisting of no more than 10 milligrams of THC, with a total of 100 milligrams included in an entire package. Products which are not easily separable such as soft drinks and tinctures must include an appropriate pouring measurement to achieve a single serving. Producers may be subject to mandatory testing at any time regardless of whether their production process has been validated. Failure to pass potency or contamination tests requires destruction of the entire batch or, if possible, corrective measures to alleviate the issue before submitting the batch for retesting.

Products which satisfy testing requirements may be transported to retail stores for final sale to consumers. Customers must provide valid identification verifying that they are twenty-one or older. Stores can only sell cannabis product within a restricted access area. This area must be identified and monitored to ensure only authorized consumers are allowed to enter. Employees in the restricted access area facilitate the sale of cannabis products to consumers. This may include providing consumers information on the numerous products to suit their desired use of cannabis. Customers choose between flower, concentrates, and edible products. Purchases often involve a single class, though purchases of multiple types of products is not uncommon. Consumers may choose to purchase multiple packages of edibles. The discrete choice model of consumer demand for edibles should be viewed as an approximation to the true purchasing behavior for cannabis. Purchasers of edibles demand products based on their characteristics. Consumers often focus on the quantity of cannabinoids and price in particular. Edibles list the quantity of THC or CBD in a package. While some edibles list the inclusion of additional cannabinoids such as CBN, these products are relatively uncommon. The restriction on the quantity of THC included in a package leads to a significant number of products with the same potency. Price is therefore a strong determinant of demand between products. Edibles which display the same characteristics may differ in quality and consistency. A less desirable product may concentrate cannabinoids disproportionately among units in the package for example. Consumers may have strong preferences for certain brands of edibles as a result.

Knowledge of consumer preferences comes from a personal interview with a cannabis dispensary manager.
3 Empirical Framework

3.1 Market Demand

Consumer utility is a function of product characteristics \((x, \xi, p)\) and individual characteristics \(\nu\). Here \(x\) denotes observable product characteristics including fixed effects, \(\nu\) denotes unobserved product characteristics, and \(p\) denotes price. Parameters to be estimated are represented by \(\theta\). There are \(t=1,...,T\) markets observed with \(i=1,...,M_t\) consumers who decide between purchasing one unit of \(j=1,...,J\) products. Consumers are assumed to observe the prices and characteristics of all products in a market. The outside option of not purchasing any products in the market is denoted by \(j=0\). The indirect utility of consumers is given by:

\[
U_{ijt}(x_{jt}, \xi_{jt}, p_{jt}, \nu_i; \theta) = \alpha_i p_{jt} + x_j^\prime \beta_i + \rho_f(j) + \lambda_b(j) + \eta_c(j) + \gamma + \xi_{jt} + \epsilon_{ijt} \tag{1}
\]

Where \(x_j\) is a \(K\times1\) vector of observed product characteristics \(k\) for product \(j\), \(p_{jt}\) is average price of product \(j\) in market \(t\), \(\rho_f(j)\) is a time-invariant fixed effect measuring average consumer preferences for flavor \(f(j)\) of product \(j\), \(\lambda_b(j)\) is a time-invariant brand fixed effect which measures average consumer preferences for brand \(b(j)\) that produces product \(j\), \(\eta_c(j)\) is a time-invariant product class fixed effect which measures average consumer preferences for product class \(c(j)\) of product \(j\), \(\gamma\) is a product-invariant fixed effect that controls for changes in consumer’s preferences for cannabis products over time, \(\xi_{jt}\) is unobserved (by the econometrician) product characteristics or demand shocks for product \(j\) in market \(t\), \(\beta_i\) is a \(K\times1\) vector of marginal utilities of the \(K\) product characteristics for individual \(i\), \(\alpha_i\) is the marginal utility of income for individual \(i\), and \(\epsilon_{ijt}\) is an independently and identically distributed type I extreme value error term with mean zero. Denote this distribution by \(P_i(\epsilon)\)

Consumers have heterogeneous preferences for product characteristics. the marginal utilities of price and product characteristics for consumer \(i\) in market \(t\) are given by the following:

\[
\begin{pmatrix}
\alpha_i \\
\beta_i
\end{pmatrix} =
\begin{pmatrix}
\alpha \\
\beta
\end{pmatrix} + \Sigma \nu_i, \quad \nu_i \sim N(0, I_{K+1}) \tag{2}
\]

Where \(\nu_i\) is an unobserved consumer attribute, and \(\Sigma\) is a matrix of parameters to be
estimated. \( \nu_i \) is assumed to be independently and identically distributed with distribution function \( P_v(\nu_i) \).

Consumer utility can be decomposed into the mean utility of purchasing product \( j \) in market \( t \), \( \delta_{jt} \), and an idiosyncratic deviation from that mean according to individual characteristics, \( \mu_{ijt} \). Let \( \theta=(\theta_1, \theta_2) \), where \( \theta_1 \) denotes parameters associated with mean utility and \( \theta_2 \) denotes parameters associated with individual utility. Mean utility of choosing the outside option \( j = 0 \) is normalized to zero.

\[
U_{ijt} = \delta_{jt}(x_{jt}, \xi_{jt}, p_{jt}; \theta_1) + \mu_{ijt}(x_{jt}, p_{jt}, \nu_i; \theta_2) + \epsilon_{ijt}
\]

\[
\delta_{jt} = \alpha p_{jt} + x_j \beta + \rho f(j) + \lambda b(j) + \eta c(j) + \gamma + \xi_{jt} \tag{3}
\]

\[
\mu_{ijt} = (x_{j} p_{jt})(\Sigma \nu_i) \tag{4}
\]

Consumers choose the product \( j \) which maximizes utility given individual characteristics. The set of individual characteristics which lead to the purchase of product \( j \) in market \( t \) is given by:

\[
A_{jt}(x_{.t}, \xi_{.t}, p_{.t}; \theta) = \{(\nu_i, \epsilon_{i0t}, ..., \epsilon_{ijt}) \mid U_{ijt} \geq U_{ilt} \ \forall \ l = 0, ..., J \} \tag{5}
\]

Market shares are found by integrating the probability of purchasing product \( j \) over the distribution of characteristics which lead to the purchase of product \( j \):

\[
s_{jt} = \int_{(v, \epsilon) \in A_{jt}} s_{ijt} \ dP_v(v) dP_\epsilon(\epsilon) \tag{6}
\]

Given \( \epsilon_{ijt} \) is distributed type I extreme value, the probability that a consumer \( i \) purchases product \( j \) in market \( t \) is given by:

\[
s_{ijt}(x_{.t}, \xi_{.t}, p_{.t}, \nu_i; \theta) = \frac{\exp(\delta_{jt} + \mu_{ijt})}{1 + \sum_{k=1}^{J} \exp(\delta_{kt} + \mu_{ikt})} \tag{7}
\]
Market demand is computed as the product of market share and the number of consumers in the market, \( M_t s_{jt} \). The integral above is evaluated using simulation techniques involving random draws of consumers in a market. Random draws are generated using a Halton sequence with prime 3. The first 15 elements of the sequence are dropped to reduce the correlation between sequences in multiple dimensions (Train [2009]). Mean utility \( \delta_{jt} \) is calculated by matching simulated market shares to observed market shares using the contraction mapping suggested by BLP. Parameter estimates are found using non-linear generalized method of moments (GMM).

Instrumental variables are necessary to address the endogeneity between prices and unobserved product characteristics. Let instrumental variables \( z_{jt} = [z_{1jt}, z_{2jt}, ..., z_{Rjt}] \) be a vector of instruments which are correlated with price but uncorrelated with \( \epsilon_{ijt} \). \( R \) corresponds to instruments generated from functions of product characteristics \( k \). Instrumental variables \( z_{jt} \) satisfy:

\[
E[\xi_{jt}|z_{jt}] = 0 \quad \forall \ j, t
\]

### 3.2 Market Supply

Supply is determined by Bertrand competition in which firms choose the price of their products to maximize profits. There is a fixed number of firms \( F \). Each firm produces a subset \( J_f \in J \) of products. Product characteristics are determined exogenously prior to the pricing game. Firms observe all product characteristics as well as the prices of competing products in a market. This includes unobservable (to the econometrician) characteristics \( \xi \). Firm knowledge of \( \xi \) induces a bias in the price coefficient and necessitates instrumental variable estimation. Firms choose prices to maximize profits given the characteristics of their products and the prices and characteristics of competing products. A Nash equilibrium to this pricing game is assumed to exist. Profits for firm \( f \) are given by:

\[
\Pi_{ft} = \sum_{j \in J_f} \left( p_{jt} - mc_{jt} \right) M_t s_{jt}(x, \xi, p; \theta)
\]

Where \( mc_{jt} \) is marginal cost of product \( j \) in market \( t \). A firm \( f \) sets an average price \( p_{jt} \)
for each \( j \in J_f \) that satisfies the first order conditions:

\[
s_{jt}(x, \xi, p; \theta) + \sum_{r \in J_f} (p_{rt} - mc_{rt}) \frac{\partial s_{rt}(x, \xi, p; \theta)}{\partial p_{jt}} = 0 \tag{10}
\]

This condition provides the optimal markup for each product in a market. Marginal costs can then be calculated as a function of observed prices. This will determine producer surplus in the industry.

### 3.3 Simulation

Sales tax rates are simulated to determine tax revenue, consumer surplus, and producer surplus. Prices \( p_{jt} \) are increased by the rate of the sales tax being simulated:

\[
P_{tax_{jt}} = p_{jt}(1 + \tau) \tag{11}
\]

Where \( \tau \) is the total sales tax levied on purchases of cannabis, and \( P_{tax_{jt}} \) is the post-tax price paid by consumers. Demand parameters \( \theta \) and marginal costs \( mc_{jt} \) are held constant. New equilibrium market shares and prices are calculated given the sales tax rate. Consumer surplus for individual \( i \) in market \( t \) is measured as the following:

\[
CS_{it} = \frac{1}{|\alpha|} \cdot \ln \left[ \sum_{j=1}^{J} \exp(\delta_{jt} + \mu_{ijt}) \right] \tag{12}
\]

Dividing by \( |\alpha| \) translates consumer utility into dollars. Producer surplus is given by the profit equation. Tax revenue is calculated as the percentage of total sales.

### 4 Data

Data for this estimation comes from BDS Analytics. The data include sales from approximately 19% of dispensaries operating in Colorado. Sales data are weighted to be representative of total industry sales based on the algorithms of BDS Analytics. The data provide daily
product level average price and sales for cannabis products sold in Colorado between 2014 and 2016. Colorado is chosen as it is the first state to have opened its doors to retail adult-use cannabis sales on January 1st, 2014. The existing medical cannabis industry framework facilitated the rapid expansion of the industry relative to other states with adult-use cannabis. The data is restricted to sales occurring prior to 2017. A major provider of software which tracks sales of cannabis from dispensaries faced hacks and outages in January of 2017. This resulted in dispensaries which were forced to shut down or record sales by hand momentarily. Sales after 2016 are eliminated to avoid biases in my estimates due to this event.

Cannabis comes in the form of flower, edibles, and concentrates. Flower refers to the flower of the cannabis plant which is trimmed and dried to be made available for use. Edibles are food or drink items which contain extracts of cannabinoids, the chemical compounds found in the cannabis plant. And concentrates are extracts of the cannabis plant which come in a condensed form. I focus my estimation on sales of adult-use cannabis edibles. Edibles are the ideal product class for measuring consumer preferences for characteristics. Edibles are required to display product characteristics on their packaging. This includes the composition of cannabinoids and the number of units of the edible included in a package. Consumers everywhere in Colorado will face the same reported characteristics for an edible across time. Consumers of flower or concentrates will face different product characteristics across dispensary locations and across time due to varying potency test results. Edibles also provide observable characteristics which are not readily observable in flower or concentrates. This includes characteristics such as flavor, brand, and type of food or drink item. Additional characteristics provide greater insight into consumer valuation by eliminating some of the bias between the price coefficient and unobserved characteristics that would otherwise persist. I choose the market for adult-use cannabis as it is the adult-use industry which faces high tax rates and generates the majority of revenue from the entire industry.

Individuals choose to purchase a product in every market. Markets are defined to be monthly observations. Observable characteristics of edibles include a product class, brand, flavor, chemical composition, and number of units in a package. Product classes refer to the type of the food or drink item. Examples of product classes include beverages, candy, or baked goods. Chemical composition refers to the milligram quantity of tetrahydrocannabinol (THC) or cannabidiol (CBD) included in the edible. Price is calculated as the average retail

\[ \text{Price} = \text{Average Retail Price} \]

\[ 1 CCR 212-2-R 1004.5 \]
price of a good in that market. Prices are scaled to 2016 dollars using the biannual CPI for the Denver-Boulder-Greeley metropolitan area. Table I displays summary statistics for the products in the data.

There are over two-thousand unique product entries in the data. I reduce the sample to the top quintile of cannabis edibles in terms of total sales over this time period. A number of products in the data are not uniquely identifiable by their product name. This is because a product name may be associated with multiple characteristics. For example, an edible may come in the form of 10mg or 100mg total THC per package. These products are excluded from the data. Identifiable products in the top quintile comprise approximately 76% of all sales in the data. Product characteristics are collected from online sources. I use firm websites, cannabis product websites, product images, and other sources in order to determine product flavor, chemical composition, and units. Unobserved product characteristics are included to account for characteristics or demand shocks that are not observed in the data. A dispensary vendor may have biases that lead them to suggest a particular product to consumers for example.

I use survey data from the National Survey on Drug Use and Health as well as information in Light et al. 2014 to determine population demographics for adult-use cannabis in the state of Colorado. Nearly 13% of the Colorado population reports yearly use of cannabis, 9% report monthly use, and 3% report daily use. Approximately 84% of consumers purchase their products in the adult-use market, while the remainder purchase their products in the medical market. Approximately 7.3% of sales in the adult-use market are made to out of state consumers who visit Colorado. I use the population of monthly cannabis users in Colorado in my main specification. I explore a variety of alternative market definitions to ensure my results are robust to different market definitions.

Consumers are assumed to purchase one unit of cannabis products in a market. I define one unit of cannabis products to be the average consumption of cannabis users in a month. Survey data suggests consumers of cannabis use between 0.3-1.6 grams of cannabis flower on a day of use. I use the percentage of consumers by frequency of use to calculate average monthly usage. This provides a measure of between 13.2 - 16.6 grams per month. I utilize the pharmacokinetic equivalency of cannabis flower to convert this number into quantity of edibles (Orens et al. 2015). This measure assumes that consumers demand equivalent
psychoactive impacts of cannabis when purchasing products. This measure translates 13.2 grams of flower into 39.6 10mg edibles. Edibles are often sold in packages of ten units containing 10mg each. This suggests consumers purchase approximately four packages of edibles each month. Discussions with industry professionals suggest that this number may be large for the average consumer. I reduce this number by half and assume that consumers purchase two packages of cannabis edibles in a month, or choose the outside option of no purchase. I test a variety of alternative definitions for the number of units sold in a market to ensure the robustness of my results.

5 Instruments

Instrumental variables are used to address the endogeneity between unobserved characteristics and prices. I use BLP type instruments consisting of own and rival product characteristics as instruments for price. This includes the sum of the characteristics of every other product, the sum of the characteristics of every other product produced by the same firm, and the sum of characteristics of all products not produced by the same firm in a market. The number of competing products in a market is also considered as an instrument. I additionally compute these variables within product classes and within product flavors. Identification of the parameters comes from variation in the choice set of products in a market which determine the optimal pricing strategy for a firm. From equation (10), the pricing decision of a firm depends on market share $s_{jt}$, which is a function of all product characteristics $x$. From equation (1), the utility a consumer derives from a product depends only on that product’s characteristics. BLP type instruments therefore satisfy the relevance and exclusion requirements of instrumental variables. I test for weak instrumental variables using the Cragg-Donald F-statistic. I test the exclusion requirement using the Hansen J statistic of Hansen 1982.

6 Results

The results of equation (1) are displayed in table 2. The first and second columns display the results of the fixed coefficient logit model. This specification assumes the marginal utility
of product characteristics does not vary between consumers. The first column reports results with no instrumental variables on price. The second column includes instrumental variables on price. The coefficient on price increases in magnitude when instrumental variables are used. This is consistent with instruments which control for the correlation between price and unobserved characteristics. The fixed coefficient logit model leads to unrealistic substitution patterns between products. Cross-price elasticities are proportional to a product’s market share. Products with the same market shares will have equivalent elasticities given a change in the price of another product. This is unrealistic as one might expect consumers to substitute towards goods with similar characteristics given a change in the price of a particular product. Estimation of the BLP model addresses this concern by allowing the marginal utility of characteristics to vary by consumer.

The third column displays the results of the random coefficient logit model of BLP with a random coefficient on THC. This variable is chosen as it is expected to be the main determinant of consumer demand. The standard deviation on THC is smaller in magnitude than the THC coefficient, implying positive marginal utility with respect to THC for nearly every individual in the market. Estimation with additional random coefficients is attempted, however limitations with instrumental variables make it difficult to identify a set of instruments which satisfy the relevance requirement and exclusion restriction. Columns 2 and 3 all satisfy tests for relevance and exclusion given by the Cragg-Donald Wald F-statistics and Hansen-J statistics.

The marginal utility associated with other product characteristics are of the expected sign. CBD provides positive utility to consumers. The sign on the squared terms for THC and CBD are negative, suggesting consumers have declining marginal utility with respect to these characteristics. I have no strong priors on the sign of the coefficient on count. The coefficient on count is negative and significant at the 10% level. This suggests consumers prefer edibles which come in a lower number of separable units.

The demand elasticities implied by column (3) of table 2 are reported in tables 3 - 5. I report the own and cross-price elasticities for the top 10, middle 10, and bottom 10 products in terms of sales for the month of January 2014. This market is chosen for simulation in order to make the simulation of equilibrium prices feasible given the large number of products in the data set. The sales weighted average own-price elasticity of the products is -2.54, implying
an average markup of 51.8%. Most top brands in the industry target a markup of 50% according to industry professionals. This provides a realistic measure of marginal cost for the products in the industry.

The result of the sales tax simulation is reported in the graph below table 5. The optimal tax rate which maximizes tax revenue occurs at 65.8%. The consumer and producer surplus decrease to approximately half of their level under the current sales tax rate of 17.34%. This revenue maximizing rate is well above the sales tax rates charged by states which permit legal cannabis. This is evidence that states could safely consider charging higher tax rates in order to pursue greater revenue from cannabis.
7 Tables and Figures

Figure 1

![Colorado Cannabis Sales](image1)

Figure 2

![Colorado Cannabis Tax Revenue](image2)

Tax revenue data is displayed February 2014 through December 2016.
Table 1: Summary statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
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<td>Quantity</td>
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<td>2514.491</td>
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<tr>
<td>Price</td>
<td>19.333</td>
<td>7.166</td>
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<tr>
<td>THC</td>
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<tr>
<td>CBD</td>
<td>2.821</td>
<td>14.992</td>
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<tr>
<td>Count</td>
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<td>5.257</td>
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<tr>
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<td>6580.049</td>
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</table>

* Quantity is the number of individual cannabis edible packages sold in a market. Price, THC, CBD, and Count are measured per individual package. Population is the number of potential cannabis consumers in a market.
Table 2: Demand Estimation

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<tr>
<th>VARIABLES</th>
<th>Fixed Coefficient Logit</th>
<th>Random Coefficient Logit</th>
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<td></td>
<td>OLS</td>
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<td></td>
<td>(1)</td>
<td>(2)</td>
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</table>

<table>
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<tr>
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<td>THC^2</td>
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<td>CBD</td>
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* The following table displays the results from estimating equation (1). The first column corresponds to the fixed-coefficient logit model with no IV’s. The second column corresponds to the fixed-coefficient logit model with IV’s. The third column corresponds to the random-coefficient logit (BLP) model. Flavor, brand, class, and time fixed effects are not reported. Relevance is the Cragg-Donald Wald F statistic. Exclusion is the p-value of the Hansen J statistic. Robust standard errors in parentheses.

** p<0.01,  ** p<0.05,  * p<0.1
**Table 3: Demand Elasticity: Top 10 Products**

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<th>Item 1</th>
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<th>Item 3</th>
<th>Item 4</th>
<th>Item 5</th>
<th>Item 6</th>
<th>Item 7</th>
<th>Item 8</th>
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* The following table displays the elasticities of demand with respect to price for the top 10 products in terms of sales for January 2014.

**Table 4: Demand Elasticity: Middle 10 Products**

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* The following table displays the elasticities of demand with respect to price for the middle 10 products in terms of sales for January 2014.
### Table 5: Demand Elasticity: Bottom 10 Products

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<th>Item 1</th>
<th>Item 2</th>
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<th>Item 4</th>
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<th>Item 7</th>
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</table>

* The following table displays the elasticities of demand with respect to price for the bottom 10 products in terms of sales for January 2014.

---

![Cannabis Industry Surplus](image)

**Cannabis Industry Surplus**

- **Tax Revenue**
- **Producer Surplus**
- **Consumer Surplus**
References

1 CCR 212-2-R 1004.5 (2017).
1 CCR 212-2-R 103 (2017).
1 CCR 212-2-R 1501 (2017).
1 CCR 212-2-R 1507 (2017).


McFadden, Daniel et al. (1973). “Conditional logit analysis of qualitative choice behavior”. In:


