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

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Legalization of medical and adult-use (recreational) cannabis products in Colorado has permitted the formation of a large industry with sales of $1.31 billion in 2016. These sales generate significant tax revenue for the state. I estimate the revenue maximizing sales tax rate on cannabis products using data on sales of cannabis edibles for the adult-use market in Colorado between 2014 and 2016. I use a random coefficient logit model to estimate demand parameters that provide marginal costs, equilibrium prices, and welfare. This allows for the simulation of different rates to determine the revenue maximizing sales tax rate. I find this rate to be 47.6%.
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Legalization of cannabis has expanded considerably in recent years. Thirty-one states and the District of Columbia have legalized cannabis use for medicinal purposes. Nine states and the District of Columbia have legalized adult-use (recreational) cannabis for individuals 21 and older. A significant number of states have also passed legislation permitting the use of cannabidiol (CBD) extracts for medicinal purposes since 2014. Nebraska and Idaho remain the only states who prohibit cannabis and its extracts in all forms. Legal cannabis sales in the United States are estimated to have reached $5.4 billion in 2015

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and $6.7 billion in 2016 (Huddleston Jr., 2016). Recent expansion to California, Maine, Massachusetts, Nevada, and Vermont means that over one fifth of the US population lives in a state which permits legal adult-use cannabis (Borchardt, 2017). Implementation of taxes on cannabis products will have important implications for policymakers. This paper utilizes a random coefficient logit model to estimate the revenue maximizing sales tax rate on cannabis.

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[1]. 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[2]. 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. The 15% rate for excise and sales taxes are the maximum rates allowed under Colorado law. Increasing the sales tax rate above 15% would require the approval of Colorado voters through a ballot initiative.

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.

[1]C.R.S. § 39-26-106; § 39-28.8-202
[2]C.R.S. § 39-28.8-302

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. A total of $69.4 million has been allocated to these funds between fiscal years 2013-14 and 2015-16, 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.

I investigate the welfare implications of taxation in the cannabis industry. Consumption of cannabis is 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. My results should be viewed as a component of the discussion surrounding cannabis, and should be considered in conjunction with potential negative externalities. I assume consumers make optimal purchasing decisions taking into account the sales tax rate. Tax rates applied at the register have been shown not to be fully salient (Chetty, Looney and Kroft, 2009). Consumers reduce their demand for products when the sales tax is explicitly stated in the price of a good. The assumption that sales tax rates are salient can understate consumer demand. This may suggest the estimated revenue maximizing sales tax rate falls below its true value.

Cannabis products exhibit significant heterogeneity. I utilize a static 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 (McFadden, 1974; Berry, 1994). This implies a fixed market structure in which the number of firms producing in the industry remains unchanged given changes in tax policy. I follow closely the estimation strategy of Berry, Levinsohn and Pakes (1995) (BLP hereafter) and the notation in Nevo (2000). 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 welfare, producer welfare, and tax revenue for different tax rates.

United States public policy has historically placed little value on consumer and producer welfare in cannabis relative to its potential external costs. There are significant concerns evaluating industry welfare with consumer and producer surplus included. States have nevertheless implemented policies which suggest positive valuation of these sources of welfare. Colorado cites "individual freedom" as a reason for legalizing adult-use cannabis in its constitution. Colorado additionally passed SB 16-040 in 2016 to expand investment opportunities in medical cannabis enterprises to out of state individuals. The law intends to allow businesses greater access to capital to remain competitive in the industry. Consumer and producer welfare measures are therefore considered to provide a complete depiction of the industry for states which may wish to consider these sources of welfare. Determining the revenue maximizing tax rate is an important consideration for the industry. States which permit adult-use cannabis have implemented sales tax rates ranging from 10% in Maine to 37% in Washington. Identifying the revenue maximizing rate will have significant implications for state governments and industry participants. Simulation results in a tax revenue maximizing rate of 47.6% in total sales tax applied to cannabis.

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 or law enforcement data to infer cannabis purchases and use. The use of product-level sales data allows for estimation of the substitution patterns between many cannabis products, and permits 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 welfare in an equilibrium setting.

This research is related to previous work on excess burden and optimal taxation. This literature covers one of the oldest subjects in public finance, with roots in the nineteenth century (Dupuit, 1995; Auerbach, 1985). Optimal commodity taxes with respect to utility measures are derived in Ramsey (1927). The trade-off between tax rates and tax revenue was first coined as the "Laffer Curve" in Wanniski (1978). The idea that additional tax revenue could be raised by cutting tax rates proved influential in public policy through the tax cuts of the Reagan administration. Researchers have quantified this trade-off in a variety of contexts. Lindsey (1986) utilizes the Economic Recovery Tax Act of 1981 as a natural experiment to explore taxpayer response to tax cuts. The author concludes income tax revenue would be maximized at a rate of 40%. The prospect of choosing a revenue maximizing tax rate is especially appealing in markets associated with negative externalities. Imposing a “sin tax” can account for external costs in commodities such as cigarettes, alcohol, or more recently, cannabis. Research on cannabis is severely limited by data constraints. Markets for cigarettes and alcohol may provide useful context for the cannabis industry as they are commodities used in recreation, are associated with negative externalities, and are prohibited in certain contexts. Michael Grossman utilizes cigarette demand functions from Becker, Grossman and Murphy (1994) to predict a revenue maximizing tax of $1.26 per pack in 1993 (Grossman et al., 1993). Jackson and Saba (1997) expand on Grossman’s work by considering prices at which consumers are priced out of the market. They predict a revenue maximizing tax of $1.10 per pack. The average price of a package of cigarettes excluding the $0.24 federal excise tax was approximately $1.45 in 1993[3]. An excise tax of $1.10 suggests an effective sales tax rate of 75.9%.

Recent work has explored the revenue maximizing tax rate for cigarettes in Malaysia (Mohamed Nor et al., 2013). The authors find that revenue is maximized with an excise tax which is just over 49% of the retail price of a cigarette. This is lower than the tax applied by a majority of high-income countries , and is well below the 70% tax share in retail price suggested by the World Health Organization[4] [5]. This suggests a revenue maximizing sales tax rate of approximately 96%. Tax revenue may depend significantly on consumer’s ability to evade taxes. Goolsbee, Lovenheim and Slemrod (2009) explore this issue by estimating the relationship between internet usage and cigarette tax revenue. Purchasing cigarettes online allows consumers to evade applicable state taxes more eas-

[3] https://www.tobaccofreekids.org/assets/factsheets/0210.pdf

[4] The World Bank Economics of Tobacco Toolkit, Design and Administer Tobacco Taxes. http://www.worldbank.org/en/topic/health/publication/economics-of-tobacco-toolkit

[5] http://www.who.int/tobacco/economics/taxation/en/

ily. The authors find that tax-free internet sales of cigarettes lead to a 9% decrease in revenue between 2001-2005, though states remain well below revenue maximizing tax rates. Tax evasion through illicit smuggling is a significant concern in the cannabis industry, which currently exhibits an extensive black market in the United States. States may additionally permit home cultivation of cannabis. This provides another avenue in which cannabis consumers may evade high tax rates. These concerns could suggest a lower value of the revenue maximizing tax rate than is estimated in this paper. The revenue maximizing tax rate on alcohol is explored in Miravete, Seim and Thurk (2017). A simple theoretical model deriving the Laffer curve in industries with market power is provided. The authors utilize the random coefficient logit model of BLP to calculate the revenue maximizing sales tax rate of 39.31% when regulators are endowed with perfect foresight of firm responses to taxation. The results of these papers are consistent with those in Dutkowsky and Sullivan (2014). This paper models excise taxes using a constant elasticity of demand function under monopolistic competition. The authors compute the revenue maximizing tax-price ratios for alcohol and cigarettes to be approximately 0.25 and 0.43 respectively. This equates to sales tax rates of 33.3% and 75.4% respectively. Previous results in labor, alcohol, and cigarette markets suggest my revenue maximizing sales tax rate is feasible.

This paper is also 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 consume harder drugs (DeSimone, 1998; Van Ours, 2003; Bretteville-Jensen and Jacobi, 2011). These papers provide some evidence that cannabis use can increase the probability of further drug use such as the use of cocaine. Others have investigated the impact of cannabis legalization or decriminalization. These include Miron and Zwiebel (1995); Pacula et al. (2000); Clements and Zhao (2009); Pacula et al. (2010); Pudney (2010); Donohue III, Ewing and Pelopquin (2010); Williams, Van Ours and Grossman (2011); Jacobi and Sovinsky (2016). These papers estimate varying responsiveness of cannabis use to legalization or decriminalization. Despite the health and safety costs associated with increased cannabis use, it is argued that decriminalization or legalization are preferred to prohibition.

Research has focused on the substitution patterns between cannabis and other substances. Previous studies have investigated the relationship between cannabis and alcohol (Mark Anderson, Hansen and Rees, 2013; Baggio, Chong and Kwon, 2017; Chaloupka and Laixuthai, 1997; DiNardo and Lemieux, 2001; Saffer and Chaloupka, 1999). Studies have also investigated the relationship between cannabis and cigarettes (Cameron and Williams, 2001; Choi, Dave and Sabia, 2016; Farrelly et al., 2001). There is no consensus on whether cannabis is a substitute or a complement with cigarettes or alcohol. 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.

The impact of tax policy within the legal adult-use cannabis industry in Washington is explored in Hansen, Miller and Weber (2017). This constitutes the first paper to my knowledge to investigate tax impacts in the legal cannabis industry. The authors find Washington's original tax policy of implementing a 25% tax on gross receipts at each step of the supply chain strongly encouraged vertical integration. Tax policy was reformed to place only a 37% excise tax on retail sales. Price responses between processors and retailers are found to violate tax-invariance folk theorem, as processors did not lower their wholesale prices by the amount of their reduced tax burden. The authors find Washington to be near the peak of the Laffer curve, and state that further increases in tax rates may not increase revenue. I find this to be consistent with the results of my estimation in Colorado. Revenue gains near my maximizing rate of 47.6% are small. Additional considerations including licensing and fee revenue suggest the revenue maximizing rate may be very close to that of Washington's.

The paper proceeds as follows. Section I discusses the history of cannabis prohibition and legalization in the United States as well the production process for cannabis products in Colorado. Section II details the empirical model for the cannabis market and the simulation undertaken to determine the revenue maximizing tax rate. Section III describes the data. This details the characteristics used in estimation as well as the assumptions made to permit the estimation of the discrete choice model. Section IV reports the results of the estimation. This includes a description of instrumental variables. The results of the demand estimation and simulation of tax rates are discussed. Section V concludes.

I. Background

A. 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.

Strong opposition to cannabis grew in the early twentieth century. Consumption of cannabis in the West was strongly associated with individuals of Mexican descent. Economic conditions combined with political turmoil as a result of the Mexican Revolution in 1910 created an influx of immigrants in the United States (Durand, Massey and Capoferro, 2005). It is widely argued that prejudice against Mexican immigrants coupled with their growing population significantly contributed to cannabis prohibition.

Early states to consider cannabis prohibition include Utah, New Mexico, Texas, Montana, and Colorado. Legislation was typically successful with relatively little debate and public attention. A short reference to Texas prohibition in the press at the time describes cannabis as “A Mexican herb...said to be sold on the Texas-Mexican border.” The issue was given greater coverage in Montana with the passage of a bill which made cannabis possession and use without a prescription a misdemeanor. The Montana Standard noted the following statement made in the Montana House Health Committee regarding the bill: “When some beet field peon takes a few rares of this stuff, he thinks he has just been elected president of Mexico so he starts out to execute all his political enemies... The

Silver Bow and Yellowstone delegations both deplore these international complications (Bonnie and Whitebread, 1970)." The Federal Bureau of Narcotics (FBN) Commissioner Harry J. Anslinger personally blamed Mexico for the dispersion of cannabis use at this time. Anslinger presided over the FBN and is one of the primary individuals responsible for the de facto prohibition of cannabis in the United States in the 1930's.

Prejudice was not the only source of growing opposition to cannabis. Many feared the negative consequences of its use. There was relatively low use of cannabis among individuals in eastern states. Early prohibition nevertheless occurred in states including New York, Massachusetts and Maine. Prohibition was driven by fear that cannabis use might increase in narcotics addicts as a result of greater restrictions on opiate and cocaine use. Reports of heinous criminal activity and irreparable health conditions reported by Anslinger and others bolstered the argument for state and federal regulation. Anslinger viewed cannabis use as a societal threat, stating "how many murders, suicides, robberies, criminal assaults, holdups, burglaries, and deeds of maniacal insanity it causes each year, especially among the young, can be only conjectured. The sweeping march of its addiction has been so insidious that, in numerous communities, it thrives almost unmolested, largely because of official ignorance of its effects (Anslinger and Cooper, 1937)." The 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. All but two states adopted the Uniform State Narcotic Drug Act by the end of 1936.

Fears regarding the dangers of cannabis 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 imposed de facto prohibition in the United States. The Marijuana Tax Act was replaced by the Controlled Substances Act (CSA) of the Comprehensive Drug Abuse Prevention and Control Act 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[6].

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 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[7].

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. Registered 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 Licensing 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

[6] 21 U.S.C. § 812
[7] Colo. Const. Art. XVIII, Sec. 14

cannabis center. Authorization 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[8].

Relatively little is known regarding optimal taxation in this industry. Early states to legalize adult-use cannabis like Colorado, Washington, and Oregon opened up markets for popular cannabis products for which there was very little data on prices or use. Most previous studies have been able to observe some data on quantities and prices of cannabis flower. It has widely not been possible to observe data on the use of edibles and concentrates. A description of these products is included in the following section. Prior experience with illicitly produced cannabis edibles or concentrates are unlikely to provide necessary knowledge of these products to predict consumer demand and the implications for tax revenue in the adult-use industry. Legalization of these products has allowed for large production facilities, innovation, differentiation of products, and consistency of products which was not available in the illicit market. State legislatures additionally have varying motivation for legalization. States may value reduction in law enforcement and incarceration costs, or may value personal freedom and the expansion of legal businesses

[8]https://www.denverpost.com/2013/12/31/a-colorado-marijuana-guide-64-answers-to-commonly-asked-questions/

in their state for instance. The result has been a wide range of tax policies across states with adult-use cannabis.

Maine has implemented the lowest tax rate with a 10% sales tax being the only tax applied to cannabis sales. Washington has implemented the highest tax rate with a 37% excise tax applied to retail sales. This is in addition to relevant state and local taxes. The state sales tax rate for Washington is 6.5%. Washington's Department of Revenue estimates a weighted average local sales tax rate of 2.82% for 2018[9]. This implies adult-use retail cannabis sales are taxed at a total rate of 46.32%. Remaining states which permit adult-use cannabis sales have implemented tax rates typically significantly lower than that of Washington. California has implemented a 15% excise tax on the average market price of cannabis on retailers. Cultivators are additionally charged a specific tax of $9.25 per ounce of cannabis flower. Massachusetts has implemented an excise tax of 10.75% on retailers. Nevada charges a 10% excise tax on retail sales in addition to a 15% tax on wholesale sales paid by cultivators. Oregon charges a tax rate of 17% on retail sales, with an option for localities to increase this rate to 20%. Finally, Alaska charges an excise tax of $50 per ounce of cannabis flower charged to cultivators. Vermont recently passed legislation permitting adult-use cannabis. A dispensary and tax system have yet to be established. The District of Columbia additionally does not have a formal dispensary system established[10].

B. 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[11] 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

[9]"Marijuana sales tax table" accessed at https://dor.wa.gov/about/statistics-reports/recreational-and-medical-marijuana-taxes

[10]All information is current as of September, 2018

[11]C.R.S. 12-43.4-401.

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[12]. Cultivators pay an excise tax equal to 15% of the average 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 dry 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[13]. 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

[12]Knowledge of cultivation comes from a tour of an anonymous cultivation center in Denver, CO.
[13]1 CCR 212-2-R 103; 1 CCR 212-2-R 605(A)(2)

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[14].

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[15]. Concerns over misuse of edible products encouraged restrictions on 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[16].

Products which satisfy testing requirements may be transported to retail stores for final

[14] 1 CCR 212-2-R 1501
[15] 1 CCR 212-2-R 1503
[16] 1 CCR 212-2-R 604(C.5.); 1 CCR 212-2-R 1507

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[17]. 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 of the true purchasing behavior for cannabis. This is similar to the assumption utilized in the market for cereal in Nevo (2001). 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 tetrahydrocannabinol (THC) or cannabidiol (CBD) in a package. While some edibles list the inclusion of additional cannabinoids such as cannabinol (CBN), these products are relatively uncommon. 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[18].

[17] 1 CCR 212-2-R 402

[18] Knowledge of consumer preferences comes from a personal interview with a cannabis dispensary manager.

II. Empirical Framework

A. Market Demand

Consumers demand cannabis edibles based on their characteristics. They are assumed to demand one serving of edibles which provides maximum utility in a market. Consumers will have heterogeneous preferences for the characteristics of edibles based on individual tastes. Edibles are differentiated across a variety of factors. This includes the composition of THC or CBD in the edible. This will be a primary source of demand for a product. A package will be divided into a varying number of units of edibles. Some consumers may prefer units of edibles with a high concentration of cannabinoids per unit. Others prefer a package of edibles to be divided into a greater number of units to provide smaller and more easily controlled doses of cannabinoids. There are different broad classes of edibles such as beverages or candy. These are available in a variety of flavors like chocolate or fruit. Finally, edibles will be differentiated according to the brand which produced them. As previously stated, the brand of edible may be of particular importance to consumers in this industry as a signal of product quality and consistency.

Consumer utility is modeled as a function of product characteristics (x, ξ, p) and individual characteristics ν. Here x denotes observable product characteristics including fixed effects, ξ denotes unobserved product characteristics, and p denotes price. Parameters to be estimated are represented by θ. There are t=1,...,T markets observed with i=1,...M_t consumers who decide between purchasing one unit of j=1,...J products. Markets are defined to be monthly observations for the state of Colorado. 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:

$$(1)\quad U_{ijt}(x_{jt},\xi_{jt},p_{jt},\nu_i;\theta) = \alpha_i(1+\tau)\cdot p_{jt} + x_j'\beta_i + \rho_{f(j)} + \lambda_{b(j)} + \eta_{c(j)} + \gamma_t + \xi_{jt} + \epsilon_{ijt}$$

Characteristics x_j denote a K$\times$1 vector of observed product characteristics k for product j, p_{jt} is the average pre-tax 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, γ_t is a product-invariant fixed effect that controls for changes in consumer's preferences for cannabis products over time, and ξ_{jt} is unobserved (by the econometrician) product characteristics or demand shocks for product j in market t. The parameter τ denotes the sales tax rate. This is equivalent to the sum of the cannabis sales tax, the state sales tax, and the average local sales tax for Colorado in the demand estimation. Parameters β_i denote a K$\times$1 vector of marginal utilities of the K product characteristics for individual i, α_i is the marginal utility of income for individual i, and ϵ_{ijt} is an independently and identically distributed type I extreme value error term with mean zero. Denote this distribution by $P_\epsilon(\epsilon)$ 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:

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

Characteristic ν_i is an unobserved consumer attribute, and Σ is a matrix of parameters to be estimated. Individual characteristics ν are assumed to be independently and identically distributed with distribution function $P_\nu(\nu_i)$.

Consumer utility can be decomposed into the mean utility of purchasing product j in market t, δ_{jt}, and an idiosyncratic deviation from that mean according to individual characteristics, μ_{ijt}. Let θ=(θ_1, θ_2), where θ_1 denotes parameters associated with mean utility and θ_2 denotes parameters associated with individual utility. Mean utility of choosing the outside option $j = 0$ is normalized to zero.

$$U_{ijt} = \delta_{jt}(x_{jt}, \xi_{jt}, p_{jt}; \theta_1) + \mu_{ijt}(x_{jt}, p_{jt}, \nu_i; \theta_2) + \epsilon_{ijt} \tag{3}$$

$$\delta_{jt} = \alpha p_{jt} + x_j' \beta + \rho_{f(j)} + \lambda_{b(j)} + \eta_{c(j)} + \gamma_t + \xi_{jt} \tag{4}$$

$$\mu_{ijt} = (x_j \quad (1+\tau) \cdot p_{jt})(\Sigma \nu_i) \tag{5}$$

Consumers choose the product j which maximizes utility given individual characteristics. The set of individual characteristics A_{jt} which lead to the purchase of product j in market t is given by:

$$A_{jt}(x_{.t}, \xi_{.t}, p_{.t}; \theta) = \{ \ (\nu_i, \epsilon_{i0t}, ..., \epsilon_{iJt}) \mid U_{ijt} \geq U_{ilt} \ \ \forall \, l = 0, ..., J \ \} \tag{6}$$

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:

$$s_{jt} = \int_{(v,\epsilon) \in A_{jt}} s_{ijt} \, dP_v(v) dP_\epsilon(\epsilon) \tag{7}$$

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

$$s_{ijt}(x_{.t}, \xi_{.t}, p_{.t}, \nu_i; \theta) = \frac{exp(\delta_{jt} + \mu_{ijt})}{1 + \sum_{k=1}^{J} exp(\delta_{kt} + \mu_{ikt})} \tag{8}$$

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 Halton sequences (Train, 2009). Mean utility δ_{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 ϵ_{ijt}. R corresponds to instruments generated from functions of product characteristics k. Instrumental variables z_{jt} satisfy:

$$E[\xi_{jt}|z_{jt}] = 0 \qquad \forall\, j, t \tag{9}$$

B. 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 ξ. Firm knowledge of ξ 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:

$$\Pi_{ft} = \sum_{j \in J_f} (\ p_{jt} - mc_{jt}\ ) M_t s_{jt}(x, \xi, p; \theta) \tag{10}$$

Where mc_{jt} is marginal cost of product j in market t. Marginal costs are assumed to be constant. A firm f sets an average price p_{jt} for each $j \in J_f$ that satisfies the first order conditions:

$$s_{jt}(x,\xi,p;\theta) + \sum_{r \in J_f} (\, p_{rt} - mc_{rt}\,) \frac{\partial s_{rt}(x,\xi,p;\theta)}{\partial p_{jt}} = 0 \tag{11}$$

This condition provides the optimal markup for each product in a market. Define a matrix Ω by the following:

$$\Omega(x,\xi,p;\theta) = \begin{cases} \frac{\partial s_{rt}(x,\xi,p;\theta)}{\partial p_{jt}}, & r,j \in J_f; \\ 0, & otherwise. \end{cases} \tag{12}$$

The J first order conditions may therefore be expressed by a vector of marginal costs:

$$mc = p + \Omega^{-1}(x,\xi,p;\theta)s(x,\xi,p;\theta) \tag{13}$$

Marginal costs can then be calculated as a function of observed prices. This will determine producer surplus in the industry.

C. Simulation

New sales tax rates τ are simulated holding constant coefficients θ and marginal costs mc_{jt}. It is assumed that there are no changes to the outside option for different tax rates. It is additionally assumed that there is no entry or exit of firms. This implies new market shares s_{jt} and equilibrium prices p_{jt} which determine welfare for the industry. Consumer surplus for individual i in market t is measured as the following:

$$CS_{it} = \frac{1}{|\alpha|} \cdot ln[1 + \sum_{j=1}^{J} exp(\delta_{jt} + \mu_{ijt})] \tag{14}$$

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 revenue.

III. 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 pre-tax 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 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.

I focus my estimation on sales of adult-use cannabis edibles. Edibles comprise approximately 17% of cannabis sales between 2014 and 2016. Focusing on this segment of the cannabis industry is similar to the strategy employed in Miravete, Seim and Thurk (2016), in which the authors focus on sales of spirits and exclude beer and wine from their analysis. Edibles are the ideal product class for measuring consumer preferences for characteristics in the data. All cannabis products are required to list their composition of cannabinoids measured through potency tests[19]. This means consumers will face different characteristics for a product across dispensary locations and across time. I am unable to provide potency information on flower and concentrates as a result. However, a majority of edibles will have a stated composition of cannabinoids displayed on their

[19] 1 CCR 212-2-R 1004.5

packaging which is constant through time. The stated composition of a package of edibles is often reported on dispensary menus, and is more readily viewed by consumers choosing between cannabis products compared to potency test results. I assume consumers choose edibles based on their stated composition of cannabinoids rather than their potency test results. Additionally, flower and concentrate products created from a particular strain of cannabis may be produced by multiple firms. I am unable to observe the producing firm of these products in the data. A particular edible will be produced by a unique firm. The ability to observe the brand of edible permits estimation of the profit maximizing behavior of firms. 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 for the entire industry.

I use BDS Analytics consumer survey data to consider differences in the population of individuals who consume edibles compared to the entire population of individuals who purchase cannabis at dispensaries[20]. The largest share of cannabis Consumers is between the ages of 25 and 34. Consumers are significantly more likely to have obtained a bachelor's degree or higher. Consumers are less likely to be married, and less likely to have children in their household compared to the Colorado population. Consumers who prefer edible cannabis products differ in characteristics compared to Dispensary Shoppers. Consumers of edibles are older on average by 2.3 years. Preference for edibles is significantly less likely for individuals aged 21-24, while preference for edibles is significantly more likely for individuals aged 55-64. Women are more likely than men to prefer edibles. Individuals who prefer edibles are more likely to hold a bachelor's degree or higher, earning close to $10,000 more per year in household income compared to Dispensary Shoppers. Consumers of edibles consume cannabis less frequently. They are significantly less likely to consume daily, and more likely to consume on a less than weekly basis. Differences between individuals who consume edibles rather than flower or concentrates are likely to influence the revenue maximizing tax rate on cannabis. Higher income may imply individuals who consume edibles are less price sensitive, leading to a tax rate which overstates the revenue maximizing rate for the entire industry. In this

[20]BDS Analytics: "Cannabis in the USA; Public Attitudes and Actions Toward Legal Cannabis in CO" Q1 (2017).

case the tax rate may be viewed as an upper bound on the revenue maximizing rate for all cannabis products.

Individuals choose whether or not 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. Categories of flavor are generated to control for consumer taste. Examples of flavor categories include chocolate, fruit, and caramel. Chemical composition refers to the milligram quantity of THC or CBD included in the edible. I additionally include an indicator for an edible containing 100 mg THC in a package to account for products whose chemical composition meets the maximum allowed by law. Price is calculated as the average pre-tax retail price of a good in that market. Prices are scaled to 2016 dollars using the biannual CPI for the Denver-Boulder-Greeley metropolitan area. The average state sales tax rate is calculated as the sum of the special adult-use cannabis sales tax, the state sales tax, and the average local sales tax in Colorado as calculated by the Tax Foundation[21].

Product characteristics must be collected for each individual edible. I link products to their composition of THC and CBD, units per package, and flavor using firm websites, cannabis product websites, product images, and other online sources. There is partial information regarding these characteristics for some products in the data. However, this must be completed through individual search for a majority of the products. Table 2 displays summary statistics for the products used in estimation. There are over two-thousand unique product entries in the data. This includes a significant number of unpopular items which sell infrequently, as well as items from firms who briefly produced in the industry before exiting or merging with other cannabis firms. It is a concern with the large number of products that coefficient estimates may be largely driven by the value of the error term in order to explain consumer choices. Additionally, collection of product character-

[21]https://taxfoundation.org/state-and-local-sales-tax-rates-2014/; https://taxfoundation.org/state-and-local-sales-tax-rates-2015/; https://taxfoundation.org/state-and-local-sales-tax-rates-2016/

istics is significantly time consuming. I reduce the sample to the top quintile of cannabis edibles in terms of total sales over this time period to feasibly permit the collection of product characteristics. 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. This results in a selected data set of products which sold relatively well in a market. This will potentially bias my coefficient estimates. This issue is detailed in Gandhi, Lu and Shi (2017). A selected sample may bias the price coefficient and demand elasticity towards zero. This could lead to an estimated revenue maximizing tax rate which overstates the true rate by predicting less price sensitive consumers. I nevertheless estimate demand elasticities which predict product markups which closely resemble what is observed in the industry. My estimates potentially provide credible measures of consumer demand for cannabis as a result.

I use BDS Analytics consumer survey data to determine population demographics for adult-use cannabis in Colorado[22]. Consumers of cannabis are defined to be adult Colorado residents who have consumed cannabis in the previous six months. Consumers comprise 25% of the adult population of Colorado. 84% of Consumers do not have a medical card and are supplied cannabis through the adult-use market. I utilize this population in my preferred specification. I consider alternative market size measures using survey data from Light et al. (2014). This survey determines nearly 13% of the total Colorado population reports yearly use of cannabis, 9% report monthly use, and 3% report daily use. 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 who receive cannabis through the adult-use market to test the robustness of my results with respect to the choice for market size.

Consumers are assumed to purchase one unit of cannabis products in a market. I de-

[22]BDS Analytics: "Cannabis in the USA; Public Attitudes and Actions Toward Legal Cannabis in CO" Q1 (2017).

fine one unit of cannabis products to be the average consumption of cannabis users in a month. This is similar to the strategies employed by Nevo (2001) and Miravete, Seim and Thurk (2016). Nevo calculates market shares by defining a unit of cereal to be equivalent to the serving size suggested by the manufacturer, and Miravete et al. define a unit of alcohol spirits to be equivalent to a 750 ml bottle. 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 consider units defined to be four packages of edibles to test the robustness of my results with respect to the choice for serving size.

IV. Results

A. Instrumental Variables

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. I am unable to link cost characteristics to the individual products for use as instrumental variables due to data constraints. Instrumental variables include 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).

B. Demand Estimation

The results of equation (1) are displayed in table 3. The first and second columns display the results of the fixed coefficient logit model[23]. This specification assumes the marginal utility of product characteristics does not vary between consumers. The first column reports OLS logit results. The second column reports instrumental variables estimation. The coefficient on price increases in magnitude and significance 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 price[24]. Edibles frequently exhibit similar concentrations of THC. Price is a strong determinant of consumer demand for an edible as a

[23]Estimation of coefficients is undertaken using the Stata random coefficient logit command, accessible at: https://econpapers.repec.org/software/bocbocode/s458216.htm

[24]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.

result. The standard deviation of the coefficient on price is smaller in magnitude than its mean coefficient. This implies negative marginal utility with respect to price for every individual in the market. Columns 2 and 3 both satisfy tests for relevance and exclusion given by the Cragg-Donald Wald F-statistic and Hansen-J statistic.

The marginal utility associated with other product characteristics are of the expected sign. THC and CBD provide positive utility to consumers. The sign on their squared terms are negative, suggesting consumers have declining marginal utility with respect to these characteristics. I have no strong priors on the sign of the coefficient for units per package. Consumers may prefer strong edibles which come in a smaller number of units, or consumers may prefer a larger number of separable units in their edibles package to allow for smaller and more easily controlled doses of cannabinoids. The coefficient on Units is negative and insignificant in the BLP specification. The coefficients on THC and its square are used to construct consumers' willingness to pay for THC depicted in figure 3. Marginal utility is positive for THC concentrations up to 95 milligrams per edible. Total utility from an edible is maximized near the legal limit of 100 milligrams chosen by many edibles producers. The THC component of a 100 milligram edible is valued at $8.95. Additional valuation of an edible is explained through preferences for flavors, brands, classes of edibles, and product invariant consumer preferences for edibles through time. This arguably provides a realistic measure of consumer utility for THC.

C. Simulation

Consumer characteristics ν are simulated using Halton sequences[25]. The demand elasticities implied by the BLP estimation are reported in tables 4 - 6. 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. The sales weighted average own-price elasticity of the products is -2.73. Constant marginal costs implied by equation (13) are calculated from the predicted market shares. The average marginal cost to produce a package of edibles is estimated

[25] See Train (2009). Estimation of predicted market shares is undertaken using 200 draws to approximate the integral in equation (7). This is the number of draws in which there is little change in the set of random coefficients. Simulation results are similar when the number of draws is increased to 1,000.

to be \$12.55 with a standard deviation of \$4.24. Predicted costs range from \$0.61 to \$24.67. The lowest cost item corresponds to a single 10 milligram serving edible which sells at low prices. The highest cost item corresponds to an edible containing high concentrations of both THC and CBD. Adult-use products which include both cannabinoids typically sell at significantly higher prices. Marginal costs imply an average markup of 40.8%. Most top brands in the industry target a retail markup of 50% according to industry professionals. This suggests my estimates provide a realistic measure of marginal cost for the products in the industry. Different sales tax rates τ are simulated. Marginal costs and demand parameters are held constant. Varying sales tax rates imply a new profit maximizing pricing decision for firms and purchasing decision for consumers. New equilibrium prices and market shares are calculated given the sales tax rate. This allows for the estimation of consumer surplus, producer surplus, and tax revenue for any rate τ. I simulate welfare for sales tax rates between 0-100% in intervals of 5. I then conduct simulation necessary to determine the revenue maximizing rate within 0.1%.

The result of the sales tax simulation is reported in figure 4. Simulation is conducted for the month of June, 2015. This month signifies the midpoint of the data set. The revenue maximizing tax rate occurs at 47.6%. Over two-thirds of the maximum revenue is achieved at the current tax rate of 17.44%. This corresponds to a maximum revenue of \$1.78 million relative to current revenue of \$1.23 million. The actual sales tax revenue raised from the entire adult-use cannabis industry in June 2015 was approximately \$5.90 million. This suggests the industry could achieve a maximum of \$8.52 million in revenue if the state had implemented a sales tax rate of 47.6%. Consumer and producer surplus decline by 52.7% and 31.8% respectively from their current rates when the tax rate is raised to 47.6%. Revenue changes near tax rates of 47.6% are relatively small. 96.4% of maximum revenue is achieved at a tax rate of 35% for instance. States which value cannabis consumer or producer surplus may therefore wish to consider charging a tax rate less than the revenue maximizing rate. States which do not value cannabis consumer and producer surplus can charge the revenue maximizing rate and expect significantly decreased production and consumption from the legal market.

The simulation results do not account for additional revenue that may be raised through excise taxes on cultivators and through licensing and fees. These sources of revenue are significant. Revenue from excise taxes on recreational cannabis totalled 6.0% of the value of total sales between 2014-2016. It is unclear how these sources of revenue will change with the sales tax rate. Excise taxes are calculated as 15% of the Average Market Rate (AMR) for unprocessed cannabis sold between a cultivator and another licensed cannabis firm. AMRs are calculated biannually by the Department of Revenue. The quantity of unprocessed cannabis used in a package of edibles will vary across time and between firms. Unprocessed cannabis will possess different levels of cannabinoids. Firms will have varying levels of efficiency in converting this flower into their particular variety of edible. Sales tax rates may additionally influence the wholesale price of unprocessed cannabis and directly impact the calculation of the AMR. It is difficult to predict how license and fee revenue will change with higher sales tax rates. Higher rates could reduce firm entry and more drastically reduce license and fee revenue. I conduct a back-of-the-envelope calculation to consider the impact of excise taxes, licensing, and fees. I assume revenue from these sources remains a constant fraction of total sales, as calculated by the ratio of total excise, licensing, and fee revenue to total sales from 2014-2016. Revenue from all sources is maximized at a sales tax rate of 39.2% under this assumption.

I test the robustness of my results by considering an alternative definition for the size of the market and a unit of cannabis edibles. I define the market size to be the population of monthly cannabis users who are supplied through the adult-use cannabis industry based on Light et al. (2014). This results in a measure of market size which is just under half of the preferred market size. Simulation results in a revenue maximizing sales tax rate of 59.5%. The revenue maximizing sales tax rate does not appear to be largely dependent on the definition for market size given the substantial difference in the two measures. The market size defined to be the population of adults who have consumed cannabis in the past six months is preferred to this definition as it is derived from more recent survey data using respondents who have had the opportunity to participate in the adult-use cannabis industry. This additionally takes into account infrequent users who may not use cannabis every month, but may nonetheless be a significant consideration for the market. I additionally redefine a unit of cannabis to contain four packages of edibles and use my preferred measure for market size. This definition results in a revenue maximizing tax rate of 43.8%. My results do not appear to be strongly dependent on the definition for a serving of edibles.

The revenue maximizing tax rate is estimated for alternative methods of taxation. Legislators could impose a tax on the quantity of edibles packages sold. The revenue maximizing tax on quantity occurs at a rate of $10.65 per package. The average price of an edible is approximately $18.89 before taxes. This excise tax rate is therefore equivalent to a 56.4% sales tax rate applied to a package of edibles sold at the average price. Legislators could also impose a tax on the concentration of THC in an edible. This could more directly address concerns regarding the negative impact of THC. The revenue maximizing tax on THC concentration occurs at 12.7 cents per milligram of THC. The average concentration of THC in an edible is 83.8 milligrams per package. This tax rate on THC is therefore equivalent to a 56.3% sales tax rate applied to the average edible.

There may be concerns that the sample used in estimation includes a large number of products. Consumer choice may be largely explained by the value of the error term as a result. I consider reducing the sample to include the top ten and top five percent of products in terms of sales over the sample period. Estimation within these samples achieves qualitatively similar coefficient estimates for the fixed-coefficient logit model. However, estimates suffer from weak instrumental variables. Simulation is not conducted within the reduced samples as a result. My sample includes a comparable number of products to Miravete, Seim and Thurk (2016).

These results may be sensitive to the modeling assumptions. I assume a fixed number of producing firms with constant marginal costs. There has been variation in the number of firms in the industry. There were a large number of firms which began production at the start of the industry in 2014. This included inexperienced and inefficient firms which produced edibles at high cost or low quality. Firms have additionally faced large fixed costs in complying with industry regulations such as licensing and product testing.

There has been consolidation of firms as a result [26]. Larger and more experienced firms are able to produce higher quality edibles at lower cost. This trend may persist as the industry continues to grow. Lower costs will increase total welfare in the industry and provide the opportunity to extract greater revenue from sales. This may suggest a higher revenue maximizing sales tax rate.

The results may be sensitive to the type of cannabis product used in estimation. Consumers of edibles differ from consumers of flower and concentrates. Edibles consumers are typically higher income, older, and less frequent users of cannabis. This may suggest less price sensitive consumers who have a revenue maximizing rate which is higher than the rate for the cannabis industry as a whole.

The potential to raise revenue through the cannabis industry is substantial. Colorado has collected $638 million in total revenue from the industry between 2014 and 2017. Implementation of the revenue maximizing sales tax rate may raise additional funds to provide for important government programs. The industry has permitted the contribution of over $150 million to public school works between fiscal years 2013-14 and 2016-17. Funds have provided for public programs in substance abuse, mental health services, affordable housing, and many others. Funds have additionally been allocated towards more effective law enforcement and correction services through training, diversion programs, and jail-based behavioral services.

There are trade-offs of imposing high tax rates. Producer surplus declines significantly at the revenue maximizing rate. Lower profits for legitimate business means less employment and growth in the industry. This may place additional pressure on smaller scale producers and reduce competition. Consumers have a variety of substitutes to the adult-use industry. Consumers may be encouraged to undertake home cultivation to avoid high tax rates. Consumers could additionally find it possible to obtain certification to access medical cannabis at lower tax rates. Finally, consumers could increasingly find it worthwhile to procure cannabis on the black market. Increased illicit activity means higher law enforcement and incarceration costs for a state and profits from cannabis which fund

[26]Knowledge of firm consolidation comes from a personal interview with a cannabis product manufacturer.

criminal organizations. Black market production additionally means consumers access products for which there are no health or safety regulations.

V. Conclusion

Legalization of cannabis has become a topic of significant interest to legislators in recent years. Legal cannabis provides the opportunity to generate tax revenue for a state that may fund important programs in education, health, and law enforcement. This paper provides the first estimate of the revenue maximizing sales tax rate in the industry measured using a structural model of consumer and firm behavior in equilibrium. This rate will be an important consideration for policymakers. States have implemented sales tax rates for adult-use cannabis ranging from 10% - 37%. States have varying motivations for legalizing adult-use cannabis. Colorado has implemented policies which place value on cannabis consumers and seek to increase firm access to capital to improve competitiveness and facilitate innovation in cannabis products. Washington has implemented relatively steep tax rates which generate significant revenue at the expense of industry growth. States currently prohibiting adult-use cannabis which may consider legalization in the future may consider potential tax revenue to be of primary concern. The results of this paper should provide context for the welfare implications of varying adult-use cannabis policy.

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Tables and Figures

FIGURE 1.

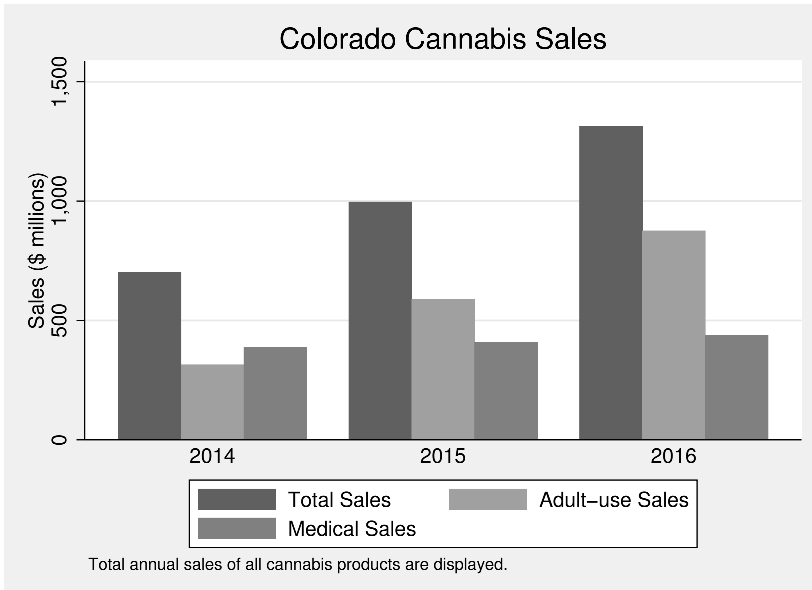


FIGURE 2.

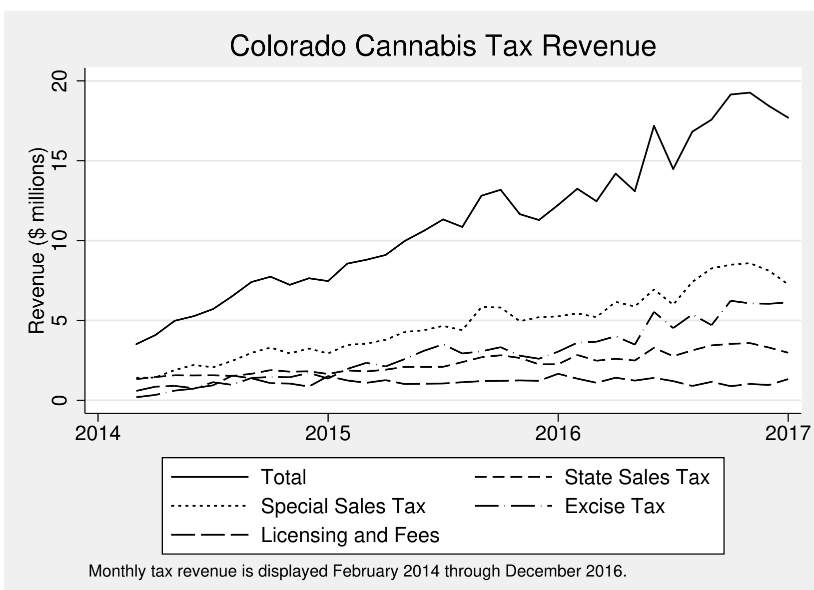
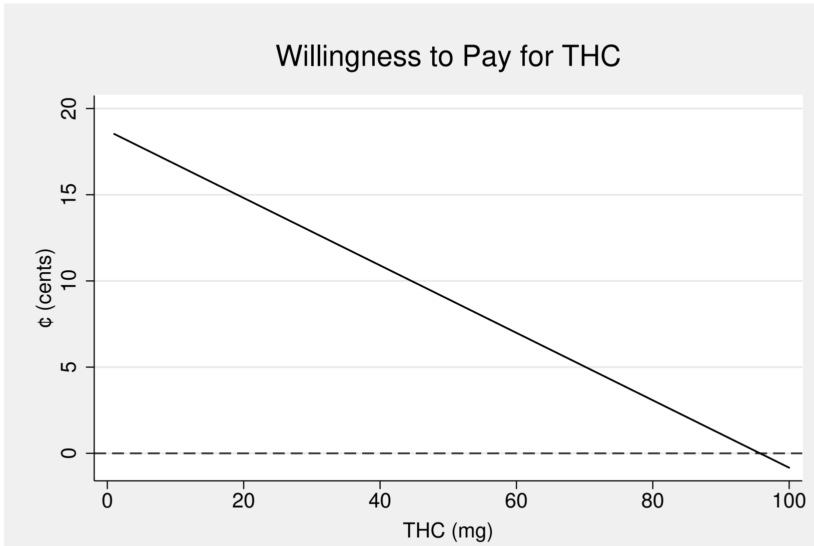
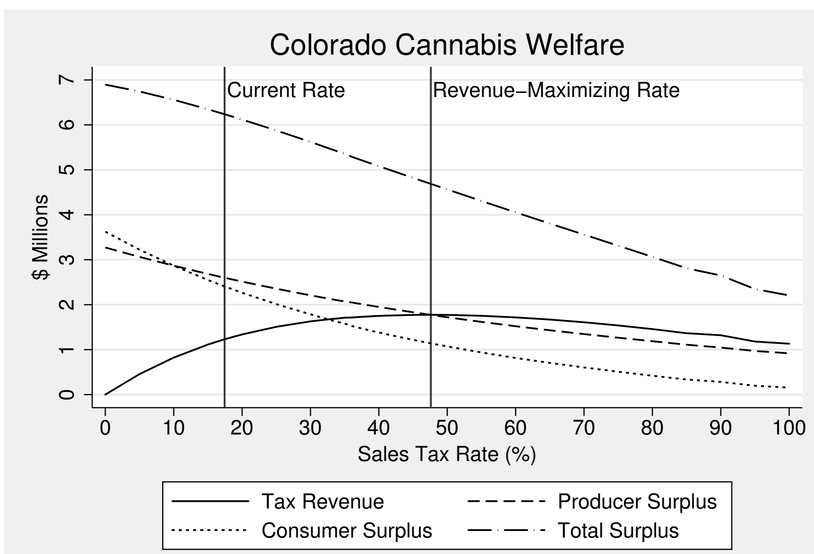


FIGURE 3.



Results from BLP specification. Utility is converted to cents using the mean of the price coefficient.

FIGURE 4.



Simulation results for BLP specification.

TABLE 1—COLORADO DEMOGRAPHICS. FIGURES ARE FOR 2016.

Variable	Value
Population	5,530,105
African-American	4.5%
Asian/Pacific Islander	3.5%
Native-American/Alaskan	1.6%
White	87.5%
Other	3%
Hispanic	21.3%
Female	49.8%
Median Age	36.4
Aged 20-24	7.1%
Aged 25-34	14.9%
Aged 35-44	13.5%
Aged 45-54	13.4%
Aged 55-64	12.6%
Aged65+	12.6%
Bachelor's Degree or Higher	38.7%
Average Household Income	$84,384

TABLE 2—SUMMARY STATISTICS

Variable	Mean	Std. Dev.
Quantity	1666	2473
Price	18.89	6.96
THC	83.8	27.4
CBD	2.9	15.2
Units/pkg.	8.3	5.2
Market Size	848925	11181
obs.	7,469	

* Quantity is the number of sales for an individual edible in a month. Price, THC, CBD, and Units are measured per individual package. Market Size is the number of potential cannabis consumers in a market.

TABLE 3—DEMAND ESTIMATION

	Fixed Coefficient Logit		Random Coefficient Logit
	(1)	(2)	(3)
Variables	OLS	IV	BLP
Standard Deviation			
$Price$	.	.	0.111**
			(0.0543)
Marginal Utility			
$Price$	-0.00460	-0.188***	-0.275***
	(0.00434)	(0.0660)	(0.0547)
THC	-0.00193	0.0467**	0.0516***
	(0.00444)	(0.0184)	(0.0156)
THC^2	1.73e-05	-0.000231**	-0.000269***
	(4.13e-05)	(0.000103)	(9.02e-05)
CBD	0.0267***	0.0816***	0.0780***
	(0.00401)	(0.0203)	(0.0172)
CBD^2	-0.000317***	-0.000118	-0.000516***
	(4.04e-05)	(8.74e-05)	(8.62e-05)
$Units$	-0.115***	-0.0566*	-0.0497
	(0.0227)	(0.0333)	(0.0310)
$Units^2$	0.00409***	0.00170	0.00160
	(0.000929)	(0.00135)	(0.00127)
$Constant$	-9.669***	-9.416***	-9.398***
	(0.340)	(0.440)	(0.414)
Relevance	.	19.200	11.839
Exclusion	.	0.8908	0.3697
Observations	7,411	7,411	7,411

* The following table displays the results from estimating equation (1). The first column corresponds to the OLS fixed-coefficient logit model. The second column corresponds to the fixed-coefficient logit model with IV's. The third column corresponds to the random-coefficient logit (BLP) model. Units refers to units per package of edible. Flavor, brand, class, and time fixed effects are not reported. F-stat 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 4—Demand Elasticity: Top 10 Products

	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10
Item1	-2.91095	.02177	.03115	.03387	.01902	.03475	.04338	.03162	.02384	.05205
Item2	.02253	-3.04429	.03364	.03691	.02055	.03814	.046	.03446	.02618	.05391
Item3	.02258	.02356	-3.0279	.03667	.02044	.03786	.04585	.03424	.02598	.05388
Item4	.02253	.02372	.03365	-3.03137	.02056	.03815	.04601	.03448	.02619	.05392
Item5	.02258	.02358	.03348	.0367	-3.0418	.03789	.04587	.03427	.02601	.05389
Item6	.02247	.02383	.03377	.03709	.02064	-3.03351	.0461	.03463	.02632	.05391
Item7	.02263	.02319	.03299	.03608	.02015	.03719	-2.99522	.03369	.02552	.05366
Item8	.02253	.02372	.03365	.03693	.02056	.03816	.04601	-3.03397	.02619	.05392
Item9	.02246	.02383	.03378	.0371	.02064	.03836	.04611	.03465	-3.04577	.0539
Item10	.02257	.02258	.03222	.03514	.01968	.03614	.0446	.03281	.0248	-2.94612

* The following table displays the elasticities of demand with respect to price for the top 10 products in terms of sales for June 2015.

Table 5—Demand Elasticity: Middle 10 Products

	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10
Item1	-3.03717	.0035	.00386	.00364	.00341	.00375	.00214	.00306	.00359	.00369
Item2	.00345	-2.95861	.00364	.00357	.0034	.00359	.00235	.00314	.00341	.00349
Item3	.00363	.00347	-3.07074	.00363	.00334	.00386	.00186	.00289	.00373	.00387
Item4	.00349	.00347	.0037	-2.98164	.0034	.00363	.0023	.00312	.00346	.00354
Item5	.00337	.0034	.0035	.00351	-2.89637	.00348	.00245	.00316	.0033	.00336
Item6	.00361	.0035	.00395	.00365	.00339	-3.05875	.00203	.003	.00366	.00378
Item7	.00215	.00239	.00199	.00241	.0025	.00212	-1.73176	.0027	.00194	.00192
Item8	.00307	.00319	.00308	.00327	.00321	.00313	.00269	-2.66563	.00293	.00297
Item9	.00363	.00349	.004	.00364	.00337	.00384	.00194	.00295	-3.06788	.00382
Item10	.00363	.00348	.00404	.00363	.00334	.00385	.00188	.00291	.00373	-3.07071

* The following table displays the elasticities of demand with respect to price for the middle 10 products in terms of sales for June 2015.

Table 6—Demand Elasticity: Bottom 10 Products

	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10
Item1	-2.28901	.00013	.00001	.0004	.0002	.00004	.00023	.00013	.00004	.00027
Item2	.00003	-3.05897	.00001	.0003	.0002	.00008	.00019	.00018	.00004	.00036
Item3	.00003	.00023	-3.07244	.00032	.0002	.00007	.0002	.00018	.00004	.00036
Item4	.00004	.00013	.00001	-2.35383	.00021	.00004	.00023	.00013	.00004	.00028
Item5	.00004	.00017	.00001	.0004	-2.73411	.00006	.00024	.00015	.00004	.00032
Item6	.00003	.00023	.00001	.00031	.0002	-3.06883	.0002	.00018	.00004	.00036
Item7	.00004	.00015	.00001	.0004	.00021	.00005	-2.50602	.00014	.00004	.0003
Item8	.00004	.00022	.00001	.00035	.00021	.00007	.00022	-3.0542	.00004	.00036
Item9	.00004	.00018	.00001	.00039	.00022	.00006	.00023	.00016	-2.8627	.00034
Item10	.00004	.00021	.00001	.00036	.00022	.00007	.00022	.00018	.00004	-3.02374

* The following table displays the elasticities of demand with respect to price for the bottom 10 products in terms of sales for June 2015.

Appendix

Table A1 reports the first stage regression of price on instrumental variables for the fixed and random coefficient logit models reported in columns (2) and (3) of table 3. IV1 in column (1) corresponds to the sum of THC for all other products in the same class in a market. IV2 of column (1) corresponds to the number of competing products of the same flavor in a market. IV1 of column (2) corresponds to the sum of CBD for all other products in the same class in a market. IV2 of column (2) corresponds to the sum of CBD for all products of the same flavor in a market. And IV3 of column (2) corresponds to the number of competing products of the same flavor in a market. Both of the first stage results satisfy the test for weak instruments given by the Cragg-Donald Wald F statistic.

Table A2 records the results of the demand estimation for alternative specifications. Column (1) reports the results when the squared terms for THC, CBD, and $Units$ are excluded. The marginal utility with respect to price remains negative while the marginal utilities with respect to THC and CBD remain positive. The marginal utility with respect to $Units$ remains negative but is significant at the 5% level in this specification. This suggests consumers prefer edibles which are packaged with a lower number of separable units. Revenue is maximized at a sales tax rate of 42.6% under this specification. Estimation with squared terms is preferred to this specification. This is because squared terms permit the estimation of declining marginal utility with respect to cannabinoids in a package. This is believed to be important for estimating cannabis demand based on survey information and discussions with industry professionals.

Column (2) reports the results for the alternative definition for the market of cannabis consumers defined in Light et al. (2014). Column (3) reports the results when a serving of edibles is defined to be four packages in a month. Coefficients are qualitatively similar to those in the preferred specification.

TABLE A1—FIRST STAGE RESULTS

	Fixed Coefficient Logit	Random Coefficient Logit
Variables	(1)	(2)
IV1	0.000432***	-0.00283***
	(7.48e-05)	(0.000530)
IV2	-0.0115***	0.000877**
	(0.00398)	(0.000355)
IV3	.	-0.0106***
		(0.00403)
THC	0.263***	0.268***
	(0.0164)	(0.0164)
THC^2	-0.00131***	-0.00139***
	(0.000155)	(0.000155)
CBD	0.304***	0.301***
	(0.0128)	(0.0128)
CBD^2	0.00106***	0.00105***
	(0.000134)	(0.000134)
$Units$	0.336***	0.313***
	(0.0720)	(0.0721)
$Units^2$	-0.0137***	-0.0128***
	(0.00301)	(0.00301)
Constant	2.238	1.372
	(1.551)	(1.551)
F-Statistic	19.200	11.83
Observations	7,411	7,411

[*] This table displays the first stage regression of price on instrumental variables for the fixed and random coefficient logit models reported in columns (2) and (3) of table 3. IV's 1 and 2 in column (1) correspond to the sum of THC for all other products in the same class and the number of competing products of the same flavor in a market respectively. IV's 1-3 in column (2) correspond to the sum of CBD for all other products in the same class, the sum of CBD for all products of the same flavor which are not produced by the same brand, and the number of competing products of the same flavor in a market respectively. Flavor, brand, class, and time fixed effects are not reported. F-Statistic is the Cragg-Donald Wald F statistic. Robust standard errors in parentheses.
** $p<0.01$, ** $p<0.05$, * $p<0.1$

TABLE A2—ALTERNATIVE DEMAND ESTIMATION

	Random Coefficient Logit		
Variables	(1)	(2)	(3)
Standard Deviation			
$Price$	0.0926*	0.0992**	0.122**
	(0.0474)	(0.0480)	(0.0601)
Marginal Utility			
$Price$	-0.261***	-0.230***	-0.323***
	(0.0579)	(0.0549)	(0.0547)
THC	0.0173***	0.0507***	0.0534***
	(0.00658)	(0.0157)	(0.0156)
THC^2	.	-0.000259***	-0.000284***
		(9.04e-05)	(9.04e-05)
CBD	0.0423*	0.0810***	0.0760***
	(0.0228)	(0.0173)	(0.0172)
CBD^2	.	-0.000511***	-0.000516***
		(8.48e-05)	(8.90e-05)
$Units$	-0.0298**	-0.0505	-0.0470
	(0.0116)	(0.0312)	(0.0311)
$Units^2$	.	0.00163	0.00148
		(0.00127)	(0.00127)
Constant	-8.650***	-8.989***	-9.789***
	(0.484)	(0.417)	(0.414)
Relevance	11.327	11.839	11.839
Exclusion	0.9283	0.3546	0.4056
Observations	7,411	7,411	7,411

[*] This table displays alternative results from estimation equation (1). The first column removes the squares of the variables THC, CBD, and $Units$. The second column reports the estimation results using the alternative market definition from Light et al. (2014). And the third column reports the estimation results when a serving of edibles is defined to be four packages in a month. Units refers to units per package of edible. Flavor, brand, class, and time fixed effects are not reported. F-stat is the Cragg-Donald Wald F statistic. Exclusion is the p-value of the Hansen J statistic. Robust standard errors in parentheses.
** $p<0.01$, ** $p<0.05$, * $p<0.1$