Marijuana Taxation and Imperfect Competition

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ABSTRACT

We investigate the tax implications for the new recreational marijuana industry in the United States, which reached a size of $9 billion in 2017. We exploit administrative data from Washington state to evaluate market conduct, and we estimate the elasticity of supply to be 1.46 . In addition, we conduct a survey of marijuana producers and retailers in Colorado, Oregon, and Washington, calculating the elasticity of demand to be -1.84. We use these estimates to determine how much of the tax burden is borne by consumers. The answer depends on market conduct. In perfectly competitive markets, producers pay slightly more of the tax than consumers, but in a monopoly market consumers would pay most of the tax. Additionally, we calculate that the change in deadweight loss due to the tax is $63 million per year, or 48% of total marijuana tax revenues in 2015. This calculation, however, depends critically on estimates of consumption externalities.

Keywords: Marijuana, Deadweight Loss, State Taxation

JEL Classification: H21, L13

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1. Introduction

In 2012, marijuana was the most commonly used illicit drug in the US, with \$18.9 million past-month users and \$5.1 million persons using marijuana daily or almost daily.[1] While recreational marijuana use has persisted as a black-market activity throughout the United States, Colorado and Washington made history by legalizing the retail sale of marijuana in 2012. New industries pose an interesting problem for policymakers who must balance safety, economic growth, and potential tax revenues. State legislatures confront these trade-offs as they design and implement the legalization of marijuana. In this paper, we harness administrative data from the state of Washington to estimate the elasticity of supply for marijuana and conduct a survey to calculate the elasticity of demand. We show that the market for marijuana is imperfectly competitive and that this has implications for the efficiency of marijuana taxation and how much of the tax is passed onto consumers. This evidence is important in understanding the implications of expanding legalized marijuana to other states and at the federal level and provides broader evidence on the effects of taxes.

Our analysis exploits administrative data born from the highly regulated nature of the Washington industry. In particular, Washington requires careful tracking of marijuana from "seed to sale." This requirement results in detailed data at the retail level, including measures of psychoactive ingredients, weight, price of each transaction, and the precise geo-coded location of all retail outlets. From these data, we capture the evolution of the marijuana industry from 2014–2016. These dynamics are reflected in the downward price trends, starting at \$40 per gram in 2014 and falling to \$13 per gram in 2016. Similarly, just 44 retailers operated in 2014, and this grew to 355 retailers by 2016. Finally, markets were initially highly concentrated, with an average Herfindahl-Hirschman Index (HHI) of roughly 7,000. Despite new entry, the HHI remained quite high in 2016, at 3,862.

We exploit the legalization and retail sales of marijuana in Oregon, a state that borders Washington, to identify the elasticity of supply for marijuana in Washington. In particular, the early sales period

[1] "Results from the 2012 National Survey on Drug Use and Health: Summary of National Findings". US Department of Health and Human Services.

for recreational marijuana that began in Oregon on October 1, 2015, provides an exogenous reduction (shift) in demand for marijuana in Washington. We hypothesize that the reduction in demand varies based on the distance between a Washington retailer and the Washington/Oregon border. We combine an instrument that identifies the border shock with the distance between retailers and the border to estimate the elasticity of supply via an instrumental variables methodology. We find that the elasticity of supply for marijuana is 1.38–1.46.

In addition, we make use of a unique survey that we conducted to identify the elasticity of demand for marijuana in Washington. The Banking, Entrepreneurship, Regulation, and Tax (BERT) survey asked owners and managers to fill out an hour-long survey with details about their firm and industry. Through several waves, the survey contains detailed information from roughly 20% of firms in Washington and at least some information from more than 90% of firms. This survey follows recent surveys of firms by Graham and Harvey (2001), providing unique evidence of how firms believe their sales would be affected if they raised their price or the government increased the tax. Firms report that they expect their sales would decrease by 18.5% if they raised their price by 10%, which suggests an elasticity of demand of -1.85.[2] This elasticity of demand is substantially larger than elasticity estimates in the literature for alcohol or cigarettes, which find elasticities of demand around -0.4 (Chaloupka and Warner, 2000; Nelson, 2013).[3]

We provide insights into the incidence and efficiency of the marijuana excise tax in Washington by combining our demand and supply elasticities with a stylized framework (Weyl and Fabinger, 2013a). The framework highlights the importance of externalities and market power. In the marijuana industry, calculations of deadweight loss and, ultimately, policy prescriptions are quantitatively and qualitatively different if market power is ignored. We also consider how externalities affect the potential deadweight loss from marijuana excise taxes. Our objective is not to determine the value of externalities, that re-

[2]The survey asked firms how they would expect their sales to change if they changed their price both in percentage and in levels, to account for any potential difference in interpretation.

[3]Some of the difference in estimates is due to the level at which the elasticity is estimated. The survey evidence provides firm-level estimates, which we would expect to have a magnitude greater than -1 by profit maximization.

search is ongoing by others, but to quantify the potential differences in deadweight loss calculations given different levels. Our insights demonstrate the importance of jointly considering taxes and regulations, which impact market concentration. For example, we find that in perfectly competitive markets, producers would pay slightly more of the tax than consumers. Consumers, however, would pay the bulk of the tax in a monopoly market.

This paper adds to a new and quickly expanding literature on the legal recreational marijuana industry. The first paper to use the administrative data from Washington is Hansen et al. (2017). This groundbreaking paper focuses on the July 2015 tax reform in Washington that replaced a gross receipts tax with a sales tax. Hansen et al. (2017) find convincing evidence that taxes distorted the vertical integration of the marijuana industry. Berger and Seegert (2020), the first paper to use the survey data, finds that access to banking has large impacts on firm decisions and, ultimately, profits. Additionally, a series of early papers look at the impacts of legal marijuana, including pioneering papers by Mark Anderson et al. (2013, 2015), and Jacobi and Sovinsky (2016).

This paper also adds to a literature on the incidence, salience, and effect of local, state, and sin taxes. Poterba (1996) looks at how prices change with local sales taxes. Feldman and Ruffle (2015) tests the salience of sales taxes experimentally when they are included or excluded in the price. An interesting feature of the marijuana industry is that it is mostly, almost 100%, a cash business. Because of this, businesses often include the tax in the listed price. Harding et al. (2012) looks at the incidence of taxes on cigarettes and finds heterogeneity across geography and income distribution. Conlon and Rao (2015) investigate alcohol taxes and regulations and find states may be able to increase tax revenues through different taxes and regulations. A new working paper by Lockwood and Taubinsky (2017) identifies an important trade-off between the regressive and corrective nature of sin taxes. Using a calibrated model, they provide insights into sugary beverages.

The rest of this paper proceeds as follows. In Section 2, we provide a background on marijuana taxation in the United States and on the optimal taxation framework. In Section 3, we describe the administrative database from Washington and use these data to describe marijuana transactions, market structure, and competition. In Section 4, we provide an empirical estimation of the supply elasticity of marijuana, exploiting the legalization of marijuana in Oregon. In Section 5, we describe the BERT survey and associated empirical evidence on the demand elasticity of marijuana. Finally, in Section 6, we combine all of this evidence with a stylized framework to evaluate the incidence and efficiency of the marijuana excise tax in Washington.

2. Background

Currently, marijuana production and consumption are illegal in the United States because it is classified as a Schedule I substance. The Comprehensive Drug Abuse Prevention and Control Act of 1970 includes a schedule of five tiers of controlled substances based on characteristics such as acceptable medical use, the potential for abuse, and general safety. Schedule I substances are defined as drugs with no currently accepted medical use and a high potential for abuse; examples include heroin, LSD, and marijuana (Drug Enforcement Administration).[4] Despite clear federal regulations, California became the first state to legalize marijuana for medical use in 1996. In 2012, Colorado and Washington became the first states to legalize recreational marijuana for adults 21 years of age or older. The first legal sale of recreational marijuana occurred on January 1, 2014. As of 2019, 25 states permit the production and use of marijuana for medical purposes, and eight states have legalized recreational marijuana—each with their own distinct and sometimes idiosyncratic rules.[5]

The Ogden Memorandum, announced on October 19, 2009, by Deputy United States Attorney David W. Ogden, states that those in compliance with state medical marijuana laws would not be an enforcement priority for the Department of Justice. While most medical marijuana businesses have not been raided or prosecuted following this memorandum, there have been several instances in Montana, California, Nevada, Colorado, and Michigan, where business property has been seized.

[4] https://www.dea.gov/druginfo/ds.shtml

[5] Washington D.C. and Puerto Rico also permit medical use of marijuana.

2.1. Regulations and Taxes

The items a retail marijuana store can sell vary by state. Here we focus on Colorado, Oregon, and Washington, because our survey evidence covers those three states. In Colorado, retail marijuana stores are restricted to selling only retail marijuana and may not sell anything else, including cigarettes, tobacco products, alcohol beverages, non-alcohol beverages, or food. In Washington, retail dispensaries often sell marijuana accessories such as pipes and bongs. In Oregon, some retail dispensaries sell non-alcohol beverages as well as accessories—the reasons why a dispensary may also sell juice at their store may be tax-related, as we discuss below.

All states have some set of licensing requirements for businesses in order to work with and sell marijuana—often different for producers, processors, and retailers. These licensing rules fundamentally shape the market. For example, originally, Colorado had a vertical integration rule that required retailers to sell mostly products that they grew.[6] In Washington, individuals are allowed only one retail license, and initially, this license was restricted to operations in up to three locations. In addition, Washington permits vertical integration of producers and processors, but these processes must be organizationally distinct from retailers.

One of the motivations for legalizing marijuana is the potential tax revenues collected from the sales. In Colorado, there is a 10% sales tax on retail marijuana (added to the state's 2.9% standard sales tax) as well as a 15% excise tax between cultivators and retailers that apply to recreational, but not medical, marijuana. Originally in Washington, there was a 25% tax on each marijuana transaction, including from grower to processor, processor to retailer, and retailer to end consumer. On July 1, 2015, Washington replaced that tax structure with a 37% tax between retailer and consumer and no taxes between businesses.[7] In Oregon, there is a 17% sales tax on marijuana at the state level, and localities may impose an additional 3% tax.

[6] The vertical integration rule was lifted October 1, 2014.

[7] For an excellent discussion of the legislative background on this tax change, see Hansen et al. (2017).

Despite marijuana being illegal at the federal level, the Internal Revenue Service (IRS) expects marijuana business owners to pay federal income tax. However, the rules on what constitutes a marijuana business's income differ from other businesses. In particular, due to Section 280E, taxpayers with income from controlled substances are disallowed deductions incurred from the generation of that income. This distinction means that while other businesses pay income tax on net income, with deductions for rents and wages, the marijuana business is disallowed from these deductions and pays income tax on their gross income, which is gross sales less returns minus cost of goods sold.

2.2. Optimal Taxation

Optimal commodity taxation primarily depends on the characteristics of the good and the product market. In the most basic form, these tax rates are chosen to minimize the excess burden generated while satisfying an exogenous government revenue constraint. Under the assumption of perfectly competitive supply, the classic solution proposed by Ramsey (1927) prescribes tax rates that are inversely proportional to the relative demand elasticities among the set of taxable goods. Said differently, relatively inelastic commodities are taxed at higher rates. Within this framework, economists and policymakers are often concerned with tax incidence, or the relative burden of taxation among consumers and producers.

Guided by these principles, there are two common tools for commodity taxation: 1) specific, or per-unit taxes and 2) *ad valorem* taxes, or sales taxes. Perfect competition implies neutrality between these two mechanisms. In other words, these taxes can inter-changeably raise the same revenue and result in the same consumer and producer prices. However, monopoly markets present an important deviation from this result, wherein *ad valorem* taxation strictly dominates a specific tax (Wicksell, 1896; Suits and Musgrave, 1953; Skeath and Trandel, 1994). Moreover, monopoly markets can result in overshifted taxes, whereby the consumer price increases by more than the full value of the tax (Musgrave, 1959; Katz and Rosen, 1985; Besley, 1989). Finally, a more recent literature expands these analyses to imperfect competition governed by Cournot (Seade, 1983; Stern, 1987; Delipalla and Keen, 1992; Skeath and Trandel, 1994; Keen, 1998; Hamilton, 1999; Weyl and Fabinger, 2013a) and Bertrand (Anderson et al., 2001) dynamics.

The rest of the paper focuses on estimating several key parameters that can be used characterize the marijuana market and investigate the efficiency and incidence of marijuana taxes. These parameters include the market conduct parameter, which characterizes the nature of imperfect competition in a given market, and the elasticities of demand and supply.

3. Washington: Data and Market

Most states that have legalized recreational marijuana production and consumption legislate extensive data reporting requirements. BioTrackTHC is one company that provides technology that tracks cannabis from "Seed-to-Sale," with contracts in Delaware, New Mexico, Illinois, New York, Hawaii, and, for our purposes, notably, Washington. Firms are required to provide data on all plants from planting, harvesting, production, and final retail sale, or from "seed to harvest." Firms record characteristics of each plant, including weight and primary psychoactive ingredients tetrahydrocannabinol (THC), tetrahydrocannabinol acid (THC-A), and cannabidiol (CBD). We focus on the legalization experience of Washington state for two reasons. First, it is one of the earliest, and, therefore, most developed marijuana market. Second, richly detailed administrative data collected by the state of Washington is publicly available.

We utilize an extract of the Washington administrative data that includes records from July 2014–December 2016, and we focus on usable buds.[8] These data include all plants, licensed cultivators, processors, retailers, and transactions. For our purposes, important components of these data are at the transaction level, including the weight, strain, and price of marijuana buds sold. In addition, more than 99% of retailers report geographic locations based on precise latitudes and longitudes. For a detailed

[8]The retail marijuana market also includes the sale of edible marijuana. We exclude this product from our analysis because the unit of sale is not uniform across products. By comparison, the sale of usable buds is uniquely characterized by weight.

description of these data, see Hansen et al. (2017). We employ several steps to clean these data, detailed in Section A.

In the remainder of this section, we utilize this data to investigate the marijuana market in Washington. First, we describe important elements of the retail industry, including transaction characteristics related to pricing. Next, we characterize the industrial organization of the retail market, including entry and exit, product differentiation, and market concentration. This descriptive evidence provides context for the optimal taxation of marijuana.

3.1. Production Characteristics

Marijuana production in Washington is regulated by production licenses, which limit the amount of marijuana producers can grow. Tier 1, 2, and 3 licenses allow for marijuana canopies of 2,000, 10,000, or 30,000 square feet, respectively. Discussions with local growers reveal several important production characteristics that we detail below.

To begin, Marijuana is most frequently grown indoors or in greenhouses, as direct rainwater can lower the THC content of marijuana production. In Washington, marijuana that is produced outdoors is typically harvested in October and is used to produce marijuana extracts due to the lower THC content of the resulting marijuana.

In addition, Marijuana production from seed to maturity can take up to 8 months. Often producers "clone" a mother plant by exposing marijuana branches cut from the mother plant to growth hormones, thereby producing an identical plant (Cervantes, 2006). This limits variation in harvest quality. Marijuana clones can mature and flower in as little as four months. The majority of the THC-bearing marijuana buds are produced in the flowing stage, during which time the marijuana plant slows growth and begins producing flowering buds that contain THC. Upon flowering, marijuana must be dried, a process also known as curing, to prevent the development of mold and improve the taste. Curing was reported to take between one to three weeks, depending on the local grower interviewed.

Finally, Marijuana processors are most often responsible for drying and packaging marijuana. Processors will often source marijuana from multiple growers. In 2019, one processor we interviewed indicated that their products sold best when retailers limited the price mark-up to 250% of the wholesale price.

3.2. Retail Transaction Characteristics

Marijuana is most commonly sold in quantities of one gram, one-eighth ounce (3.5 grams), or one-quarter ounce (7 grams) and is defined by several dimensions of product differentiation. Marijuana is frequently characterized based on measured levels of THC, THC-A, and CBD. THC-A is a non-psychotropic compound and is typically converted to the psychotropic compound THC via the heat applied through smoking (Verhoeckx et al., 2006). Medicinal marijuana is often high in the non-psychotropic compound CBD, which has been shown to treat inflammation, diabetes, cancer, and affective or neurodegenerative diseases (Izzo et al., 2009).

Marijuana is typically branded by a strain. In 2015 the top three selling strains were “Blue Dream,” “Dutch Treat,” and “Gorilla Glue #4,” selling 1.29 million grams, 624 thousand grams, and 470 thousand grams, respectively. Similar to wine varietals, marijuana strains exhibit unique fragrances and tastes. Consumers also report that marijuana strains result in different types of highs.[9]

Insert Figure 1 about here.

Figure 1 depicts the average price per gram sold from 2014–2016. The price per gram dropped quickly from $40 initially to $20 in 2015 and $13 in 2016. The prices of the top thirty strains sold are depicted by the thin gray lines to show the variation in prices across strains. The rapid decrease in price is likely related to several factors, including the proliferation of marijuana brands and market expansion. In the case of the former, Figure 2 shows the growth in the number of distinct strains of

[9] https://www.marijuanabreak.com/why-does-marijuana-produce-so-many-different-highs-hint-its-not-thc

marijuana sold in Washington. In July 2014, there were 43 strains on the market. This grew to 1,918 strains by December of 2015 and 3,022 strains by December of 2016. In the case of the latter, Table 1 provides retailer summary statistics in 2014, 2015, and 2016. In 2014 there were 82 retailers, and this quadrupled to 355 by the end of 2016. In 2014, the average retailer sold 11,590 grams of marijuana across 56 different strains, resulting in $304 thousand in gross sales. The nearest retailer was 6.9 miles away, and there were 2.8 retailers within a 10-mile radius. By 2016, the average retailer sold 98,445 grams of marijuana across 293 different strains and earned $968 thousand in gross sales. The nearest retailer decreased to 2.5 miles away, and there were 17.6 retailers within a 10-mile radius.

Insert Figure 2 about here.

Insert Table 1 about here.

3.3. Market Characteristics

There is no universally accepted method used to define the boundaries of a product market. At a high level, economists often seek to draw the smallest boundary around a particular product such that a hypothetical monopolist could maintain a small price increase without significant erosion in sales.[10] To this end, we consider the impact on the price of adding a retailer to a market for markets defined by increasing geographic radii from a given retailer. Amid this background, Figure 3 shows the impact on the price for markets ranging from 1 to 10 miles from a given retailer. Intuitively, the impact of adding a new retailer on price decreases as the market size increases. For example, for the smallest market, defined by a 1-mile radius for a given retailer, price decreases by 3.8% with each new retailer. The effect of adding a new retailer is substantially smaller when using a 10-mile radius: price decreases by

[10] In the context of antitrust regulation, the Department of Justice and the Federal Trade Commission has provided guidelines used for the determination of market boundaries. https://www.justice.gov/atr/horizontal-merger-guidelines-08192010#5c

0.27% with each new retailer. The convergence of the price impact for market boundaries of at least five miles (-0.81%) suggests that markets are not hyper-local to retailers.

Insert Figure 3 about here.

In Table 2, we provide summary statistics assuming that county borders roughly approximate for market boundaries.[11] Summary statistics are provided quarterly for 2014–2016 (panel A–C, respectively). Similar to statistics at the retailer level, this table depicts a growing industry. In the third quarter of 2014, there were just two retailers per county, and the average Herfindahl-Hirschman Index (HHI) was alarmingly high at 7,700 (column 1 and 8).[12] One year later, there were 5.5 retailers per county, and the HHI had decreased to an average of 5,067. Finally, in the third quarter of 2016, there were 9.4 retailers per county, and the HHI had decreased to 3,872.[13] This table also highlights the proliferation of marijuana strains, increasing from an average of 44 per county in 2014 to 713 per county in 2016 (column 4).

Insert Table 2 about here.

Figure 4 depicts the geographic variation in price, and Figure 5 depicts geographic variation in sales across counties in 2015. Counties with higher prices or more marijuana sold are shaded in darker colors. In addition, retail locations are depicted within these maps, where darker shading identifies retailers

[11] In practice, large urban areas are mutually exclusive across counties in Washington. Given the concentration of retailers within large urban centers, counties are simply proxies for large urban centers. Moreover, Seattle, the largest city, can be approximated by a 5-10 mile radius from its city center, and this conforms with our market boundary analysis.

[12] County market boundaries ensures that markets are mutually exclusive and permits tractable geographic analysis. On the other hand, markets need not be geographically mutually exclusive. As in the market boundary analysis, we calculate HHIs using geographic radii around a retailer in Table B.1. This analysis reveals a similarity in market size and concentration between a 5-mile market (Table B.1, panel B) and county boundaries (Table 2).

[13] In the 2010 Horizontal Merger Guidelines, the Department of Justice defines markets with an HHI over 2,500 as concentrated markets. Based on this metric, the marijuana industry is concentrated based on county market boundaries. https://www.justice.gov/atr/horizontal-merger-guidelines-08192010#5c

with higher prices and sales, respectively. There are a few counties with no retail locations, mostly located in the east of the state. Aside from these counties, much of the retail activity is concentrated near major urban centers like Seattle, Tacoma, and Olympia. In addition, many retailers are located along the Washington/Oregon border, most likely to take advantage of marijuana tourism. These figures reveal significant geographic dispersion in price, ranging from $9.46 to $18.90 per gram. In general, prices were highest in counties with the fewest retailers and along the Washington/Oregon border. Similar patterns emerge for marijuana sales, with an increased emphasis on the importance of border sales, as seen by the high concentration of sales per capita in two border counties near to Portland, Oregon, and Vancouver, CA. Consistent with these sales patterns, Figure 6 reveals that retail entry was concentrated in and around the largest cities in Washington and certain border areas. Finally, Figure 7 depicts HHI by county in 2015. This figure also highlights important geographic dispersion, with HHIs ranging from 1,112 to 10,000. In general, counties near urban centers are more competitive than rural areas, with the exception being near the Washington/Oregon border.

Insert Figures 4, 5, 6, and 7 about here.

This descriptive evidence is consistent with a growing and imperfectly competitive market. Despite industry growth, market concentration remained higher than typical thresholds employed by the DOJ for identifying concentrated markets. Moreover, there is significant price and sales variation by market. In light of this evidence, it is of critical importance to account for the dynamics of imperfect competition in the evaluation of efficiency and incidence in marijuana markets. We begin by estimating the elasticity of supply. In evaluations of efficiency and incidence, the elasticity of supply is often assumed to be infinite, which is consistent with assuming perfect competition. These descriptive statistics, however, suggest that this assumption may not be appropriate in the marijuana industry in Washington.

4. Empirical Evidence: Elasticity of Supply

Analysis involving the equilibrium price and quantity of cannabis sold involves confronting a classic form of endogeneity in explanatory variables: simultaneity bias. In particular, both price and quantity are jointly determined through a market clearing mechanism. For illustrative purposes, consider a simple structural supply equation

$$q_s = \beta p_s + \varepsilon_s$$

where ε_s contains other factors, both measurable and unmeasurable, that determine the quantity supplied. A log transformation would transform the interpretation of β_1 into an estimation of the average elasticity of supply. However, the observed price of cannabis is not exogenously determined but rather is jointly determined according to the equilibrium condition defined by $q_d = q_s = q$.

Given the market clearing condition, the simultaneous system that determines equilibrium price and quantity can be written as

$$q = \alpha_1 p + \beta_1 z + u_1$$

and

$$q = \alpha_2 p + u_2$$

where z are factors that affect the demand for cannabis. The factors z shift the demand function, providing an identification strategy for the supply for cannabis. This identification comes from the structural equations of the model and imposed exclusion restrictions. In particular, it must be that factors identified as affecting the demand of cannabis do not also affect the supply for cannabis except through the shift in demand function. To this end, we exploit the legalization of marijuana in Oregon, which provides an important shift in the demand for cannabis in Washington.

4.1. Instrumental Variables for Supply Elasticity: Oregon Legalization

Oregon has been a leader in the decriminalization and legalization of cannabis at the state level. To begin, the passage of the Oregon Decriminalization Bill of 1973 made Oregon the first state to decriminalize the possession of small amounts (less than 1 ounce) of cannabis. In November 1998, Oregonians passed the Oregon Medical Marijuana Act, which established the Oregon Medical Marijuana Program. In 2014, Measure 91, which legalized non-medical cultivation and use of marijuana, passed. As a result, Oregonians could legally possess marijuana beginning July 1, 2015. On July 27, 2015, Governor Kate Brown signed an emergency bill, SB-460, which allowed retail purchases of marijuana from existing medical dispensaries during an early sales period beginning October 1, 2015. During the first week alone, medical dispensaries reported $11 million in sales, compared with $2 million in sales during the first month of legal purchases in Washington.[14]

The expansion of the market for marijuana in Oregon impacted the local demand for marijuana in Washington. The post-legalization period provides an exogenous shift to the demand for marijuana in Washington. A potential mechanism for this shift is related to marijuana tourism. In particular, expanded legal markets should unambiguously reduce marijuana tourism, and this translates to a reduction in demand for marijuana in Washington. For this reason, the post-tax period provides an instrument for the elasticity of supply in marijuana.

In addition, the fact that legalization occurs in a border state creates a differential impact on demand that is characterized by the distance between Washington retailers and the Oregon border. In particular, retailers closer to the border should experience a larger decrease in demand than those further from the border because border sales were more likely to be driven by cross-border shoppers from Oregon. This variation provides two additional instruments that exploit the intensity of the demand shock: the interaction of the post-tax period with distance to the border and the quadratic instrument to the border. Finally, we include the distance to the border and the quadratic distance in order to fully saturate the

[14] https://web.archive.org/web/20160523045920/http://www.kgw.com/news/oregons-first-week-of-recreational-pot-sales-tops-11-million/156928

instrument in the first stage. This analysis leads to five instrumental variables that provide the variation necessary for the identification of the elasticity of supply for marijuana.

4.2. Instrumental Variables: Identifying Assumptions

A necessary assumption is that the legalization of marijuana in Oregon does not directly affect the marginal cost of producing marijuana in Washington. In particular, it must be that $\mathbb{E}[\varepsilon_i|\mathbf{Z}] = 0$ in order for our proposed instruments to be valid. This condition will be true if our proposed instruments are relevant, exogenous, and excluded. While the OLS estimator of the log-transformed equation for supply

$$\ln(q_s) = \beta_0 + \beta_1 \ln(p_s) + \gamma Z + \varepsilon_s \tag{1}$$

will be inconsistent, the two-staged least squares instrumental variable estimator, for the otherwise endogenous price, will consistently estimate the elasticity of supply for cannabis.

The relevance of these instruments, or whether these instruments either separately or jointly account for significant variation in the endogenous variable, is embedded in the structural assumptions of the model. There is a battery of statistical tests, however, that lend support to the assumption that these instruments are important inputs into the supply of cannabis. An identification that relies on weak instruments will lead to imprecise estimators with standard errors that can be many times larger when compared to the inconsistent OLS estimators. One standard diagnostic test is the *F* test for the joint significance of the instruments in the first-stage regression of the endogenous price on the instruments and exogenous factors affecting demand. We will explore the output of this statistical test in the results section of the paper.

4.3. Supply Elasticity

In Table 3, we present the results of our main empirical specification measuring the average elasticity of supply for cannabis focusing on a one-month window surrounding the legalization of marijuana in Oregon (September–October 2015). Panel A reports the first-stage coefficients of all two-stage least squares estimates, and panel B reports the coefficient on the natural log of price, which reflects the elasticity of supply. Column (1) presents endogenous results estimated by Ordinary Least Squares, and column (2) presents results estimated using two-stage least squares instrumental variables. In particular, we rely on five instruments in an over-identified system: legalization, distance to the border (linear and quadratic), and associated interactions. With five instruments, the critical value for a 5% relative bias of the 2SLS estimator compared to OLS is 13.91, and the critical value for a 5% relative bias of the Wald test is 22.30. In column (3), we add city-specific fixed effects. These fixed effects control for components of the marginal cost that are time-invariant at the city level. This includes variable costs of production that are regulated by the city, such as water and electricity prices, in addition to local labor costs, which are roughly time-invariant over this short window. In column (4), we control for variation caused by day-of-week sales patterns. Finally, in column (5), we control for levels of primary psychoactive ingredients in the product sold, which are correlated with marginal costs of production.

Insert Table 3 about here.

Assessing the sign and magnitude of coefficients in the first stage of a two-stage least squares estimation provides support for the relevance of the included instruments. In this case, we should expect that the Border Shock variable, defined as $\mathbb{1}(t = October)$, negatively impacts the equilibrium price of marijuana sold in Washington. Indeed, row (1) of panel A reveals a negative and statistically significant impact of the border shock, where prices decrease by 5.4–7.0 percent in the month after early sales of marijuana begin in Oregon (columns 2–5). In addition, we should expect that equilibrium price increases as distance between retailers and the border grows, and this is again reflected in the positive and statistically significant coefficient in row (2) of panel A. The negative coefficient on Shock

$\times$ Distance^2 indicates that this relationship is concave, or that the impact of border distance on prices falls with distance to the border. Altogether, the sign, magnitude, and statistical significance of these instruments support the relevance assumption underlying the instrumental variables estimation strategy.

In Column (2) of panel B, we estimate the elasticity of supply to be 2.607 based on a basic log-log specification with no additional controls, and it is statistically significant at the 0.01% level. Here, as with all specifications, there is a dramatic difference between the OLS and IV estimation of the elasticity. In particular, one would estimate the elasticity of supply to be wrong-signed when estimated endogenously (-0.281, column 1 panel B). That these estimates are very different supports the IV identification strategy. Further, the *F* statistic from the first stage, reported in the bottom row, is 49.44, firmly rejecting the null hypothesis of weak instruments based on Stock and Yogo (2005). In this basic specification, we see evidence that the supply for cannabis in Washington is, on average, elastic, which is consistent with market characteristics earlier described. Moreover, the price sensitivity of producers has implications for the incidence of the tax of the tax and the efficiency of the tax base.

Columns (3)–(5) reveal the importance of adding control variables when estimating the elasticity of supply for marijuana. In particular, the elasticity is estimated to be 1.46 based on within-city variation (column 3), which controls for several components of the variable cost of production, such as electricity rates, water rates, and local labor market rates, all of which are roughly time-invariant during this two month analysis period. Additional controls do not meaningfully impact the estimated elasticity of supply. In Table B.2, we find that the estimated elasticity of supply is robust to variation in the window of analysis around the change, where the elasticity of supply is estimated to be 2.03 using a two-month window and 1.756 using a three-month window.

Our estimates suggest that marijuana suppliers are relatively sensitive to price changes: a 1% percent increase in price results in a 1.46% increase in quantity supplied. This evidence is consistent with earlier evidence that marijuana markets are local. We combine this evidence with estimates of the demand elasticity to evaluate the incidence and efficiency of the marijuana excise tax in Washington.

5. Survey Evidence: Elasticity of Demand

We estimate the elasticity of demand using survey evidence from a large scale survey we conducted on all marijuana dispensaries in Washington, Colorado, and Oregon.

5.1. Banking, Entrepreneurship, Regulation, and Taxes (BERT) Study

As part of the Banking, Entrepreneurship, Regulation, and Taxes (BERT) Study, we contacted all retail cannabis dispensaries, medical and recreational, through several waves.[15] First, we mailed letters that contained information and instructions on how to take the survey with an enclosed $2 bill as a gift to increase participation. Second, we called all the businesses. If their given phone number did not work, we used internet searchers to find updated numbers. Third, we partnered with several industry groups that emailed their members information about the survey. Fourth, we sent another wave of letters. Fifth, we had a research assistant canvas for two months. Finally, we did an additional round of phone calls. Participation entailed going to a website and filling out a 45 minute to an hour-long survey. Participants were paid $50 for participating and entered to win a $500 reward, which was given away randomly to two participants.

Our sample contains 325 firms that completed the full survey. Our response rate of 21% is similar to other surveys of businesses; Graham and Harvey (2001) obtained 16% and Trahan and Gitman (1995) 12%. Our goal was to have owners or managers fill out the survey. One of the first questions asks the participant whether they are an owner, manager, both, or neither. In our sample, 65% of respondents were either an owner or owner and manager, and 31% of respondents were managers, and the remaining eight responses were filled out by someone else such as an accountant or office manager. We implemented two versions of the survey with different ordering of the nondemographic sections to test if participant fatigue impacted the quality of answers and find no evidence of differential response

[15]The BERT study information can be found at eccles.link/bert.

rates. Berger and Seegert (2020) provides more information on the BERT study in their study focused on banking and the marijuana industry.

5.2. Demand Elasticity

Table 4 reports evidence on the elasticity of demand from the survey. Survey participants answered the question, “If you raised your price by 10 percent what percent (%) less in sales would you expect.” Participants answered this question for high-end retail plants, low-end retail plants, high end infused products, and low end infused products. Column 1 reports across all products the elasticity of demand is -1.85, which is calculated by dividing the participant’s answers by 10. The elasticity estimate is -1.27 for high-end retail plants and -1.70 for low-end retail plants. The estimates are slightly higher for infused products; -1.75 for high-end and -3.50 for the low-end. The demand elasticity estimates suggest that consumers of low-end products are more price sensitive than consumers of high-end products, potentially due to differences in consumer preferences.

A natural comparison of interest is between our survey evidence and estimates of the elasticity of demand for other sin goods subject to excise taxes, such as alcohol and cigarettes. There is a deep empirical literature estimating the elasticity of demand for these goods, generally finding consumers to be relatively price insensitive. For example, the range of estimates for the demand elasticity of beer is between -0.26 and -0.46 (Nelson, 2013). Demand elasticity estimates for wine and spirits range from -0.34 to -0.70 and -0.49 to -0.80, respectively. In comparison, we estimate of the elasticity of demand for marijuana to be -1.85, which is substantially larger but in a range consistent with profit maximization.

Marijuana seems to be more elastic than cigarettes, too. Chaloupka and Warner (2000) report price elasticities for cigarettes that typically fall within a small neighborhood of -0.4. Goolsbee, Lovenheim and Slemrod (2010), however, show that the elasticity may be as high as -0.832 when taking into account smuggling from online sales.[16]

The extent of smuggling in a market changes the inferences policymakers should make from estimates of the elasticity of demand. In principal, the elasticity of demand provides policymakers with details about the efficiency and corrective potential of sin taxes. Small elasticities of demand are consistent with small efficiency costs and large tax revenue potential. Large elasticities are consistent with sin taxes changing individual behavior. If, however, large elasticity estimates are due to smuggling, then these taxes will not have the same change in individual behavior as in the case without smuggling. Moreover, one of the policy objectives of legalizing recreational marijuana is to diminish smuggling and the black market. If, however, high taxes cause consumers to stay in the black market, then legalization will be ineffective at this policy objective. Our large estimates of the elasticity of demand for marijuana suggest either there is scope for smuggling through the black market or there is high competition among legal retailers. More research is needed to disentangle these potential mechanisms.

6. Incidence and Efficiency Calculations

This section combines our estimates of market organization and the elasticity of supply and demand to investigate the incidence and efficiency of marijuana taxes. We combine the work of Fullerton and Metcalf (2002) and Weyl and Fabinger (2013a) to investigate incidence and deadweight loss. This analysis (1) allows for imperfectly competitive markets, (2) is stated in terms of demand and supply elasticities, and (3) allows for consumption externalities (positive or negative).

[16]Goolsbee et al. (2010) estimate the tax rate elasticity of -0.267 and calculate the price elasticity as $e_{\text{price}} = e_{\text{tax}} \times (p + t/t)$. See Lovenheim (2008) for a discussion of different types of elasticities for policy purposes.

6.1. How Much of the Tax Burden Do Consumer Pay?

The relative incidence of the marijuana tax between consumers and producers has real consequences for tax policy. In this section, we calculate the incidence of the marijuana tax. We draw on Weyl and Fabinger (2013a), who undertake a general theoretical analysis of economic incidence in the presence of imperfect competition. In particular, the authors find that the tax incidence on consumers[17] is given by

$$\rho = \frac{1}{1 + \frac{\varepsilon_D - \theta}{\varepsilon_S} + \frac{\theta}{\varepsilon_{ms}}}. \tag{2}$$

In this equation θ is the conduct parameter, as in Bresnahan (1989). The conduct parameter characterizes the competitiveness of a market. Perfectly competitive markets are characterized by $\theta = 0$, and monopoly markets are characterized by $\theta = 1$. Imperfectly competitive markets are characterized by $\theta \in (0,1)$. The parameter ε_{ms} is the elasticity of marginal surplus, which measures the curvature of the logarithm of demand (Weyl and Fabinger, 2013b).[18]

From Equation 2, a calculation of the economic incidence of marijuana taxes requires knowledge of the conduct parameter, θ, supply and demand elasticities, ε_S and ε_D, the elasticity of marginal surplus, ε_{ms}, values of taxes, τ, and the equilibrium quantity and price, x, and p. To calibrate our baseline, we rely on estimates of the supply and demand elasticities from previous sections and observed taxes, quantities, and prices. In addition, we calibrate the elasticity of marginal surplus and the conduct parameter. We calibrate the elasticity of marginal surplus to be -3, following Weyl and Fabinger (2013a).[19] We calibrate the conduct parameter as in the elasticity adjusted Lerner Index (Weyl and Fabinger, 2013a): $\theta = \left(\frac{p - mc}{p}\right)\varepsilon_D$. Empirically, the average markup[20] is 0.26, which implies that the conduct parameter under our baseline is 0.497.

[17]We make the simplifying assumption that $\frac{1}{\varepsilon_\theta} = 0$, which is true for many common models of imperfect-competition including Cournot and Dixit-Stiglitz monopolistic competition.

[18]This paper relies on the interpretation that the elasticity of marginal surplus is the negative of the Pareto tail index, $\varepsilon_{ms} = -\alpha$ (Gabaix et al., 2016).

[19]Because Saez (2001) calibrates models of optimal income taxation based on the interpretation that the elasticity of marginal surplus is the negative of the Pareto Tail index, we can leverage this to learn that $\varepsilon_{ms} \in [-3, -1.5]$.

[20]The administrative data includes information on the wholesale marijuana price to retailers and the ultimate retail price. However, these data do not include information on other sources of marginal cost, including labor

Under our baseline calibration, we find that producers and consumers roughly share the incidence of the tax: consumers pay 57% and producers pay 43%. These estimates may change as institutions and consumer preferences continue to evolve and the market matures. Said differently, we should expect variation in market conduct and elasticities of supply and demand over time. To this end, we analyze how the incidence changes as these key parameters change.

Insert Figure 8 about here.

Empirically, we find that the market conditions have a large impact on the incidence of the marijuana tax on consumers. Panel (a) of Figure 8 plots variation in the incidence of the tax due to variation in the conduct parameter, holding all other parameters as in our baseline calibration. The incidence on consumers ranges from 44% in a perfectly competitive market to 81% in a monopoly market. The incidence of the tax also differs with the elasticity of demand, shown in panel (b). We graph three lines: (1) our baseline calibration (solid line), (2) monopoly market (dashed line), and (3) perfectly competitive market (dotted line).[21] In addition, the vertical line designates the incidence under our baseline calibration, where consumers pay for 57% of the tax. There is a negative relationship between the incidence of the tax on consumers and the elasticity of demand across across all market structures. This is consistent with the familiar intuition that consumers pay for more of the tax as they become more insensitive to price. In addition, this figure reveals the possibility of an over-shifted tax in situations with relatively insensitive consumers and high market concentration ($\theta = 1$, $|\varepsilon_D| < 1.5$).

In Section 5, we find differences in the elasticity of demand along two important dimensions: (1) retail plant vs. infused products, and (2) high and low-quality products. In particular, the elasticities of demand range from -1.27 for high-end retail plants to -3.50 for low end infused products (Table 4, columns 2 and 5). We find that consumers pay the majority of the tax for retail plants, high-end and

and other variable costs. For this reason, we utilize a 21% scaling factor based on the cost structure of another large retailer (Walmart, Form 10-K for Fiscal year Ending Jan 31, 2019).

[21]A profit maximizing firm will never choose a price such that the elasticity of demand is inelastic, so we exclude values of the elasticity of demand that are less than one.

low-end, and high-end infused products: 73%, 60%, 59%, respectively. Producers, however, pay the majority of the tax (65%) for low-end infused products. Policymakers currently tax these goods identically; in light of this evidence, policymakers might consider differential taxes for plant and infused products.[22]

Finally, we investigate variation in the incidence due to the elasticity of supply in panel (c) of Figure 8, holding all other parameters as in our baseline calibration. The incidence on consumers is zero when producers are perfectly inelastic, and the incidence on consumers increases as producers become more price sensitive. As in panel (b), the vertical line designates our baseline calculation, and two additional lines depict incidence where $\theta = 0$ and $\theta = 1$. All else equal, the incidence on consumers increases as the elasticity of supply increases, and we again see the possibility of an over-shifted tax in markets with high concentration and relatively elastic supply.

The simulations in Figure 8 highlight how market structure and tax incidence are linked. This relationship suggests that tax policy and market conditions must be jointly considered otherwise incidence inferences will be quantitatively and qualitatively incorrect. This relationship also implies that regulations that restrict competition will increase the pass-through of the tax onto consumers.

6.2. How Efficient is the Tax in Light of Externalities?

The traditional Harberger triangle captures the deadweight loss from the imposition of a tax relative to a perfectly competitive market outcome without externalities. Empirical studies often make the additional assumption of perfectly elastic supply. In the case of the marijuana industry, none of these assumptions are appropriate. We have previously shown that the marijuana industry is imperfectly competitive with a conduct parameter of 0.497 and an estimated elasticity of supply of 1.46. There is also a growing literature exploring the externalities in the marijuana market. Based on this literature, reviewed below, we allow for a wide range of consumption externalities, ϕ, because there is uncertainty

[22] The efficiency gains from differential taxation would, of course, need to be contrasted with additional costs from firms changing product characteristics to be labeled in the lower tax category.

about the sign and the magnitude of these externalities. We calculate deadweight loss by combining these estimates with an equation for deadweight loss in the presence of imperfect competition, a supply curve that is not perfectly elastic, and externalities. To determine the importance of loosening these assumptions, we also calculate deadweight loss under several different cases.

Deadweight loss from a tax in an imperfectly competitive market is measured as the change in deadweight loss with the tax relative to the untaxed equilibrium. This calculation is necessary because there is deadweight loss in imperfectly competitive markets absent the tax. The impact of the tax is captured by a Harberger trapezoid, which measures the change in deadweight loss relative to the untaxed imperfectly competitive outcome.[23]

Changes in deadweight loss from a tax with externalities can be positive or negative depending on whether the tax moves the equilibrium closer to the efficient quantity. In perfect competition, the deadweight loss minimizing tax is one that equals the externality. This feature need not be true in imperfectly competitive markets.

The deadweight loss in the presence of a tax, imperfect competition, and an externality is given by a trapezoid defined by two bases and a height. The first base is the mark-up at the untaxed equilibrium plus the externality, $(p^0 - MC^0 + \phi)$. The second base is the difference between consumer and producer price, which reflects the mark-up and the tax, and the externality, $(p^c - p^p + \phi)$. The height is the change in quantity due to the tax, dQ. Taken together,

$$DWL = \frac{1}{2}\left((p^0 - MC^0 + \phi) + (p^c - p^p + \phi)\right) \cdot dQ. \tag{3}$$

In Appendix D, we transform this formula to take advantage of the empirically derived parameters in our context, following insights by Fullerton and Metcalf (2002), Auerbach and Hines Jr (2002), and Weyl and Fabinger (2013a). This gives a formula for deadweight loss as a function of $\varepsilon_D, \varepsilon_S, \theta, \tau, p^c, Q^\tau, \phi$, and $\rho(\varepsilon_D, \varepsilon_S, \varepsilon_{MS}, \theta)$

[23]This intuition is developed in more detail in Appendix D and Figure B.1.

$$DWL = \frac{1}{2} \cdot \varepsilon_s \cdot \tau \cdot \frac{Q^\tau}{p^c} \left[\left(\frac{\theta}{|\varepsilon_D|} \right) (2p^c - \tau(1+\rho)) + \tau + 2\phi \right] (1-\rho). \quad (4)$$

We calculate deadweight loss based on the same baseline calibration used in our incidence calculations.[24] The final parameter we need to calibrate is the size of the externality.

Despite a large and growing literature, there remains uncertainty about the sign and magnitude of the externalities associated with marijuana consumption. On the one hand, medical research finds many negative health effects of smoking marijuana, and it is rarely argued that healthy individuals benefit from marijuana consumption. For example, it is well documented that smoking marijuana is detrimental to respiratory health because marijuana contains many of the same harmful substances as tobacco (Gates et al., 2014). Evidence also suggests that marijuana is addictive, impairs axonal fiber connectivity in the brain, and results in irreversible neuropsychological decline with continued use (Volkow et al., 2014; Zalesky et al., 2012; Meier et al., 2012). On the other hand, there is increasing evidence of medical benefits for individuals with specific health conditions. For example, Sabia et al. (2017) find that the passage of medical marijuana laws resulted in a \$58 to \$115 per-person annual reduction in obesity-related medical costs to individuals and the healthcare system. Whiting et al. (2015) also find that marijuana use reduces spasticity, nausea, and vomiting due to chemotherapy, sleep disorders, and Tourette syndrome.

There is also uncertainty around the size of the externalities of marijuana because of its potential substitution effect with other negative externality goods such as opiods, tobacco, and alcohol. For example, survey evidence indicates that marijuana users substitute away from opioid consumption in favor of marijuana because marijuana is associated with fewer side effects and enhanced pain management (Lucas et al., 2013; Reiman et al., 2017). As a result, marijuana use has been linked to lower opioid use, mortality, and hospitalizations (Bachhuber et al., 2014; Smart, 2015; Shi, 2017; Shah et al., 2019), resulting in a large reduction in public health expenditures (Bradford and Bradford, 2016; Bradford et al., 2018; Liang et al., 2018; Wen and Hockenberry, 2018). Marijuana use has also been

[24]The formula for deadweight loss in equation 4 is not general. The formula is correct for the range of parameter values we consider and other cases exist for different parameter values.

associated with a decrease in tobacco use, resulting in a cost savings of \$4.6 to \$6.9 billion per year in medical costs (Scherma et al., 2016; Kerr et al., 2017; Choi et al., 2019).[25] Table 5 provides a summary of the evidence on consumption externalities.

In light of empirical uncertainty about the externality, we calculate the change in deadweight loss due to a tax for a range of externalities. Deadweight loss varies between -\$4 million and \$14 million per month for $\phi \in [-10, 10]$. The wide range of estimates suggest that knowing the magnitude of these externalities is critical to assessing the efficiency of marijuana taxes. In fact, this range suggests the optimal tax on marijuana may be larger or smaller than its current level. Finally, the deadweight loss with no externalities, which defines our baseline calibration, is \$5.28 million per month.

When we assume that markets are perfectly competitive and ignore externalities, the deadweight loss is estimated to be \$4.91 million a month. This estimate is 7% less than our baseline calculation. When we further impose perfectly inelastic supply, the change in deadweight loss grows to \$7.61 million per month, which is 44% larger than our baseline calculation.[26] These estimates suggest that estimates of deadweight loss that do not take into account imperfect competition may be too small, that estimates that assume perfectly elastic supply may be substantial overestimates, and that in markets with externalities knowing the magnitude is critical for assessing efficiency of tax policy.

7. Conclusion

We investigate the tax implications for the new recreational marijuana industry in the United States. We estimate the elasticity of supply and evaluate market conduct based on administrative data, and

[25]The effect of marijuana use on traffic accidents is currently inconclusive. Smart (2015) and Els et al. (2019) find that marijuana use resulted in higher traffic accidents and fatalities. Mark Anderson et al. (2013) and Kim et al. (2016) find opposing results. Although marijuana decreases driving ability (Hartman and Huestis, 2013), drivers high on marijuana are argued to drive slower and engage in less risky driving behaviors. There is also evidence that marijuana use reduces alcohol consumption (Mark Anderson et al., 2013; Lucas et al., 2013; Sabia et al., 2017; Johnson et al., 2018), though the evidence is heterogeneous by age groups (Wen et al., 2015; Smart, 2015; Cerdá et al., 2018).

[26]Deadweight loss without externalities, perfectly competitive markets, and perfectly elastic supply is given by $(1/2)\tau^2\varepsilon_d(Q/p^c)$.

we harness survey data to calculate the elasticity of demand. We apply the insights of public finance to the new marijuana industry in Washington to provide policymakers insights into who pays these new excise taxes and related efficiency costs. We highlight the importance of incorporating empirical evidence of market structure and externalities. We show that the implications for tax policy differ substantially under different model assumptions, and these differences underscore the importance of jointly considering regulation and taxation.

In addition, externalities play an important role in evaluating the efficiency of tax policy in this industry. We review a growing literature that empirically estimates these consumption externalities, finding that there is no consensus in the literature on the sign, let alone magnitude. We emphasize that one of the reasons for the large uncertainty over the consumption externality is uncertainty over the importance of substitution toward marijuana and away from other goods with potentially larger externalities such as opioids, tobacco, and alcohol.

We find that marijuana taxes in Washington cause $63 million of deadweight loss per year and that consumers likely pay more of the tax than producers. These calculations (1) combine our estimates of market structure, the elasticity of supply, and the elasticity of demand and (2) assume no consumption externality, reflecting positive and negative empirical estimates. These calculations, however, depend on the nature of competition. For example, deadweight loss could be as low as $59 million in a perfectly competitive market or as high as $91 million in perfectly competitive markets with perfectly elastic supply. To put this range into context, marijuana excise tax revenues were $130 million in 2015. The deadweight loss, therefore, ranges between 45% and 70% of total tax revenues.

Finally, efficiency calculations depend crucially on the sign and the magnitude of any consumption externalities. For example, the right Pigouvian tax (subsidy) could eliminate the deadweight loss. Alternatively, taxing a good that causes a positive externality will only magnify the efficiency costs. Ultimately, our calculations motivate much more research on this topic.

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Table 1
Retailer Summary Statistics

This table provides summary statistics of retail marijuana sales in Washington State by year.

	2014 (1)	2015 (2)	2016 (3)
Weight (grams)	11,590	78,761	98,445
Sales	304,467	1,009,078	968,664
Strains	56	240	293
Price	29	16	13
Transactions	7,871	57,708	81,478
Nearest Retailer (miles)	6.9	4.1	2.5
Retailers $\leq$1 mile	0.3	0.5	1.2
Retailers $\leq$2 miles	0.7	1.2	2.5
Retailers $\leq$5 miles	1.6	3.7	7.7
Retailers $\leq$10 miles	2.8	8.8	17.6
Observations	82	199	355

Table 2

Market Summary Statistics

This table provides summary statistics of the retail marijuana sales by county-quarter in Washington State. Weight is in units of grams, distance is in units of miles, sales is in units of dollars, and HHI is defined by weight and county.

	Total Retailers (1)	Avg Weight (2)	Avg Sales (3)	Total Strains (4)	Avg Price (5)	Weight Per Person (6)	Sales Per Person (7)	HHI (8)	Nearest Neighbor (9)	Avg Entry (10)
Panel A: 2014										
Quarter 3	2.0	12,859	416,470	44	39.07	0.06	1.97	7,713	13.3	0.1
Quarter 4	3.2	27,750	670,604	118	27.26	0.12	2.90	6,470	13.3	0.1
Panel B: 2015										
Quarter 1	4.3	60,083	1,135,283	252	22.23	0.25	4.61	5,861	11.6	0.3
Quarter 2	5.2	104,135	1,755,203	346	21.42	0.47	7.64	5,011	10.1	0.5
Quarter 3	5.5	158,922	1,738,289	403	15.10	0.73	8.01	5,067	8.6	0.7
Quarter 4	6.0	180,762	1,935,986	444	14.63	0.78	8.30	4,503	5.7	0.8
Panel C: 2016										
Quarter 1	7.0	198,102	2,083,714	513	13.93	0.89	9.33	4,319	6.2	0.9
Quarter 2	8.3	245,819	2,425,398	598	13.44	1.16	11.60	3,904	5.2	1.2
Quarter 3	9.4	319,425	3,058,347	688	13.32	1.53	14.77	3,872	7.0	1.5
Quarter 4	10.0	299,020	2,894,188	713	12.88	1.40	13.59	3,862	5.5	1.4

Table 3
Elasticity of Supply: 1 Month Window

Notes: This table provides estimates for the average elasticity of supply for cannabis focusing on a one-month window surrounding the legalization of marijuana in Oregon (September–October 2015). Border Shock is a dummy variable equal to 1 for sales after the legal sale of Marijuana in Oregon began on October 1, 2015. Border Distance measures the distance from a retailer to the Washington/Oregon border in hundres of miles. Panel A reports the first-stage coefficients of all two-stage least squares estimates, and panel B reports the coefficient on the natural log of price, which reflects the elasticity of supply.

	OLS	IV	IV	IV	IV
	(1)	(2)	(3)	(4)	(5)
Panel A: First Stage					
Border Shock		-0.0546***	-0.0677***	-0.0702***	-0.0681***
		(0.00643)	(0.00650)	(0.00650)	(0.00650)
Shock × Distance		0.125***	0.139***	0.140***	0.136***
		(0.0138)	(0.0140)	(0.0140)	(0.0140)
Shock × Distance^2		-0.0551***	-0.0558***	-0.0560***	-0.0549***
		(0.00758)	(0.00774)	(0.00774)	(0.00774)
Distance		-0.0542***	-2.830***	-2.839***	-2.814***
		(0.0100)	(0.224)	(0.224)	(0.224)
Distance^2		0.00837	1.104***	1.108***	1.100***
		(0.00553)	(0.102)	(0.102)	(0.102)
F-Statistic		49.39	76.94	75.87	113.0
Panel B: Second Stage					
ln(Price)	-0.281***	2.607***	1.460***	1.381***	1.446***
	(0.00163)	(0.203)	(0.108)	(0.170)	(0.181)
City Fixed Effects			✓	✓	✓
Day-of-Week Fixed Effects				✓	✓
Product Controls					✓
Observations	687,335	687,335	687,335	687,335	687,335

Table 4
Demand, Pass Through, and Price—Survey Evidence

This table reports our analysis from the BERT survey questions. Row 1 reports the elasticity of demand estimates that are calculated by dividing business's answers by 10 from the question, "If you raised your price by 10 percent what percent (%) less in sales would you expect?" Standard errors are reported in parenthesis.

		Top Selling			
		Retail Plant		Infused Product	
	All Products	High end	Low end	High end	Low end
	(1)	(2)	(3)	(4)	(5)
Elasticity of Demand	-1.85	-1.27	-1.70	-1.75	-3.50
	(0.45)	(0.08)	(0.11)	(0.05)	(0.19)
Observations	242	242	242	242	242

Table 5
Externalities of Marijuana Use

This table summarizes potential externalities of marijuana use and legalization, as documented by existing literature.

Potential Externality	Findings	Papers
Marijuana and Heath Concerns	Negative health effects	Meier et al. (2012); Zalesky et al. (2012); Gates et al. (2014); Volkow et al. (2014)
	Positive health effects	Whiting et al. (2015); Sabia et al. (2017)
Marijuana and Opioid Use	Marijuana use or legalization negatively associated with opiod mortality or hospitalizations	Bachhuber et al. (2014); Smart (2015); Shi (2017); Powell et al. (2018)
	Marijuana use or legalization negatively associated with opiod use	Lucas et al. (2013); Bradford and Bradford (2016); Nielsen et al. (2017); Reiman et al. (2017); Wen and Hockenberry (2018); Bradford et al. (2018); Liang et al. (2018); Shah et al. (2019)
Marijuana and Tobacco Use	Marijuana use or legalization negatively associated tobacco use	Scherma et al. (2016); Kerr et al. (2017); Choi et al. (2019)
Marijuana and Alcohol Use	Marijuana use or legalization negatively associated with alcohol use or binge drinking in some age groups.	Mark Anderson et al. (2013); Lucas et al. (2013); Smart (2015); Sabia et al. (2017); Cerdá et al. (2018); Johnson et al. (2018)
	Marijuana use or legalization positively associated with alcohol use or binge drinking in some age groups.	Wen et al. (2015)
Marijuana and Traffic Fatalities	Marijuana use or legalization positively associated with traffic accidents or fatalities	Hartman and Huestis (2013); Smart (2015); Els et al. (2019)
	Marijuana use or legalization negatively associated with traffic accidents or fatalities	Mark Anderson et al. (2013); Kim et al. (2016)

Figure 1. Price of Marijuana Over Time: Top Thirty Strains

The above figure shows the smoothed average retail sales prices of marijuana from July 2014 to January 2017. Thin grey lines depict the average sales price of the 30 most popular strains by number of sales transactions. The black think line represents the average price of all marijuana sold. Prices are adjusted to exclude a 25% gross receipts tax prior to July 1, 2015, and a 37% excise tax following July 1, 2015.

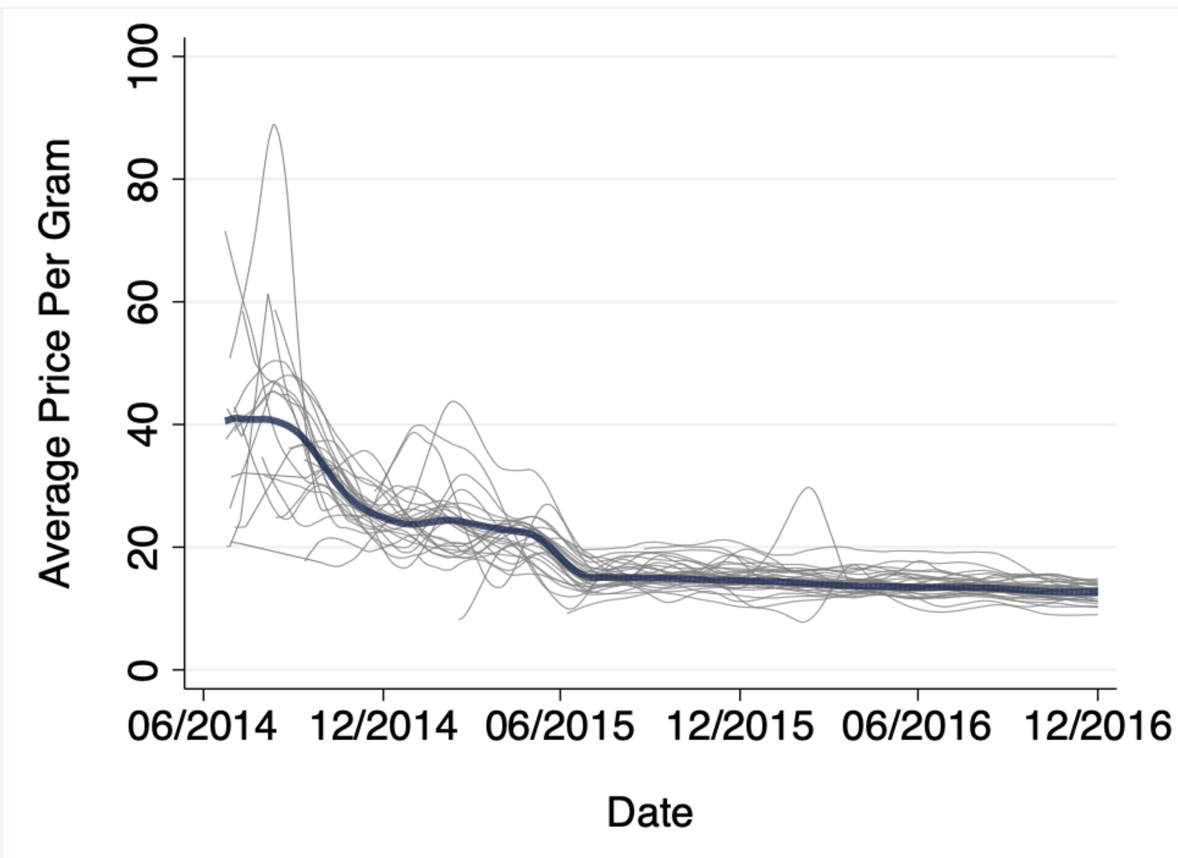


Figure 2. Strains of Marijuana Over Time

This figure depicts the total number of strains available in Washington and the total number of strains available per retail location from July 2014 to December 2016. Data are collapsed to the weekly level.

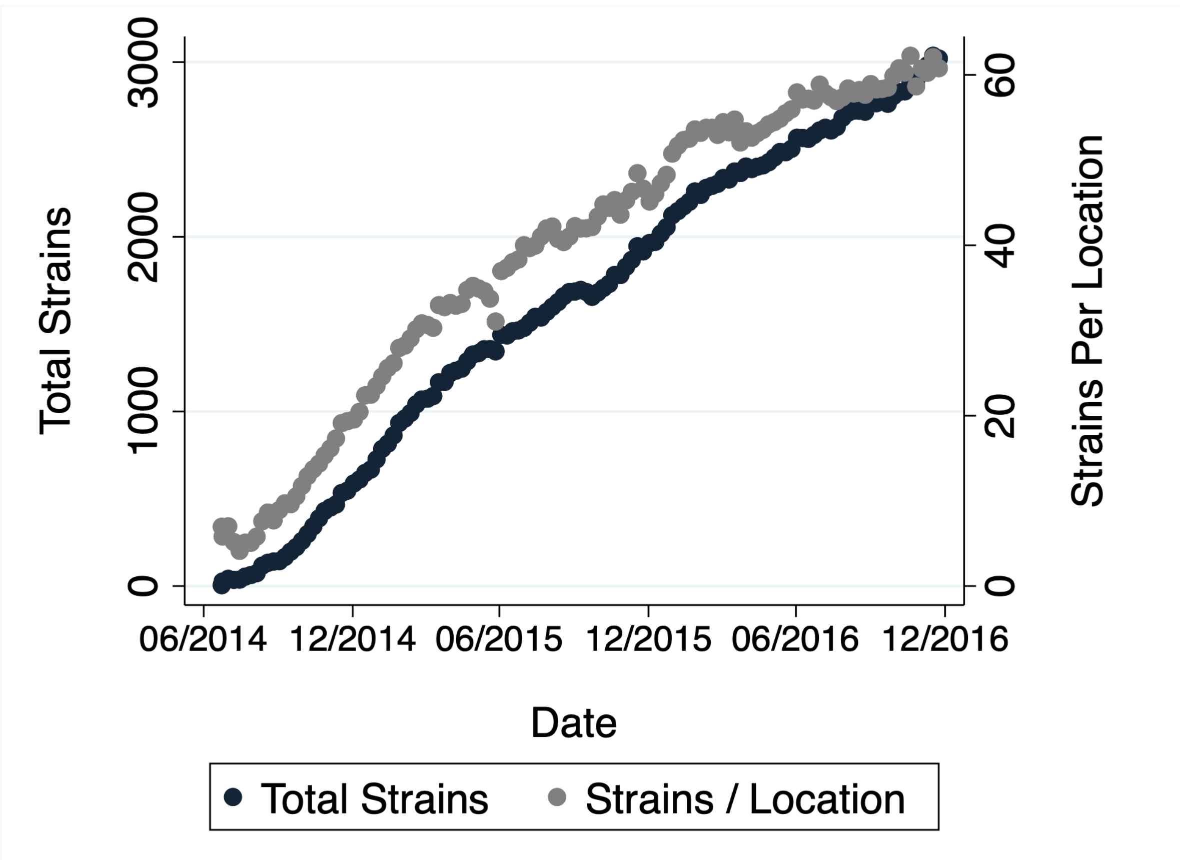


Figure 3. Variation in Price: Market Definitions

This figure relates price to various market sizes. A market is defined by a geographic radius from a given retailer. The price is regressed on the number of neighboring retailers within a given market according to the following regression:

$$\ln(\text{price})_i = \beta_0 + \beta_1 \text{neighbors}_i$$

Figure displays β_1 for market radii between 1 and 10 miles.

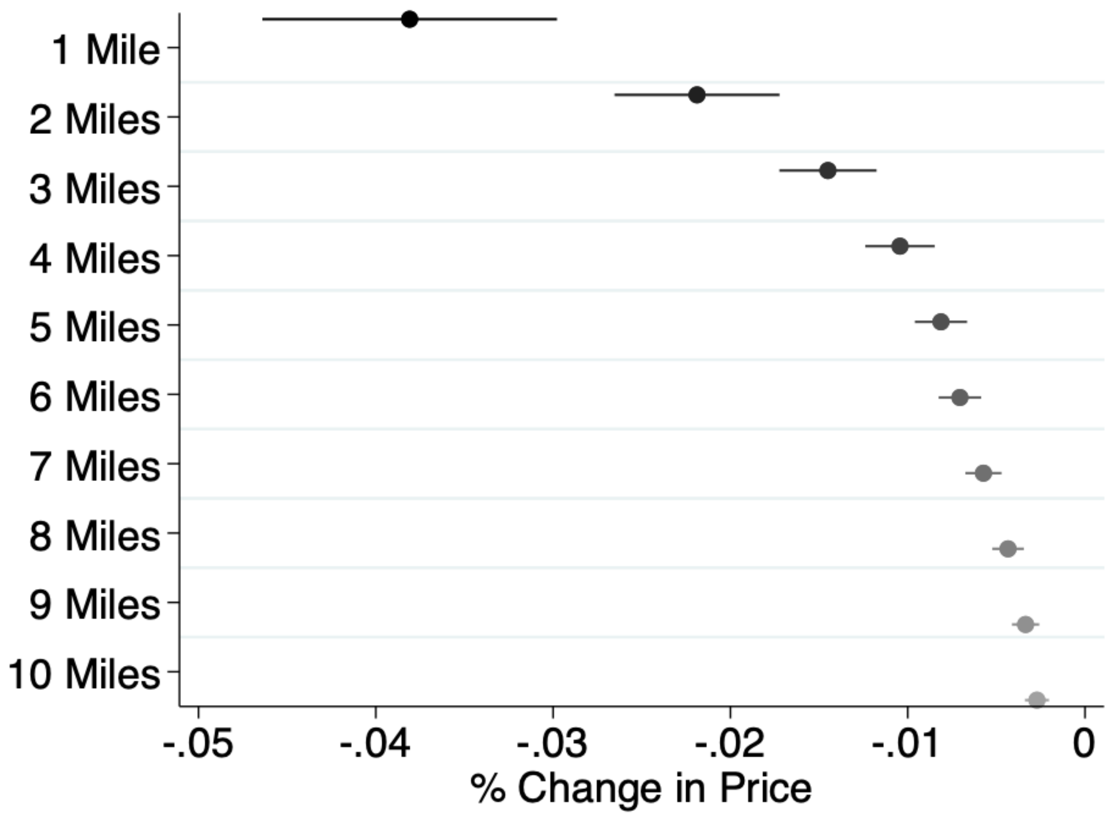


Figure 4. Geographic Variation in Average Price per Gram: 2015

This figure depicts the average tax-inclusive price of marijuana per gram in 2015. Borders reflect county lines. Averages range from 9.46 to 18.90 per gram, where darker shading at the county-level indicates higher average prices. Retail locations are demarked by circles. Darker shading reflects higher deciles of price per gram.

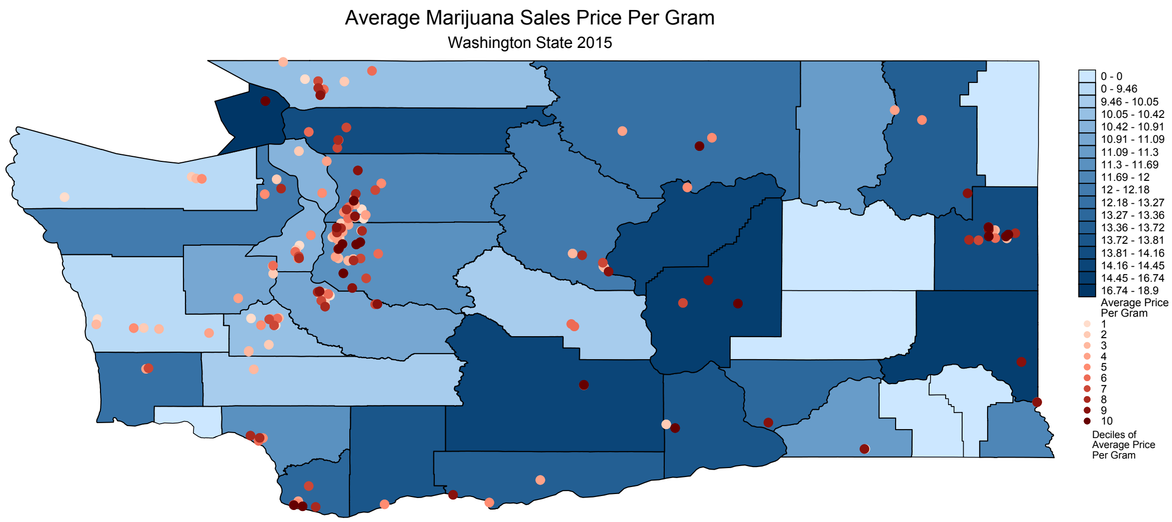


Figure 5. Geographic Variation in Marijuana Sold Per Capita: 2015

This figure depicts marijuana sales as a fraction of county population in 2015. Marijuana sales are measured by grams of marijuana sold. Borders reflect county lines. Sales per capita range from 0 to 247 grams per capita, where darker shading at the county-level indicate higher grams of marijuana sold per capita. Retail locations are demarked by circles. Darker shading reflects higher deciles of total marijuana sold, as measured by grams of marijuana sold.

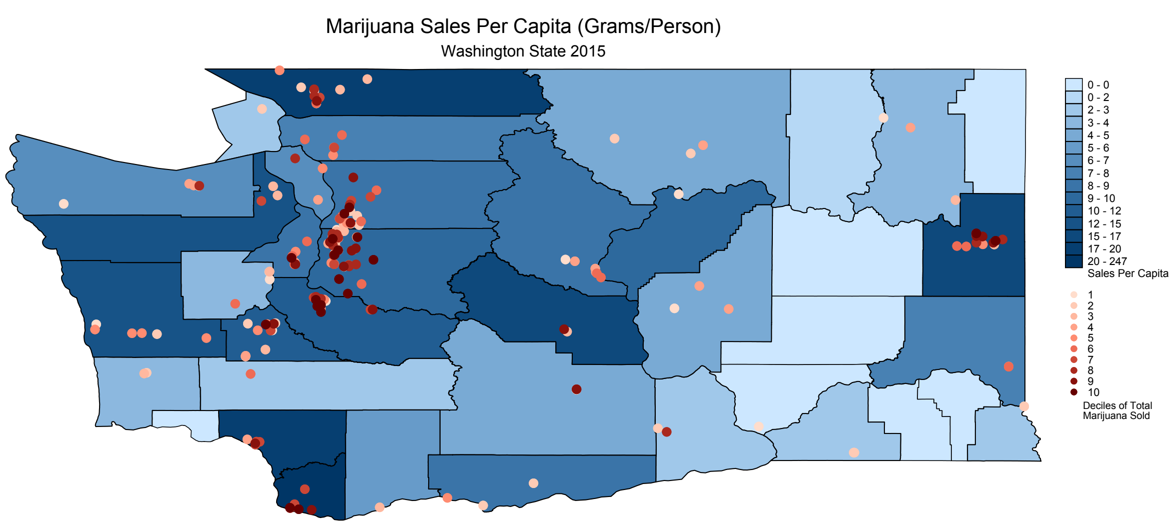


Figure 6. Retailer Entry: 2015

This figure depicts new entrants into the retail marijuana market in 2015. Borders reflect county lines. New retail locations are demarked by circles. Shading reflects variation in retailer entry by county, ranging from 0 to 29.

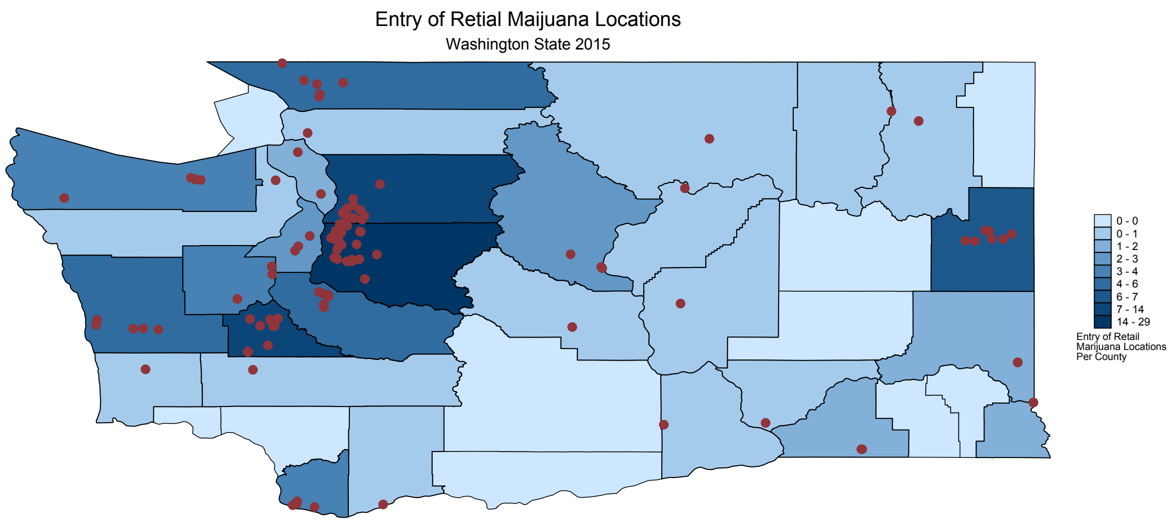


Figure 7. Geographic Variation in the HHI: 2015

This figure depicts variation in the Herfindahl-Hershman Index (HHI) in 2015. Market shares are defined based on a retailer's share of total marijuana sold as measured by grams of marijuana. HHI ranges from 0 to 10,000. Retail locations are demarked by circles.

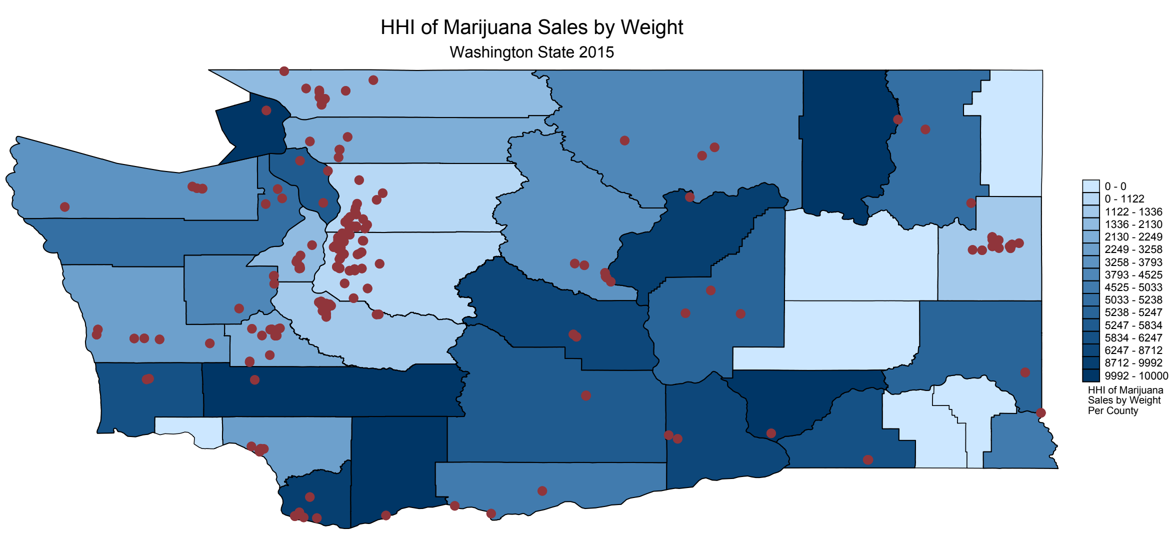
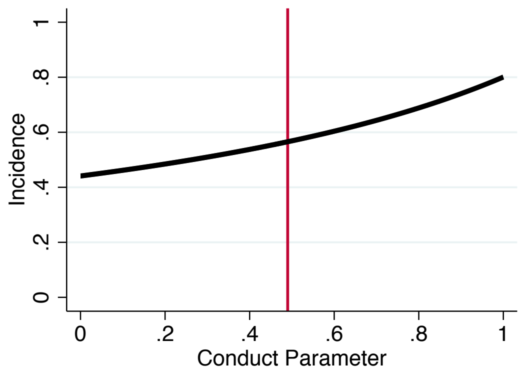
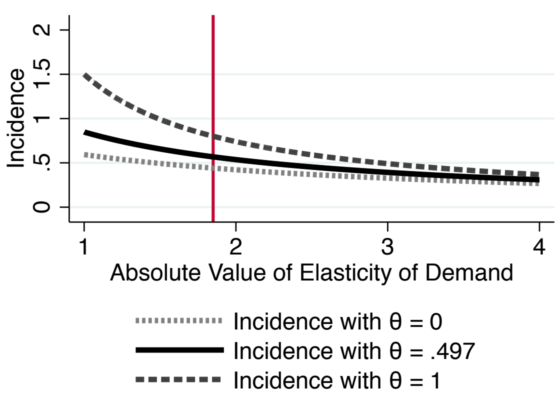


Figure 8. Simulated Incidence of Marijuana Tax on Consumers

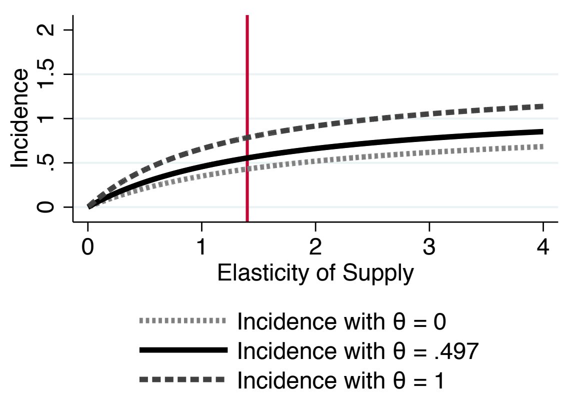
(a) Incidence, varying Market Power



(b) Incidence, varying Elasticity of Demand



(c) Incidence, varying Elasticity of Supply



Notes: This figure graphs the incidence of the marijuana tax on consumers, varying market power quantified by the conduct parameter (Panel A), the elasticity of demand (Panel B), and the elasticity of supply (Panel C). Panels B and C graph incidence with the conduct parameter equal to 0.497, the baseline calibration, 0.1 and 0.9 to give the range of incidence for varying market concentrations. The baseline estimates use elasticity of demand equal to -1.85, the elasticity of supply equal to 1.4, the average price of 15.02, the average sales per month of 4,011,309, the specific tax of $5.56 (which is 0.37 times the average price), and an elasticity of marginal surplus of -3. Vertical lines in the graphs reflect our baseline parameter values.

A. Data

We utilize an extract of the Washington administrative data that includes records from July 2014–January 2017. These data include 62,646,282 transactions between retailers and consumers. Several characteristics of this data indicate that reported sales prices are tax-inclusive. For example, Hansen et al. (2017) report that marijuana retailers sell marijuana in whole-dollar or quarter-dollar increments, while the observed sales data only lands within such increments less than 5% of the time. Furthermore, more than 95% of the data are reported at a precision greater than two decimal points, again suggesting that reported data include sales tax. Given these data characteristics, we assume all prices reported in the database are tax-inclusive, and therefore we deflate the prices to account for the 25% gross receipts tax for transactions occurring prior to July 1, 2015, and the 37.5% excise tax for transactions occurring after July 1, 2015.

We also take several other cleaning steps to ensure that sales data are reflective of a typical retail transaction. We drop transactions that are refunded, deleted, or occurred within the first two weeks of an organization's establishment. We also calculate the unit price of each transaction as price per weight and drop transactions that are less than 60% or more than 140% of the mode unit-price. Unit prices are further winsorized at the 1% an 99% percent levels. These cleaning steps help to control for transactions that were incorrectly reported or represented. For example, Hansen et al. (2017) document that errors in reported price can stem from misplaced decimals, and that some transactions actually represent gifts which are recorded to comply with Washington's marijuana tracking laws. For example, samples given to the retailer by the processor often report a price of one cent so that marijuana movements can be tracked within the BioTrackTHC system. We also limit our sample to marijuana buds, which we define as dried and cured flowers which are consumed by smoking, to make retail sales comparable across time and products.

B. Additional Tables and Figures

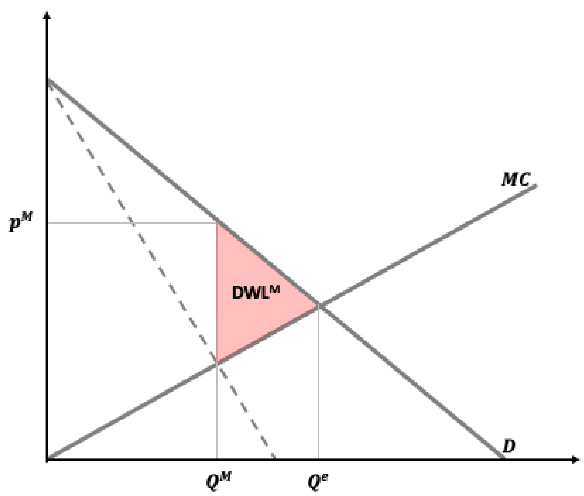
Table B.1
Market Summary Statistics: Varying Market Boundaries

This table presents summary statistics of marijuana sales with varying definitions of market boundaries. Panel A defines a market boundary as 1 mile, while Panels B and C use market boundaries of 5 and 10 miles. Panel D defines a market boundaries by county.

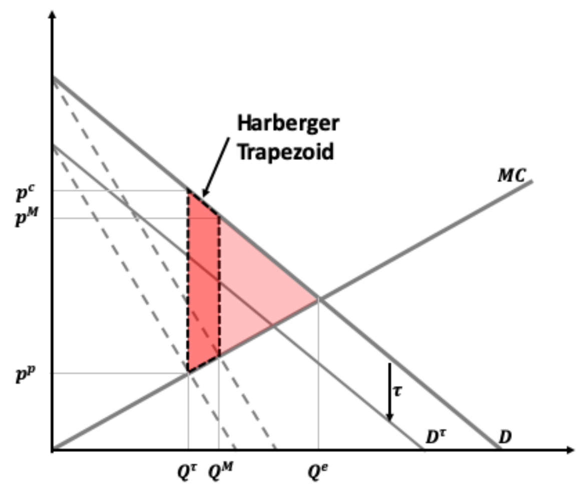
	Weight (1)	Price (2)	Size (3)	HHI (4)
Panel A: 1 Mile Radius				
2014	9,144	31	1	9,552
2015	31,407	17	1	9,088
2016	50,122	13	2	8,282
Panel B: 5 Mile Radius				
2014	16,486	31	2	8,033
2015	116,612	17	4	5,811
2016	268,483	13	8	4,279
Panel C: 10 Mile Radius				
2014	30,710	32	3	6,931
2015	279,424	17	9	4,155
2016	661,261	13	20	2,884
Panel E: County Markets				
2014	21,320	32	3	7,007
2015	130,091	18	5	5,075
2016	266,513	13	9	3,986

Figure B.1. Harberger Trapezoid: Deadweight Loss with Imperfect Competition

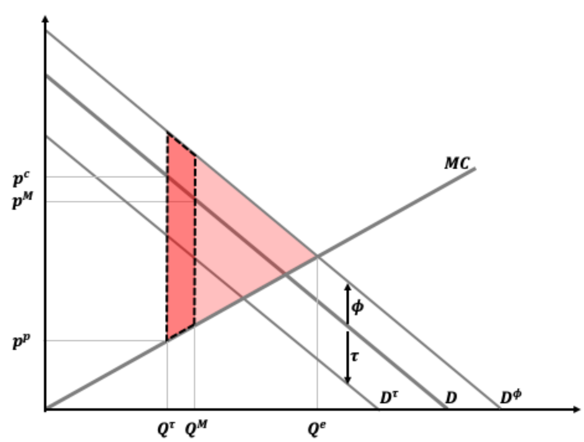
(a) Monopoly DWL



(b) Δ in DWL with Tax



(c) Δ in DWL, Tax and Positive Externality



(d) Δ in DWL, Tax and Negative Externality

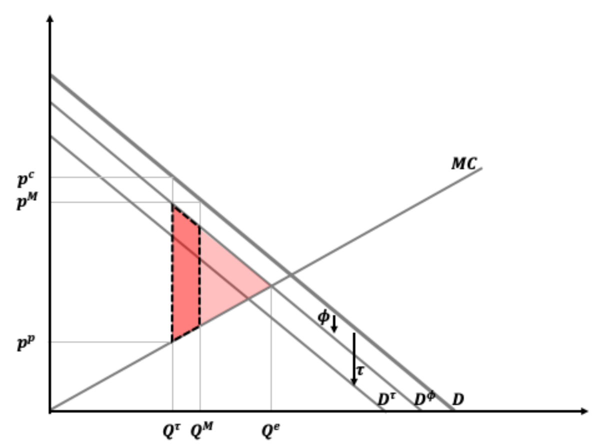


Table B.2
Elasticity of Supply: Variation in Window Around Change

This table provides estimates for the average elasticity of supply for cannabis focusing on a two- and three-month windows surrounding the legalization of marijuana in Oregon (September–October 2015). Panel A reports two-stage least squares estimates using a two-month window surrounding the legalization of marijuana in Oregon, while panel B reports two-stage least squares estimates using a three-month window.

	OLS (1)	IV (2)	IV (3)	IV (4)	IV (5)
Panel A: Two-Month Window					
ln(Price)	-0.286*** (0.00114)	3.216*** (0.186)	1.784*** (0.0951)	1.846*** (0.144)	2.032*** (0.156)
F-Statistic		82.3	128.3	128.2	197.9
Observations	1,353,211	1,353,211	1,353,211	1,353,211	1,353,211
Panel B: Three-Month Window					
ln(Price)	-0.287*** (0.000926)	2.723*** (0.119)	1.773*** (0.0656)	1.578*** (0.0847)	1.756*** (0.0898)
F-Statistic		154.7	267.0	266.6	347.0
Observations	2,038,101	2,038,101	2,038,101	2,038,101	2,038,101
Controls			✓	✓	✓
City Fixed Effects				✓	✓
Day-of-Week Fixed Effects					✓

C. Discussion of Federal Income Tax

The discussion of the differential treatment of legal and illegal income began as early as the discussion of the federal income tax itself. In 1913, in discussing the bill that introduced the federal income tax in the United States, Senator Williams stated that the goal of the income tax is to tax a person's net income, "what he has at the end of the year after deducting from his receipts his expenditures or losses. It is not to reform men's moral character." From the beginning of the income tax, business deductions were allowed for illegal businesses including gambling, prostitution, racketeering, and other forms of organized crime. The exception to this is the public policy doctrine, which disallows deductions which directly contradict public policy; Congress defined these explicitly as items such as illegal bribes or illegal kickbacks.

In 1982, Congress passed Section 280E, which dramatically changed the status quo from taxing all businesses based on net income to taxing legal businesses on net income and illegal business on gross income. The following simplified example highlights the differential tax treatment of legal and illegal businesses.

Gross sales less returns	$1,000,000
Cost of goods sold	$600,000
Gross income	$400,000
Total deductions	$300,000
Net income	$100,000

A legal business, which is taxed on net income after deductions, has a taxable income of $100,000. An illegal business, which is taxed on gross income and disallowed deductions, has a taxable income of $400,000. Using the individual tax brackets for 2017, this suggests that the legal business has a tax liability of $20,981.07[27] while the illegal business has a tax liability of $115,398.24[28]. Said differently, the legal business has an average tax rate on its net income of 21% while the illegal business has an average tax rate on its net income of 115%.

Note, the illegal business is taxed on gross income, which is sales minus cost of goods sold. This adjustment was allowed under 280E due to concerns over Constitutional challenges, which are outside of the scope of this paper. There is a potential for marijuana businesses to lower their tax liability by using inventory capitalizing rules to increase their stated cost of goods sold, though it is not clear whether any business in practice does this.

Another way marijuana businesses can lower their tax liability is to sell goods other than marijuana, in states where that is legal. Wages paid to employees that sell t-shirts, pipes, or

[27] 9325*.1+(37950-95326)*.15+(91900-37951)*.25+(100000-91901)*.28=20,981.07

[28] 9325*.1+(37950-95326)*.15+(91900-37951)*.25+(191650-91901)*.28+(400000-191651)*.33=115,398.24

juice could be deducted from profits where wages paid to employees that sell marijuana could not. The rules on this seem to be less clear, but there does seem to be some anecdotal evidence of this type of tax avoidance.

D. Deadweight Loss Derivation

In this section we derive change in deadweight loss that results from the imposition of a tax in an imperfectly competitive market. In Section D.1 we modify the stylized model in Fullerton and Metcalf (2002) to derive the "Harberger Trapezoid." We then transform this formulation to make use of the observable parameters in our particular setting. Finally, we modify the model to account for any consumption externalities in Section D.2.

D.1. Imperfect Competition: the Harberger Trapezoid Due to a Tax

The traditional Harberger Triangle captures the deadweight loss from the imposition of a tax relative to a perfectly competitive market outcome. In this case, the market is assumed to be efficient absent the tax. In an imperfectly competitive market with market power, however, the equilibrium outcome is not the efficient outcome. Said differently, there is a deadweight loss in imperfectly competitive markets absent the tax. For this reason, we measure the *change* in deadweight loss due to the tax, relative to the un-taxed equilibrium. To develop this intuition, Panel (a) of Figure B.1 depicts the deadweight loss due to market power in an un-taxed monopoly market, the familiar Harberger Triangle. If a specific tax, τ, is imposed, this results in an *increase* in the deadweight loss, highlighted in Panel (b). The impact of the tax is captured by a Harberger Trapezoid, which measures the change in deadweight loss relative to the untaxed monopoly outcome.

Formally, the market outcome with market power is (Q^0, p^0), resulting in a deadweight loss measured by $\frac{1}{2}(p^0 - MC^0) \cdot dQ$. When a tax is imposed in this market, the market becomes (p^c, Q^τ) and the deadweight loss increases by the Harberger Trapezoid:

$$\frac{1}{2}\left((p^0 - MC^0) + (p^c - p^p\right) \cdot dQ^\tau \tag{D.1}$$

We transform this formula to take advantage of the empirically derived parameters in our context. To begin $(p^0 - MC^0)$ measures the monopoly mark-up in equilibrium without a tax. We recover the mark-up from our estimate of the conduct parameter, the elasticity of demand,

and market prices. We follow Auerbach and Hines Jr (2002) and assume that θ is unaffected by the tax in the short run and for small changes in the tax. As a result:

$$p^0 - MC^0 = \frac{\theta}{|\varepsilon_D|} p^0 \, .$$

While we don't observe p^0, we have estimated the incidence of the tax on consumers, ρ. It follows that $p^c = p^0 + \rho\tau$, or

$$p^0 = p^c - \rho\tau \, .$$

Combining these two formulations results in an estimate of the monopoly mark-up that depends on empirically estimated parameters in our context:

$$p^M - MC^0 = \frac{\theta}{|\varepsilon_D|} (p^c - \rho\tau) \, . \tag{D.2}$$

We follow similar logic to transform $(p^c - MC^\tau)$. In particular, we note that $(p^c - MC^\tau)$ is equal to the monopoly mark-up at Q^M plus the tax. As a result,

$$p^c - MC^\tau = \frac{\theta}{|\varepsilon_D|} (p^c - \tau) + \tau \, . \tag{D.3}$$

Next, we derive dQ^τ from the elasticity of supply, following Fullerton and Metcalf (2002).

$$\begin{aligned}
\varepsilon_s &= \frac{dQ^s}{dp} \cdot \frac{p}{Q^s} \\
\varepsilon_s \frac{Q^s}{p} &= \frac{dQ^s}{dp} \\
\varepsilon_s \frac{Q^s}{p} \frac{dp}{dt} dt &= dQ^s \\
\varepsilon_s \frac{Q^\tau}{p} (1-\rho)\tau &= dQ^\tau \, . \qquad \text{(D.4)}
\end{aligned}$$

where $Q^S = Q^\tau$ in the post-tax market equilibrium.

We combine equations D.2, D.3, D.4 into equation D.1 to re-write the Harberger Trapezoid as a function of empirically estimated parameters in our context:

$$\frac{1}{2} \left[\left(\frac{\theta}{|\varepsilon_D|} \right) (2p^c - \tau(1+\rho)) + \tau \right] \varepsilon_s \frac{Q^\tau}{p} (1-\rho)\tau \, . \tag{D.5}$$

Finally, by incorporating the incidence of the tax in the presence of imperfect competition, equation (2), we derive a formula that we can estimate in the context of marijuana taxation:

$$DWL = \frac{1}{2} \cdot \varepsilon_s \cdot \tau \cdot \frac{Q^\tau}{p} \left[\left(\frac{\theta}{|\varepsilon_D|} \right) (2p^c - \tau(1+\rho)) + \tau \right] \left(\frac{\frac{\varepsilon_D - \theta}{\varepsilon_S} + \frac{\theta}{\varepsilon_{ms}}}{1 + \frac{\varepsilon_D - \theta}{\varepsilon_S} + \frac{\theta}{\varepsilon_{ms}}} \right) . \tag{D.6}$$

Note that in the case of perfect competition, where $\theta = 0$, this formula collapses to the more familiar Harberger Triangle:

$$DWL = \frac{1}{2} \cdot \varepsilon_s \cdot \tau^2 \cdot \frac{Q^\tau}{p} \left(\frac{\varepsilon_D \varepsilon_S}{\varepsilon_S + \varepsilon_D} \right) .$$

D.2. Harberger Trapezoid: Accounting for Externalities

The deadweight loss formula must be adjusted to account for consumption externalities, ϕ. In the case of marijuana consumption, we have shown that the sign of the consumption externality is unknown. For this reason, our baseline analysis assumes that the externality is zero. On the other hand, we consider the impact of the externality on the deadweight loss, both for positive and negative externalities. To this end, Figure B.1 depicts the change in DWL for positive (panel c) and negative externalities (panels d and e). In most cases[29], the area represented by the deadweight loss is

$$DWL = \frac{1}{2} \left((p^M - MC_M + \phi) + (p^c - p^p + \phi) \right) \cdot dQ^\tau .$$

As before, the deadweight loss formulation can be rewritten as a function of the empirically estimated parameters in our context as

$$DWL = \frac{1}{2} \cdot \varepsilon_s \cdot \tau \cdot \frac{Q^\tau}{p} \left[\left(\frac{\theta}{|\varepsilon_D|} \right) (2p^c - \tau(1+\rho)) + \tau + 2\phi \right] \left(\frac{\frac{\varepsilon_D - \theta}{\varepsilon_S} + \frac{\theta}{\varepsilon_{ms}}}{1 + \frac{\varepsilon_D - \theta}{\varepsilon_S} + \frac{\theta}{\varepsilon_{ms}}} \right) . \tag{D.7}$$

[29] We note one exception to this rule: when $Q^\tau < Q^e < Q^M$. We assume away this case for the purposes of our simulation.