Tax Revenues When Substances Substitute: Marijuana, Alcohol, and Tobacco

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Abstract

Proponents of recreational marijuana legalization have argued that it would increase state tax revenues. However, if marijuana and other legal substances (e.g. alcohol and tobacco) are substitutes, tax revenues from marijuana may cannibalize revenues from these goods. We study the change in substance tax revenues caused by legalizing marijuana in Washington state, accounting for potential substitutability and complementarity between marijuana, alcohol, and tobacco as well as price responses in these markets. We combine administrative data on marijuana sales and scanner data on alcohol and tobacco sales and exploit the fact that retailers opened in different areas at different times. By estimating a demand system for legal substances and controlling for prices, we find that substances are substitutes. The legalization of marijuana itself leads to a 5% decrease in alcohol and a 12% decrease in tobacco demand. Liquor and cigarette products are affected most. After total substance expenditures increase and tobacco and alcohol prices adjust, 40% of state marijuana tax revenue is cannibalized by reductions in alcohol and tobacco revenues. Since marijuana is untaxed at the federal level, legalization reduces federal tax revenues by 13%. Though Washington has the highest marijuana tax rate in the country, it is on the left-hand side of the Laffer curve — a 1% increase in the marijuana tax increases total state tax revenues 0.2%.

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1 Introduction

The median American voter supports legalizing marijuana for recreational use (Motel, 2015) and several jurisdictions around the world have legalized marijuana in some form. Advocates for legalization have pointed to the potential for tax revenue: Washington state, which we study here, earned \$150 million from marijuana taxes in 2015, the first full calendar year after its market opened. However, legalization and subsequent changes in marijuana prices may decrease tax revenues from other legal substances – sales of alcohol and tobacco in our data contributed over \$500 million to Washington's coffers in 2013. If alcohol, marijuana, and tobacco products are substitutes, the gains to total tax revenue from marijuana legalization could be smaller than expected.[1] If they are complements, the gains could be larger.

We evaluate the extensive margin effect of legalizing recreational marijuana on state and federal substance tax revenues for the first time, taking into account the potential for substitution and complementarity effects between marijuana, alcohol, and tobacco products. In addition, we estimate intensive margin changes to revenues in response to changes in the tax rates on each substance product post-legalization (i.e. the gradient of the Laffer curve), which is particularly policy-relevant given Washington's high substance tax rates relative to the rest of the country (Drenkard, 2015, Hansen et al., 2017a, Scarboro, 2017).

We collect a panel dataset of the retail prices and quantities of each substance at the county level from 2013-2016 in Washington, where recreational marijuana sales begin in July 2014. We combine alcohol and tobacco data from the Nielsen Retail Scanner Dataset with marijuana data from Washington's regulatory 'traceability' system. Our data captures a variety of product types: flower, edibles, and concentrates within marijuana; beer, wine, and liquor within alcohol; and cigarettes and other tobacco products (OTP) within tobacco. We document declines in both prices and quantities of most alcohol and tobacco products after marijuana became available.

The legalization of marijuana could influence demand differently at the substance level (e.g. consumers purchase marijuana instead of alcohol) than at the individual product level

[1] For example, prior to legalization, Washington officials projected that a recreational marijuana market would generate \$389 million in taxes under the assumption that other markets would be unaffected (Washington Office of Financial Management, 2013).

(e.g. consumers consume flower with beer). These product-level substitution patterns affect tax revenues because products are taxed at different rates. For example, the effective tax rate on beer in 2015 was 10.2%, while the effective rate on liquor was 30.5%. To capture patterns of substitution and complementarity at both the product and category levels with a micro-foundation connecting the two we model demand for legal substances with a multistage budgeting approach inspired by Deaton and Muellbauer (1980) and Hausman et al. (1994). Our model allows for flexible cross-price elasticities both across substance categories and across product types within each category. The model allows the legalization of marijuana to affect each product differently and coherently aggregates the effects across products up to the substance level.

To identify the extensive margin effect of legalizing marijuana, we use the fact that marijuana retailers opened at different times in different counties and account for the potential endogeneity of store opening dates with an instrument derived from local entry bans. We identify the intensive margin effects of price changes across substances post-legalization by instrumenting prices with wholesale marijuana prices, local tax rates, and Hausman instruments. We include county fixed effects to account for local heterogeneity in tastes for substances, political views, etc. and year-month fixed effects to account for the evolution of these markets, such as changes in black market activity or trends in consumer preferences between substances (Washington, 2018).

On the extensive margin, after controlling for price changes in alcohol and tobacco as well as county- and time-specific demand shocks, the legalization of recreational marijuana in isolation decreases the quantity of alcohol (tobacco) demanded by 5% (12%), mostly through changes in demand for liquor (cigarettes). The total tax revenues collected by Washington from sales of legal substances increased 23% ($526 million to $647 million) from 2013 to 2015. We find that 40% of the $150 million in marijuana tax revenues in 2015 came from a cannibalization of alcohol and tobacco tax revenues. Without taking substitutability into account, the increase in total revenues would be overestimated by 9.3%, or $63 million.

Our estimates of the intensive margin relationships between the price of marijuana and the quantity demanded of alcohol and tobacco are noisy, but support the hypothesis that marijuana products and cigarettes are substitutes. Despite Washington's high substance tax rates, the gradient of the Laffer curve is positive — a 1% increase in the marijuana, alcohol, and tobacco tax rates leads to a .19%, .50%, and .43% increase in total state tax revenues, respectively.

We contribute to a growing interdisciplinary literature on the relationships between marijuana and other substances. Subbaraman (2016) and Guttmannova et al. (2016) survey studies on these relationships and find inconsistent results. Our approach differs from this literature in multiple dimensions. Many studies rely on survey data (Miller et al., 2017a) or proxies for substitution such as crime (Morris et al., 2014) or emergency room reports (Model, 1993). In contrast, we use administrative data on the universe of recreational marijuana purchases with minimal measurement error. Additionally, previous work has generally focused on the impact of *medical* marijuana laws. For example, Baggio et al. (2017) shows that legalizing medical marijuana leads to a 15% reduction in alcohol sales. To the best of our knowledge, we are the first to estimate the effect of a legal *recreational* marijuana market on state and federal tax revenues from multiple substances. Furthermore, our micro-founded model allows us to estimate cross-price elasticities at both product as well as category levels.

We are also connected to the literature on the Laffer curve for substance taxes. Miravete et al. (2018) show that firm market power leads to a "flatter" Laffer curve in the liquor industry. Two recent working papers find, as we do, that Washington's marijuana tax rate is on the upward-sloping part of the Laffer curve — Hollenbeck and Uetake (2018), who study tax incidence with respect to market power, and Hansen et al. (2017a), who estimate the pass-through rate. In contrast to these papers, we explicitly incorporate the possibility of substitution across substances and calculate the Laffer curve with respect to the total substance tax revenues collected by the state.

In addition, we contribute to a public finance literature studying the trade-offs created by federal systems and the devolution of taxation powers (Musgrave, 1959, Inman and Rubinfeld, 1996, Oates, 1999). Common questions include understanding vertical tax competition between local jurisdictions and the federal government (Keen and Kotsogiannis, 2002, Brülhart and Jametti, 2006, Devereux et al., 2007) and horizontal tax differentiation and competition across jurisdictions (Jacobs et al., 2010, Agrawal, 2012, 2015). The vast majority of this literature focuses on a single good – we show that the legalization of marijuana changes the federal tax base for alcohol and tobacco and that therefore the competition between jurisdictions can take place over a range of markets.

We proceed by providing background information on Washington's marijuana market and substance taxation in Section 2. We discuss our data and provide descriptive statistics in Section 3. We describe our model of demand for recreational substances in Section 4. Section 5 details the particulars of our approach to identification and estimation. We present the results in Section 6. We conclude in Section 7 with a discussion of policy implications and suggestions for further research.

2 Background

Washington was one of the first states to legalize marijuana for recreational use.[2] Washington voters approved Initiative 502 in the election of November 2012, legalizing the sales of marijuana for recreational use to all adults over the age of 21.[3] Though the market opened in July 2014, only 26 retail locations across Washington's 39 counties opened in the first month. 85 stores across half of Washington's counties were open by the end of the year and the number of stores grew to 352 by the end of 2016. Figure 1 illustrates Washington's counties with the month of first entry by retailers.

This variation in the timing of entry provides an opportunity to identify the effect of legal marijuana by comparing counties with local retail access to counties without access. Though retailers may have wished to enter faster in areas with higher expected demand, which would create endogenous entry, the entry process was strictly controlled. Regulators initially capped the number of retail licenses at 334[4] and apportioned those licenses across geographies based on the local population share. Lotteries were held in areas where the number of applicants exceeded the quota (Thomas, 2018), which partially alleviates concerns that entry is correlated with demand shocks. Furthermore, entry in some areas was initially limited by local authorities.[5] Figure 2 illustrates the percentage of the population in each

[2] Colorado legalized recreational marijuana at the same time as Washington but does not release county-level data on its marijuana industry.

[3] Voters had previously created a medical marijuana market in 1998 (Sanna, 2014, p. 88).

[4] Each license entitles a retail firm to open up to three locations.

[5] See `http://mrsc.org/Home/Explore-Topics/Legal/Regulation/Marijuana-Regulation-in-Washington-State`.

Washington county living in an area with an entry ban in July 2014. In Section 5 we discuss the use of these moratoria as instruments in our identification strategy.

Washington assesses an excise tax on marijuana sales of 37% of the retail price – effectively the highest in the U.S. (Hansen et al., 2017a). Washington's high marijuana taxes are consistent with its treatment of other substances which are among the highest in the U.S. (Drenkard, 2015, Scarboro, 2017). Liquor sold for off-premise consumption is subject to a 20.5% tax on the retail price as well as an per-liter tax of $3.7708. Beer and wine are subject to smaller per-liter excise taxes collected from wholesalers. Cigarettes faced a per-pack excise tax of $3.025 during the period we study, while other tobacco products faced a 95% tax on the wholesale price. All marijuana, tobacco, and alcohol products, except for liquor, are subject to the state's general 6.5% 'sales and use' tax, in addition to locality taxes which may vary at the quarterly level.

As part of the ballot process, the State predicted the annual tax revenues from recreational marijuana could be as high as $389 million by using estimates of the marijuana consumption rate produced by the U.S. Department of Health and Human Services and the United Nations Office on Drug and Crime (Washington Office of Financial Management, 2013). However, this estimate did not account for changes in the prices and quantities of other goods and in the price of recreational marijuana products over time. In reality, Washington collected $150 million in marijuana tax revenues in 2015, less than 40% of their estimate. Moreover, in our data from 2013 to 2015, alcohol and tobacco tax revenues decreased by 2.3% and 12.5%, respectively (see Table 1).

To understand changes in federal taxes which stem from the legalization of marijuana, we focus on the federal excise taxes applied to alcohol and tobacco sales,[6] which remained constant during the period we study. Beer was taxed at $0.05 per 12 oz. can, while wine was taxed at rates between $0.21 and $0.67 per 750ml bottle based on the type of wine and

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`aspx` for a list of entry regulations.

[6]Marijuana retailers must pay federal income taxes, just as alcohol and tobacco retailers do. Marijuana retailers are allowed to deduct their cost of goods sold from their income when calculating the taxes they owe, just as alcohol and tobacco retailers can (see Chief Counsel Advice from the Internal Revenue Service 201504011). The difference comes elsewhere: marijuana retailers may not deduct any other expenses, such as labor and capital costs. As a consequence, the marginal federal income tax rate paid by marijuana, alcohol, and tobacco firms is similar, assuming the firms file taxes under similar organizational structures. We therefore exclude income taxes from our analysis of federal tax revenues.

its alcohol content. Liquor was taxed at $2.14 per 750ml bottle at 80 proof. Cigarettes were taxed at $1.01 per pack of 20, cigars faced a unit tax of $0.4026 each, and other tobacco products were subject to a variety of tax rates based on the weight of the product.

3 Data and Descriptive Evidence

We combine administrative data on marijuana sales obtained from the Washington State Liquor and Cannabis Board (WSLCB) with tobacco and alcohol sales data from the Nielsen Retail Scanner Dataset.[7] The WSLCB data comes from Washington's 'seed-to-sale traceability' system that tracks each marijuana product from cultivation to the final retail transaction.[8] The data are reported to the state by firms as a condition of licensing. Compliance and accuracy is enforced through frequent random audits – an average of eight audits per location per year (Hansen et al., 2018). We observe prices and quantities for each product, by retailer and day from July 2014 to December 2016. We also observe the wholesale price paid by the retailer for each product and the product's potency as measured by the concentrations of tetrahydrocannabinol (THC) and cannabidiol (CBD). We observe each retailer's entry date, and separately collect data on county- and municipality-level bans on entry.

The Nielsen Retail Scanner Dataset provides sales data from participating retailers which include four major grocery store chains, two major discount store chains, and two drug store chains in Washington. We observe the price and quantity sold of each tobacco and alcohol product (defined by a UPC) offered by each retail location each week from 2013 to 2016.[9] Retailer locations are observed at the county level; we observe sales for 37 out of Washington's 39 counties. We aggregate both datasets to the monthly level for analysis.

The Nielsen data represents approximately 48% of Washington's grocery sales (Lazich and Burton, 2014). Seo (2017) uses tax data from Washington's Department of Revenue

[7] We do not use the Nielsen Consumer Panel Dataset because the observations are too sparse to construct reliable measures of prices and quantities — even after aggregating to the quarter level, there are multiple counties with zero observations of tobacco or alcohol purchases.

[8] This system was implemented to comply with the informal federal requirements laid out in the Cole Memo (Cole, 2013) which implicitly authorized states to legalize recreational marijuana despite continued federal prohibition.

[9] We begin our analysis in 2013 to isolate the impact of Washington's privatization of the retail liquor industry in June 2012. While the simultaneous entry of marijuana and liquor retailers could pose a threat to our identification strategy, Seo (2017) shows that 98% of liquor retailers entered by the end of 2012.

to show that liquor sales from the Nielsen data captures half of the sales in the state, and that this fraction is constant over time. As long as the legalization of marijuana does not change consumer preferences for stores included in the Nielsen dataset, or change the pricing behavior of Nielsen stores compared to non-Nielsen stores, the Nielsen data can be viewed as representative and will not introduce bias into the estimated effect of marijuana legalization on alcohol and tobacco sales.

Table 1 summarizes the retail sales of alcohol, tobacco, and marijuana captured by our data by year.[10] The first panel reports the total sales in dollars by year. From 2013 to 2015, total substance expenditures increased 15.8% from \$2.5 billion to \$2.9 billion. At the same time, tobacco sales decreased 11% and alcohol sales experienced a smaller decrease of 1.1%. In 2015, marijuana captured 16% of the total expenditures on recreational substances. The second and third panels show that the decreases in sales for alcohol and tobacco were driven by both decreases in quantities and prices. The fourth panel shows that the introduction of legal marijuana increased tax receipts from 2013-2015 by 23% from \$526 million to \$647 million, though receipts from both alcohol and tobacco sales fell, by 2.8% and 12.8% respectively. Finally, the fifth panel reports that the federal excise taxes collected from substances in Washington decreased 2.5% from 2013 to 2015.

The overall pattern of decreasing prices and quantities does not translate uniformly across the product types within each substance category. Table 2 repeats the analysis of Table 1 for beer, wine, and liquor products within the alcohol category and cigarettes and other tobacco products (OTP), which include cigars, loose-leaf tobacco, and vaping products, in the tobacco category. Prices for beer and wine were nearly constant from 2013 to 2015, while the average price of liquor decreased 2.01%. Despite this decrease in the price of liquor, the quantity of liquor sold also decreased by 1.97%. Cigarettes make up over 90% of the tobacco sales. Both tobacco product types experienced decreases in both prices and quantities though quantities decreased more for cigarettes (8.44% versus 5.06%).

Finally, Table 3 reports summary statistics for marijuana from July 2014 through the end of 2016. We subdivide marijuana into three products: flower, edibles, and concentrates.[11]

[10] In Tables 1-3 we calibrate the quantities of alcohol and tobacco sales by multiplying $\frac{1}{0.48} \approx 2.083$ (Lazich and Burton, 2014) to account for the non-Nielsen retailers.

[11] Flower, also known as 'usable marijuana' within Washington's legal framework, consists of the dried

We measure the quantity of flower in grams and the quantities of other products in counts. Sales for all three products increased substantially from 2014 to 2016. The third and fourth panels document a decline in the retail and wholesale prices of all three products as retailers entered in different markets throughout the state. The bottom panel of Table 3 summarizes our data on retailer entry and local entry bans. From 2014 to 2016, the number of counties with an entry ban in at least one location decreased from 14 to 11, though the average population covered by a ban increased from 10% to 17%.

While these descriptive statistics document a decrease in alcohol and tobacco purchases at the same time that recreational marijuana became legal in Washington, and that, in general, substance prices dropped after marijuana was legalized, it is not clear from this alone that the legalization of marijuana caused these decreases. For example, a long term trend in preferences for tobacco (Nelson et al., 2008) or a change in the popularity of black market marijuana, combined with own- and cross-price elasticities for those substances could justify these changes. We therefore proceed to estimate a model of demand for recreational substances which accounts for these factors.

4 A Model of Demand for Recreational Substances

We model demand for recreational substances using a multistage budgeting approach (Gorman, 1971) and the Almost Ideal (AI) demand system (Deaton and Muellbauer, 1980, Hausman et al., 1994). AI is often used to identify relationships between products when it is not known if the products are substitutes or complements. Applications have included estimating the demand for pharmaceuticals (Ellison et al., 1997, Bokhari and Fournier, 2013), analyses of mergers (Werden and Froeb, 2008, Miller et al., 2017b), intellectual property rights (Goldberg, 2010), and strategic pricing (Dhar et al., 2005). Within this literature, we are most related to Hausman and Leonard (2002), who use a similar model to anaylze the consumer surplus impacts of introducing a new product into a narrowly defined category.

and cured flowers of the cannabis plant. Flower products are generally smoked directly by consumers. Edibles are processed foods such as brownies or hard candies which include extracts of the cannabis plant as ingredients. Concentrates consist of extracts of the cannabis plant which have been processed to increase the concentration of psychoactive chemicals. Concentrates are generally consumed via a vaporizer, similar to an e-cigarette.

In the model, a representative consumer makes decisions about expenditures at different levels. The top level models the overall demand for legal substances. The middle level specifies demand for each substance type $m \in \{\text{mj},\ \text{alc},\ \text{tb}\}$ and the bottom level models demand for product i within substance m. Figure 3 provides a diagrammatic view of the model, illustrating the decisions made in each level and the relationships between the levels.[12]

Alternatively, in Appendix A, we estimate the impact of marijuana availability on alcohol and tobacco products using a differences-in-differences strategy with Oregon as a control. While we find similar qualitative results, the differences-in-differences strategy may not be the best approach in our context. First, the absence of liquor in the Oregon data, which accounts for 37% of alcohol sales in Washington and which experienced the largest drop in prices, quantities, and sales from 2013-2015, implies that the sales we capture across the states do not reflect the full variety of products important to consumers. Indeed, if liquor and marijuana are particularly substitutable, which is what we find in our main analysis, we would expect an analysis that focused on beer and wine to be biased towards zero as substitution away from liquor would tend to offset any effects on beer and wine. The relatively brief period between Washington's market opening and Oregon's market opening implies both that preferences for legalization may be correlated between the states and that even if the assumptions needed for identification are satisfied, the data have little power to measure any effect. Furthermore, we exclude Portland, Oregon's largest city and the source of much of its substance sales, due to concerns about cross-border shopping effects (Hansen et al., 2017b). Finally, the differences-in-differences approach does not provide a micro foundation to calculate cross-price elasticities and aggregate from products to substance categories, which is key to calculating the slope of the Laffer curve for substances.

4.1 Bottom level: Demand for products

We model the demand for products within substance types using AI. This demand system is a first-order approximation to any Gorman-class demand function and allows for flexible patterns of substitution or complementarity. A market is defined by county c and time t measured in months. The representative consumer in the market (c, t) allocates a share of

[12] In Appendix B we derive an expression for cross-price elasticities at the product and substance levels.

spending s_{ict}^m to a specific product type $i \in \{1, \cdots, J^m\}$ within substance type m, where J^m is the number of product types within that substance type. Demand is given by

$$\begin{aligned} s_{ict}^m =& \beta_0 + \beta_i^m \log\left(\frac{y_{ct}^m}{P_{ct}^m}\right) + \sum_{j=1}^{J^m} \gamma_{ij}^m \log p_{jct} + \Theta_i L_{ct} 1_{m \in \{\text{alc, tb}\}} \\ &+ FX_{ic} + FX_{it} + \epsilon_{ict}. \end{aligned} \tag{1}$$

In this equation, y_{ct}^m is the expenditure on the substance type, p_{ict} is the price of product i, and P_{ct}^m is a price index for all products within the substance type. Following Hausman et al. (1994), we use a Stone-weighted price index and define $\log P_{ct}^m = \sum_{i=1}^{J^m} s_{ict}^m \log p_{ict}$. $\log\left(\frac{y_{ct}^m}{P_{ct}^m}\right)$ is an index for real quantity and becomes the dependent variable in the middle level. γ_{ij} has the same sign as the Hicksian elasticity conditional on y_{ct}^m.

L_{ct} is an indicator which is equal to one if we observe sales of marijuana (y_{ct}^{mj}) in county c at time t – in other words we define

$$L_{ct} = \begin{cases} 1 & \text{if } y_{ct}^{\text{mj}} > 0, \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

Θ captures the effect of legalizing marijuana on product shares within the alcohol and tobacco substance types.

We include county-product fixed effects FX_{ic} and time-product fixed effects FX_{it} to control for demand shocks across geographic areas and over time (we return to these fixed effects in Section 5.1). Despite these fixed effects, the demand shock ϵ_{ict} may still include a component which is unobserved to econometricians but is observed by firms and consumers (e.g. advertising) which implies the timing of entry L and the price of each product p_i may be correlated with ϵ_{ict}. Moreover, if the shock influences pricing decisions of firms that sell products $j \neq i$, the "own price" p_i is likely to be correlated with the shocks for other products ϵ_j. As a consequence, all prices in Equation 1 may be endogenous depending on the magnitude of substitutability or complementarity. As these prices are used to construct price indices for the other levels of the model, these endogeneity concerns exist in the other levels as well. We discuss our instruments for price in Section 5.2 and L in Section 5.3.

4.2 Middle level: Demand for substance types

The middle level models demand for substance type $m \in \{\text{mj, alc, tb}\}$ with a log-log form:

$$\begin{aligned}\log(Q_{ct}^m) =& \alpha_0 + \alpha_m \log Y_{ct} + \theta_m L_{ct} + \alpha'_m \log Y_{ct} L_{ct} + \delta_{m,\text{mj}} \log P_{ct}^{\text{mj}} L_{ct} \\ &+ \delta_{m,\text{alc}} \log P_{ct}^{\text{alc}} + \delta_{m,\text{tb}} \log P_{ct}^{\text{tb}} + \kappa_m OR_{ct} \\ &+ FX_{mc} + FX_{mt} + e_{mct}.\end{aligned} \tag{3}$$

The dependent variable $Q_{ct}^m = \frac{y_{ct}^m}{P_{ct}^m}$ is the real quantity of substance m. Y_{ct} is the nominal expenditure on all legal substances, which becomes the dependent variable in the top level. We interact $\log Y_{ct}$ with the marijuana availability indicator L because the overall expenditure on substances increases substantially from the sum of tobacco and alcohol expenditures to the sum of tobacco, alcohol, and marijuana expenditures.[13] The δ parameters are Marshallian own- and cross-price elasticities conditional on nominal expenditures Y. To control for any cross-border shopping (Hansen et al., 2017b), we include an indicator variable OR_{ct} which is one if the county c is adjacent to the Oregon border and the time t is after Oregon's market opened. Finally, as in the bottom level, we include county and time fixed effects for each category m.

We set $\log P^{\text{mj}} L = 0$ if $L = 0$ as prices for marijuana prior to legalization are not observable, resulting in a jump in $\log P^{\text{mj}} L$ from zero to some non-zero number at the same time that L changes from zero to one. As a result, θ includes some effect of the change in marijuana prices post-legalization in addition to the effect of legalization. We discuss our approach for estimating the effect of legalization in isolation in Section 5.4.

4.3 Top level: Demand for substances

The top level models the overall demand for legal substances via

$$\log(Y_{ct}) = \phi_0 + \phi_1 \log(\bar{Y}_{ct}) + \lambda \log \bar{P}_{ct} + \mathbf{X}'_c \phi_2 + FX_t + u_{ct}. \tag{4}$$

[13]For marijuana, the coefficient on the total expenditure on substances becomes $\alpha_m + \alpha'_m$, and $\theta_m L_{ct}$ is absorbed to the intercept.

Y_{ct} is the nominal expenditure on all legal substances. $\bar{Y}_{ct}$ is the average gross income reported by the Bureau of Labor Statistics at the county-quarter level. $\log \bar{P}_{ct} = \sum_m \frac{P^m_{ct} Q^m_{ct}}{Y_{ct}} \log P^m_{ct}$ is the Stone-weighted price index for all substances. We include time but not county fixed effects due to the short panel. Instead, we control for county characteristics $\mathbf{X}_c$, such as population, urban or rural status (population density), average age, and gender ratio.

5 Identification and estimation

One may be concerned about potential endogeneity in pricing and store entry decisions, long-term trends in the consumption of alcohol and tobacco, and geographic differences in preferences. We address these concerns with a comprehensive set of fixed effects as well as instruments for prices and our availability indicator. We discuss the middle level for simplicity but the same approach applies to the top and bottom levels.

5.1 County and time fixed effects

Preferences for substances are not likely to be constant across counties. For example, the share of people voting for marijuana legalization at the county level varied from 38% to 68%. Moreover, the unobservable taste for one type of substance may be correlated with tastes for other substances, $Corr(e^m_{ct}, e^n_{ct}) \neq 0$ for $m, n \in \{\text{alc}, \text{ tb}, \text{ mj}\}$. This implies that the county-level demand shock for one substance may be correlated with the prices of other substances $Corr(\log P^m_{ct}, e^n_{ct}) \neq 0$ and the timing of marijuana availability $Corr(L_{ct}, e^m_{ct}) \neq 0, m \neq \text{mj}$.

To control for any geographic-based heterogeneity in preferences we include county-substance fixed effects. They account for demographics of the area, such as income, education, political preferences, social norms, distance to retailers, the sophistication of the black market in the county, and any other unobserved county-specific preferences for each substance that are constant across time.

Preferences for legal substances are also not likely to be constant over time. Our sample period experiences a general shift away from tobacco consumption and within the population of tobacco users and a shift toward e-cigarettes (McMillen et al., 2015, Washington, 2018). Changes in the black market over time affect demand for legal marijuana. We address concerns with time fixed effects for each substance.[14]

5.2 Price endogeneity

If retailers adjust prices in response to county-time specific demand shocks, such as temporary advertisements, prices may still be endogenous. Prices of other substances can also be endogenous if preferences for substances are highly correlated, $Corr(\log P_{ct}^{m}, e_{ct}^{n}) \neq 0$ for $m, n \in \{\text{alc}, \text{ tb}, \text{ mj}\}$. We instrument own and other prices with time-varying local tax rates, the wholesale price of marijuana, and "Hausman" instruments.

Our first instrument comes from the fact that Washington allows localities to set sales tax rates independently. Assuming that counties are not setting tax rates in response to their own demand shocks at certain points in time, these tax rates are uncorrelated with the unobservable component of demand.[15] Roughly half of Washington's counties changed their tax rate at least once during the sample period. 20% changed their tax rate twice or more.

Our data on marijuana sales include the wholesale prices paid by firms. Restrictions on the scale of marijuana production firms[16] imply that no single firm is likely to have sufficient market power to extract rents from any demand shocks in a systematic way. We therefore interpret these wholesale prices as exogenous cost shifters for the retail firm and use them as instruments for marijuana prices. As we aggregate individual UPCs to product types, we use the average wholesale price of medium potency products sold in a county-month as an instrument. We restrict to products of medium potency (defined as the products in the 25th to 75th percentile of THC) to control for changes in the composition of sales.

Lastly, we adopt 'Hausman' instruments, which stem from the logic that prices in different locations are at least partially driven by state-wide cost shocks, such as changes in wages,

[14] We do not use existing data on the black market to control for changes in the black market for two reasons. First, there is no consensus on the estimated size of Washington's black market prior to legalization – estimates range from 85 to 225 metric tons annually (Washington Office of Financial Management, 2013, Kilmer et al., 2013). Second, although black market prices can be collected from `www.priceofweed.com` and Perfect Price, there are not enough observations to construct a price index by county and month. As a result, using this data does not add any value given that we include county and time fixed effects.

[15] The tax rate for liquor is excluded from the instruments as it is not subject to local sales taxes and is constant across counties and time. Additionally, although Washington unexpectedly changed the retail tax rate on marijuana from 25% to 37% on July 1, 2015, our time fixed effects preclude the use of this state-wide change as an instrument.

[16] Marijuana production is regulated under a tiered licensing system that restricts the area of 'plant canopy' that can be under active cultivation. The largest licensees are limited to 30,000 square feet of canopy.

wholesale costs, or fuel costs (Hausman et al., 1994, Hausman, 1996, Hausman and Leonard, 2002). As a consequence, the price of a product in one market at a particular point in time can be used as an instrument for the price of the same product in a different location at the same point in time.

The Hausman instrument exclusion restriction hinges on the absence of state-wide demand shocks. The most common concern identified in the literature is the possibility of broad-scale promotional efforts (see Hausman, 1994, and the included response by Bresnahan), which would simultaneously affect both costs and demand in an unobservable way. In our model any state-wide demand shocks at any given point in time are controlled for by the time fixed effects. The concern might still be relevant if demand shocks are correlated across some counties but not all. However, mass-market advertising of marijuana is effectively restricted to local newspapers and online channels by Washington law and the federal prohibition of the substance (WAC 314-55-155). State and local boards of health in Washington have regulated tobacco advertising beyond the nationwide restrictions of the Master Settlement Agreement (Scott, 2000). Television advertisements for alcohol are allowed, but Washington restricts joint advertising efforts between alcohol producers and retailers (WAC 314-52-090). Taken together, these restrictions imply that broad-scale promotional efforts are more expensive in this context than others explored in the literature (e.g. ready-to-eat cereal).

5.3 Endogeneity in marijuana retail entry

The extensive-margin effect of legalizing recreational marijuana on other substances is identified by the variation in timing of marijuana retail entry across counties. County fixed effects account for the potential tendency that marijuana retailers may enter earlier in areas which have a stronger preference for marijuana products, which can be correlated with alcohol or tobacco preferences. Time fixed effects, for example, account for the decline in tobacco consumption and its potential correlation with the popularity of marijuana. Moreover, as licenses were subject to a population-based quota (see Section 2), the potential correlation between marijuana availability and county-time specific demand shocks is limited.

Despite these factors, the exact timing of marijuana availability in a given county may not be exogenous – i.e. $Corr(L_{ct}, e^m_{ct}) \neq 0$. We instrument our legalization indicator L with local bans on entry. We use the percentage of the population living in areas where entry was banned, which is correlated with the availability of marijuana in a county. This instrument is valid even if local bans are correlated with local preferences because those local preferences are accounted for by county fixed effects.[17] The bottom panel of Table 3 reports these percentages across time.

5.4 Other estimation details

To account for any changes in the bottom level price index p_i stemming from changes in the composition of demand, we construct a fixed basket of goods for each product type i and estimate demand as a function of the price of this fixed basket. For alcohol and tobacco products, we use the average per-quantity price for the top sellers within each type throughout the sample period—the top 40% for cigarettes and OTP and top 15% for beer, wine, and liquor. For flower, edibles, and concentrates, we use the average price of products of medium potency. Quantities are measured by count of rolls for cigarettes, count for OTP, liters for all alcohol products, grams of flower, and counts for edibles and concentrates.

In the bottom level, we impose homogeneity of degree zero in prices and expenditures, $\sum_i \beta_i = 0, \sum_j \gamma_{ij} = 0$, and Slutsky symmetry, $\gamma_{ij} = \gamma_{ji}$. The bottom level is then reduced to $J^m - 1$ equations and estimated simultaneously with two-step multiple equation GMM. We use two-stage least squares to estimate the middle and top levels. We estimate the top level using observations where we observe positive marijuana sales ($L_{ct} = 1$) because legalization caused a large increase in the level of expenditures on substances and our purpose in estimating this equation is to recover the impact of marginal changes in the prices of substances on the overall level of expenditures.

Since $\log P_{mj} L$ changes from zero to some positive number in the middle level, the estimated coefficient on L alone does not represent the full effect of legalization. To properly

[17]In Appendix A, our differences-in-differences comparison with Oregon, we define marijuana availability in Washington with L and instrument it as described here and also explore an alternative state-level definition $\tilde{L}$ which is one if the county is in Washington after July 2014. $\tilde{L}$ is free of concerns about the correlation between local bans and local preferences. We find similar results across the two specifications, which provides evidence that our instrument is valid.

account for this simultaneous movement, we start from the actual data on prices and quantities in the year before legalization, and "turn on" the L and $P^{mj}L$ terms throughout the model, holding the prices of other goods constant. Since the dependent variables of the top and middle level become independent variables in the middle and bottom levels, respectively, we pass-through any changes in those upper-level variables when calculating lower-level changes. We also use this approach to decompose the other effects captured by the model and explore the price responses of other industries to the opening of Washington's marijuana market.

Finally, we report standard errors for coefficients that are robust to heteroskedasticity. As our estimates of cross-price elasticities, the effects of marijuana legalization, and the Laffer curve are non-linear functions of parameter estimates across multiple estimating equations, we form these estimates with 2,000 Wild bootstrap replications of our parameter estimates and report means and standard errors.

6 Results

Table 4 presents estimates of Equation 4 (the top level). Column (1) estimates the equation without any county-level covariates included. The coefficient on the log of the price index for substances indicates that substances are elastic. Column (2) adds the log of the county population as a control. Column (3) presents our preferred specification, which, in addition to the log population measure, also includes the percentage of the population which is male, which is between the ages of 15 and 34, and which identifies as white. Per Equation 9, the overall price elasticity of legal substances in our preferred specification is -0.40.

We next estimate Equation 3 (the middle level) for each of our substance categories. The results are reported in Table 5. All substance segments are price elastic, with marijuana (-1.94) more price elastic in the point estimate than tobacco (-1.75) or alcohol (-1.46), conditional on the overall level of expenditures. The negative point estimates on the indicators for legal marijuana availability implies that marijuana reduced the quantity of tobacco significantly. While the quantity of alcohol also decreased, the effect is imprecisely estimated. The coefficients on marijuana price, which aggregate different forces at the product level, are imprecisely estimated and so we draw no general conclusion about the intensive margin relationship between marijuana and the alcohol and tobacco substance categories. The coefficient on the indicator for Oregon legalization is significant and negative for marijuana which is consistent with the results of Hansen et al. (2017b).

Table 6 reports estimates of Equation 1 (the bottom level) for each of our substance categories. The first two columns report estimates for the alcohol category (with liquor as the excluded product), the next two columns report estimates for the marijuana category (concentrates are excluded), and the last column reports estimates for cigarettes within the tobacco category (OTP is excluded). An increase in real expenditures on alcohol leads to an increase in the expenditure share of beer and decreases in the share of wine and liquor. Increasing expenditures on marijuana leads to an increase in the share of flower at the cost of edibles, and an increase in tobacco expenditures leads to an increase in the share of cigarettes. An increase in the relative price of each good results either in a decrease in the expenditure share of that good or a change indistinguishable from zero. Marijuana availability leads to a decrease in the share of wine, liquor, and cigarettes. Oregon's market opening affects the share of flower more than edibles, consistent with the results of Hansen et al. (2017b).

With the estimates of each stage of the model in hand, Table 7 presents a matrix of own- and cross-price elasticities for all products in the model per Equation 6. We find that the own-price elasticities for marijuana flower (-1.53) and concentrate (-1.26) products are higher in the point estimate than the elasticity of edibles (-0.93). The cross-price elasticities between cigarettes and all three marijuana products are positive and significant – marijuana and cigarettes are substitutes. Our estimate of the own-price elasticity for beer, -1.17, is comparable to the -1.36 estimated by Hausman et al. (1994).

We use these results to analyze the effect of the legalization of marijuana itself (as opposed to subsequent changes in substance prices) on substance product purchases in Table 8 unconditional on the level of total expenditures. We decompose the overall change in the quantity demanded of each product from 2013 (in the first column) to the 2015 (in the last column) into several parts. The second column isolates the effect of legalization holding prices and other demand characteristics fixed. Legalization decreases the quantity sold of liquor by 22% and cigarettes by 12%. The third column reports the effect of increasing legal substance expenditures from pre-legalization to post-legalization levels. The fourth and fifth columns update the prices of alcohol and tobacco products, respectively, to their 2015 levels. The price changes work to offset the effects of legalization, with the tobacco price changes leading to larger changes in quantities than changes in alcohol prices. The difference between the changes captured by the model and the last column come from changes in time fixed effects and any remaining unobservable components of demand.

Table 9 reports an analogous decomposition with respect to state and federal tax revenues.[18] The first and last columns indicate the tax revenues captured in the 2013 and 2015 data, respectively. The four middle columns follow the steps of Table 8. The results indicate that the legalization of marijuana has the largest effect on tax revenues from liquor, even after the liquor industry adjusts their prices. If marijuana was legalized and the other determinants of demand had been fixed, Washington would have earned \$170 million in tax revenue from marijuana. However, the total tax revenue from all substances would have only increased by \$89 million to \$614 million. In that scenario, federal excise tax revenue falls by 16%. Alternatively, if we adjust for the increase in legal substance expenditures (but not changes in alcohol or tobacco prices), we find that Washington would have earned \$205 million in revenues from marijuana, but revenue from all substances would have increased by \$135 million to \$660 million. Under those assumptions, federal excise tax revenue falls by 14%. Finally, after adjusting for the change in expenditures and prices (but not time fixed effects), Washington would have earned \$150 million in tax revenue from marijuana, but total tax revenue would have increased by \$87 million to \$612 million. We conclude that between 35% and 50% of the state tax revenue that comes from legalizing marijuana is cannibalized from alcohol and tobacco revenues and that legalization reduces federal tax revenue by about 15%.

Table 10 reports the effects of a 1% increase in the effective tax rate of each product on the tax revenue collected by the state for each product in 2015.[19] To calculate these effects, we turn to the literature to find the rate at which tax increases are passed through

[18]In Appendix A we perform a similar decomposition via the differences-in-differences framework. The results are qualitatively similar.

[19]For example, the effective tax rate on wine in 2015 was 11.81% – the table reports the effects of an increase in the effective tax rate to 11.93%.

to consumers for different products. Hansen et al. (2017a) study a tax change within the marijuana industry and find a pass-through rate of 0.44. For tobacco, we adopt the rate of 0.85 found by Harding et al. (2012). Kenkel (2005) estimated tax pass-through rates for a variety of alcohol products. We use the average off-premise rate for each product type.[20] We use these rates to calculate new prices, and then combine our model estimates to calculate the change in the quantity purchased of each substance. The first panel reports the effect of increasing the tax rates on individual products and the second panel raises the tax rate on all products within a substance category simultaneously.

Overall, we find that Washington is on the left-hand side of the Laffer curve for each product, both in isolation and when considering the total tax revenues across all products. The largest potential gains at the product level come from increasing the tax rate on cigarettes and liquor. At the substance category level, alcohol offers the largest gains – a 1% increase in the tax rate on all alcohol products leads to a .501% increase in revenues. This is driven by the outsized role alcohol plays in the overall substance market – the product-level revenue increases generated by a 1% increase in the tax rate on marijuana are similar to those generated by an alcohol increase, but alcohol has a greater share of substance expenditures. As Washington substance tax rates are among the highest in the country, this result implies that other states are likely on the left-hand side of the Laffer curve as well.

7 Conclusion

As voters shift toward supporting the legalization of marijuana, in part due to a desire for increased state tax revenues, it appears likely that more jurisdictions in the United States and elsewhere will remove long-standing prohibitions on the substance. The public finance consequences of such a policy depend on the interaction between the marijuana industry and other substance industries. We present a model that places the legal marijuana industry in the context of other legal recreational substances, alcohol and tobacco, and that allows products within different substance segments to be substitutes or complements.

[20]The average rate for beer is 1.67, and the average rate for liquor is 1.89. Kenkel (2005) does not report off-premise rates for wine, so we use the average over beer and liquor, 1.78.

We find that marijuana and cigarettes are substitutes on both the intensive and extensive margins, and while marijuana and alcohol are substitutes on the extensive margin, we draw no conclusion on the intensive margin. Liquor and cigarette products are most affected by the availability of legal marijuana. We also find that more than one-third of the tax revenues that come from legalizing marijuana are cannibalized from other substance revenues. Finally, we find that despite Washington having the highest retail tax rate on marijuana in the United States, 37%, further increases to marijuana taxes would still lead to higher revenue collections by the state.

Our results suggest that it is important for policy-makers to incorporate substitution across industries into analyses of marijuana legalization and tax policies. For example, as additional jurisdictions choose to legalize, differences in taxation rates across substances and borders may interact to result in either greater or lower levels of cross-border shopping in a way that is not captured by analyses of a single product (Lovenheim, 2008, Merriman, 2010, DeCicca et al., 2013), price (Chandra et al., 2014), or tax instrument at a time (Einav et al., 2014). If and when the federal government chooses to legalize marijuana and apply its own excise tax, it is likely that states will respond by lowering tax rates; Fredriksson and Mamun (2008) find that cigarette taxes in states come down by roughly 48 cents in response to a $1 increase in the federal excise tax rate.

Our model can serve as a starting point for studying the broad consumption patterns of substances when product characteristics aren't comparable across substance categories or when micro-level consumption data aren't available. We discuss how our model could be extended to understand the relationship between legal and illegal substances, and discuss a method for determining the optimal tax regime.

Legal and illegal substances. Marijuana, tobacco, and alcohol are not the only substances consumed for recreational purposes. Opioids, stimulants, psychedelics, and other substances are available through black-market channels and are estimated to be consumed in significant quantities (Substance Abuse and Mental Health Services Administration, 2017). Indeed, previous research has found that medical marijuana laws reduce the number of painkiller prescriptions and deaths from overdoses (Powell et al., 2018). Our framework offers an opportunity to extend that work by incorporating illegal substances into the resource allocation decision made by the representative consumer. The challenge in doing so is in obtaining reliable data on both prices and quantities of these black-market substances.

Optimal tax rates. While we use our framework to understand the impact of a marginal change in tax rates, determining the optimal tax regime is more challenging. Our model offers a view into demand behavior but we do not model supply-side decisions. It is possible that large-scale changes in tax regimes may result in significant changes in the competitive conduct of firms, leading to different pass-through rates for consumers. We propose adding a model of the supply of recreational substances to our demand model and defining a Nash equilibrium in prices. One could estimate the supply parameters and then simulate equilibrium outcomes as a function of tax rates. The challenge lies in defining an appropriate model of supply for the different substance industries. While the marijuana industry is highly differentiated and is likely best described as having a monopolistically competitive environment with significant barriers to entry, the tobacco market is closer to an oligopoly, with the mass-market alcohol industry somewhere in-between.

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8 Figures and Tables

Figure 1: Washington counties by month of first marijuana sales

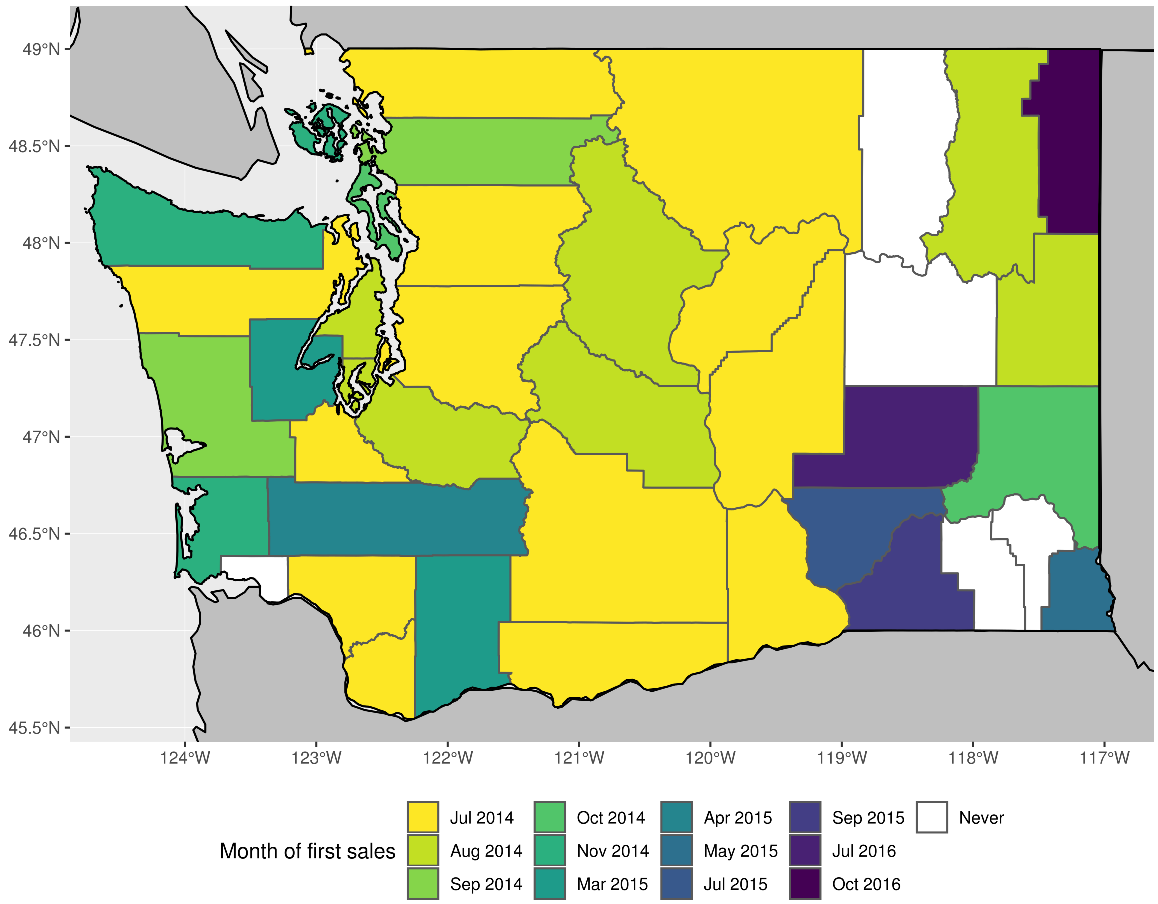


Figure 2: Percentage of population with retail entry banned by Washington county, July 2014

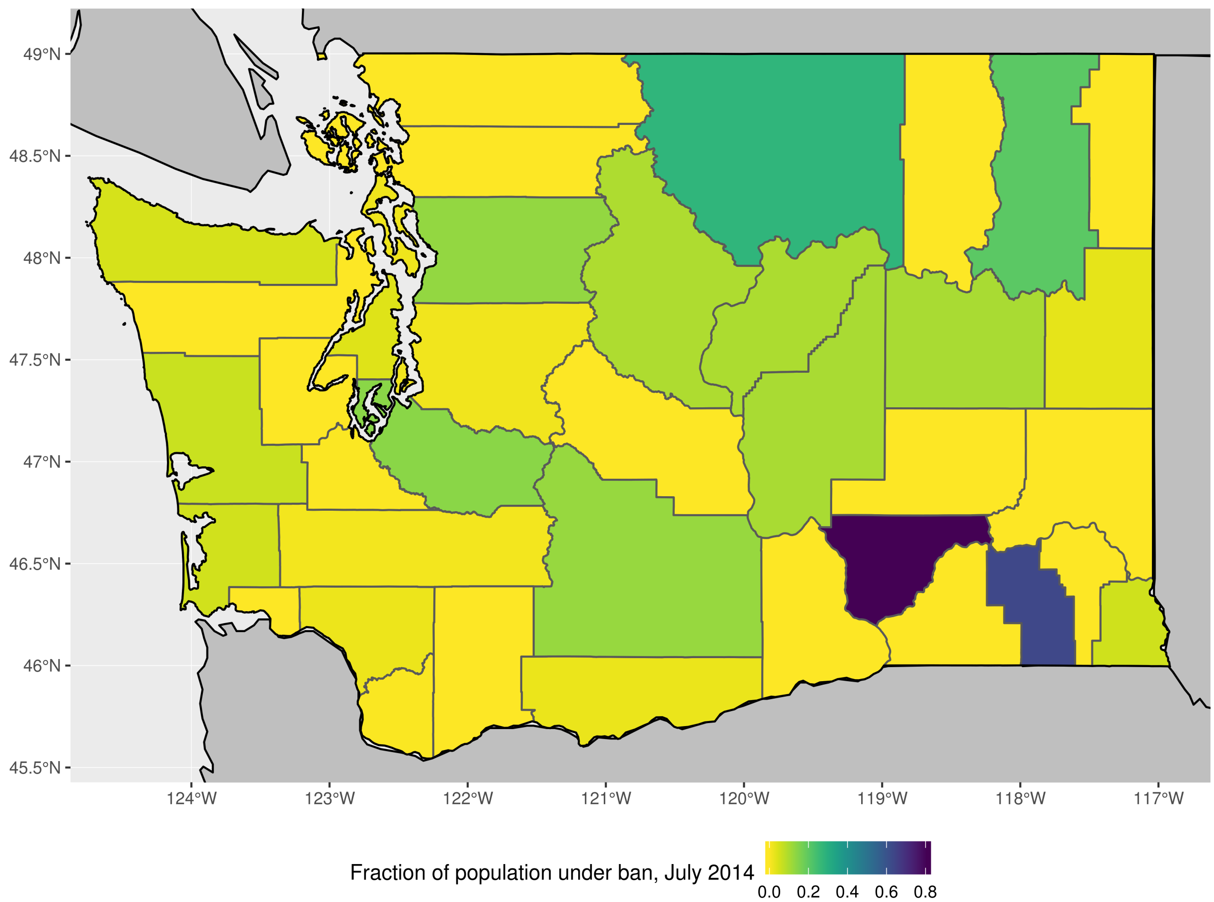
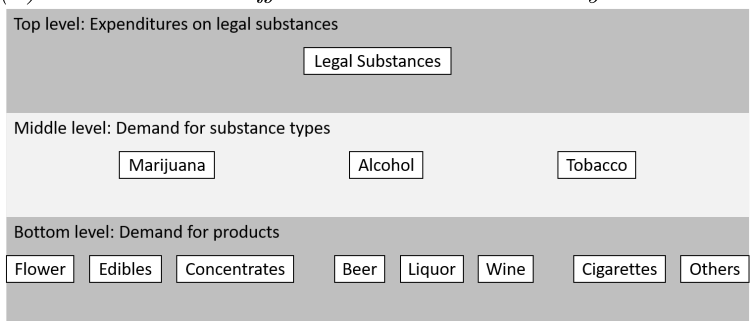
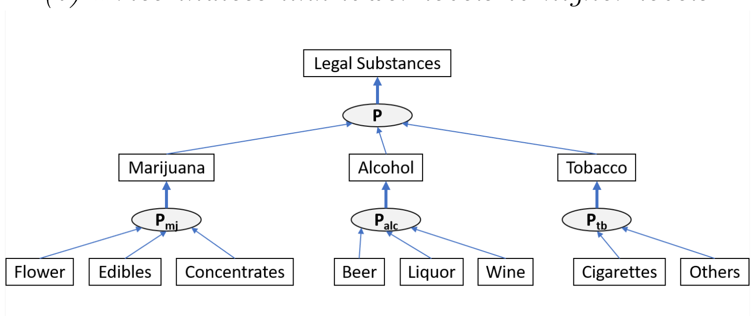


Figure 3: Multistage budgeting for legal substances

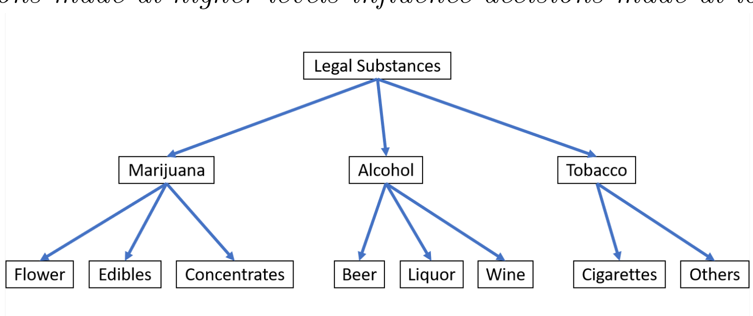
(a) Levels model different decisions made by consumers



(b) Price indices link lower levels to higher levels



(c) Decisions made at higher levels influence decisions made at lower levels



(d) Decisions are also affected by same-level prices

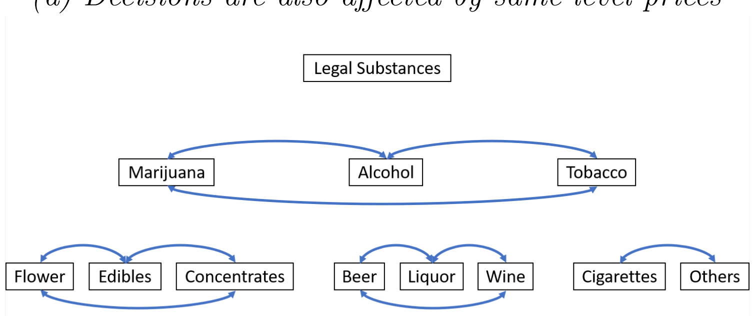


Table 1: Washington legal substance sales, prices, and taxes, 2013-2016

	Sales ($1M)				
	2013	2014	2015	2016	%Δ13-15
Alcohol	2,128	2,127	2,104	2,244	-1.12
Tobacco	389	371	346	343	-11.07
Marijuana		44	464	1,003	
Total	2,517	2,542	2,914	3,590	15.79
	Quantity (1M)				
	2013	2014	2015	2016	%Δ13-15
Alcohol	300	307	298	304	-0.85
Tobacco	643	626	588	575	-8.42
Marijuana		2	33	86	
	Sales-Weighted Average Price ($ per Q)				
	2013	2014	2015	2016	%Δ13-15
Alcohol	12.90	12.60	12.57	13.00	-2.52
Tobacco	0.95	0.87	0.83	0.84	-11.98
Marijuana		25.48	17.40	14.96	
	State Tax Revenue ($1M)				
	2013	2014	2015	2016	%Δ13-15
Alcohol	392	389	381	407	-2.83
Tobacco	133	126	116	114	-12.82
Marijuana		14	150	305	
Total	526	528	647	826	23.12
	Federal Excise Tax Revenue ($1M)				
	2013	2014	2015	2016	%Δ13-15
Alcohol	150	151	148	156	-1.21
Tobacco	34	33	31	30	-8.30
Total	183	183	179	186	-2.51

Notes: Prices and sales are in 2015 dollars and include all applicable taxes. Quantities for alcohol, tobacco, and marijuana are in units of liters, counts, and grams, respectively. All figures are state-wide; figures for alcohol and tobacco are calibrated from the Nielsen sample (Lazich and Burton, 2014). State tax revenues include both sales and use tax, locality taxes and any applicable retail or wholesale excise taxes. Marginal federal income tax rates are identical across substance retailers and are therefore excluded.

Table 2: Summary statistics for alcohol and tobacco products, 2013-2016

	Sales ($1M)				
	2013	2014	2015	2016	%Δ13-15
Beer	619	621	613	639	-1.10
Wine	713	727	727	770	2.01
Liquor	795	779	764	835	-3.94
Cigarettes	367	352	329	325	-10.48
OTP	22	19	17	18	-20.92
	Quantity (1M)				
	2013	2014	2015	2016	%Δ13-15
Beer	190	194	186	188	-1.89
Wine	77	80	79	81	2.22
Liquor	34	33	33	35	-1.97
Cigarettes	639	623	586	572	-8.44
OTP	3.0	2.9	2.9	3.1	-5.06
	Average Price ($ per Q)				
	2013	2014	2015	2016	%Δ13-15
Beer	3.26	3.20	3.29	3.40	0.80
Wine	9.28	9.13	9.26	9.54	-0.20
Liquor	23.64	23.33	23.17	23.54	-2.01
Cigarettes	0.57	0.57	0.56	0.57	-2.23
OTP	7.24	6.54	6.01	5.82	-16.71
	State Tax Revenue ($1M)				
	2013	2014	2015	2016	%Δ13-15
Beer	63	63	62	65	-0.62
Wine	84	86	86	90	2.20
Liquor	246	239	233	252	-5.12
Cigarettes	123	117	108	105	-12.13
OTP	11	9.3	8.4	8.7	-20.90
	Federal Tax Revenue ($1M)				
	2013	2014	2015	2016	%Δ13-15
Beer	27	27	23	27	-1.89
Wine	27	28	27	28	2.22
Liquor	96	96	95	102	-1.97
Cigarettes	32	31	29	29	-8.44
OTP	1.4	1.3	1.3	1.4	-5.06

Notes: Prices and sales are in 2015 dollars and include all applicable taxes. All figures are state-wide and calibrated from the Nielsen sample by $\frac{1}{0.48}$ (Lazich and Burton, 2014). Quantities of alcohol products are in liters, cigarettes and OTP are in counts. State tax revenues include both sales and use tax, locality taxes, and any applicable retail excise taxes. Marginal federal income tax rates are identical across substance retailers and are therefore excluded.

Table 3: Summary statistics for marijuana products and retailers, 2014-2016

	Sales ($1M)		
	2014*	2015	2016
Flower	36	344	676
Edible	3	47	89
Concentrate	4	70	208
Total	44	464	1,003
	Quantity (1M)		
	2014*	2015	2016
Flower	1.7	29	73
Edible	.1	2.0	4.6
Concentrate	.1	1.8	6.6
	Average Price ($ per Q)		
	2014*	2015	2016
Flower	21.54	11.95	9.28
Edible	34.43	23.62	19.30
Concentrate	54.43	39.93	31.62
	Wholesale Price ($ per Q)		
	2014*	2015	2016
Flower	9.07	3.70	3.04
Edible	12.62	7.39	6.11
Concentrate	17.51	12.45	10.57
	State Tax Revenue ($1M)		
	2014*	2015	2016
Flower	11	120	257
Edible	1.0	16	34
Concentrate	1.2	25	79
	Retailer statistics		
	2014	2015	2016
Number of retailers	85	203	352
Retailers per county	1.38	4.38	7.80
% of mkts with availability	0.54	0.84	0.91
No. counties with ban	14	12	11
% of pop. under ban[1]	0.10	0.13	0.17

Notes: Prices and sales are in 2015 dollars and include all applicable taxes. Quantities are in units of grams for flower and counts for concentrates and edibles. A market is a county-month.
* Washington's legal marijuana market opened on July 14, 2014.
[1] This figure is calculated for counties with bans.

Table 4: Estimates of the demand for legal substances

	(1)	(2)	(3)
Intercept	1.9758	-0.1717	1.5619
	(1.2906)	(0.3801)	(2.5610)
Log income	1.7948	0.2241	0.2602
	(0.0951)	(0.0607)	(0.0599)
Log price index	-0.1300	0.4976	0.5978
	(0.5560)	(0.1450)	(0.1347)
Log population		1.0859	1.1121
		(0.0303)	(0.0335)
Percent male			-6.3042
			(4.2198)
Percent aged 15-34			-0.6220
			(0.4690)
Percent white			1.0095
			(0.4539)
Year FX	Yes	Yes	Yes
N	383	383	383
1st stage adj. R-sq	0.7306	0.7433	0.7663
1st stage F-stat	190.54	196.81	166.47

Notes: This table reports 2SLS estimates of Equation 4. An observation is a county-month. The dependent variable is the log of the nominal expenditures on all substances. Hausman, tax, and wholesale instruments are used to instrument for the price index. The observations for these estimates came from the period after Washington legalized marijuana. Robust standard errors are in parentheses.

Table 5: Estimates of the demand for substance categories

	Alcohol	Tobacco	Marijuana
Intercept	11.2073	7.0232	-1.3892
	(0.4514)	(0.4720)	(1.6958)
Log substance expenditure	0.1147	0.2201	1.3141
	(0.0218)	(0.0240)	(0.0568)
Log P^{alc}	-1.4646	-0.4642	-0.3928
	(0.1565)	(0.1586)	(0.5449)
Log P^{tb}	0.6394	-1.7516	2.5419
	(0.1367)	(0.1542)	(0.7041)
MJ available * Log P^{mj}	-0.0407	0.0411	-1.9400
	(0.0545)	(0.0694)	(0.1996)
MJ available	-0.0848	-0.4200	
	(0.1416)	(0.1906)	
MJ available * Log substance expenditure	0.0104	0.0175	
	(0.0043)	(0.0054)	
Oregon available	0.0075	0.0197	-0.1439
	(0.0138)	(0.0165)	(0.0486)
County FX	Yes	Yes	Yes
Time FX	Yes	Yes	Yes
N	1252	1252	610
1st stage adj. R-sq	0.9976	0.9983	0.9575
1st stage F-stat	11521.94	27677.17	601.03

Notes: This table reports 2SLS estimates of Equation 3. An observation is a county-month. The dependent variable for each of these regressions is the log of the quantity of the particular substance in that county month. Hausman, tax, and wholesale instruments are used to instrument for prices in each regression. The percentage of population in areas in which marijuana retail is banned is used as an instrument for the MJ availability indicator, L. The Oregon available indicator is one if the county borders Oregon and the date is October 2015 or later and is zero otherwise. Robust standard errors are in parentheses.

Table 6: Estimates of the demand for specific substance products

	Alcohol		Tobacco	Marijuana	
	Beer	Wine	Cigarettes	Flower	Edible
Intercept	0.0727	0.4306	0.5192	0.6466	0.1854
	(0.0772)	(0.0656)	(0.0816)	(0.0378)	(0.0219)
Log category expenditure	0.0281	-0.0100	0.0395	0.0142	-0.0136
	(0.0070)	(0.0062)	(0.0089)	(0.0045)	(0.0033)
Log beer price ratio	-0.0442	0.0126			
	(0.0238)	(0.0179)			
Log wine price ratio	0.0126	0.0169			
	(0.0179)	(0.0198)			
Log cig. price ratio			-0.0016		
			(0.0060)		
Log flower price ratio				-0.0357	-0.0030
				(0.0142)	(0.0079)
Log edible price ratio				-0.0030	0.0117
				(0.0079)	(0.0060)
MJ available	0.0502	-0.0113	0.0097		
	(0.0087)	(0.0048)	(0.0060)		
Oregon available	0.0090	-0.0059	0.0019	-0.0287	-0.0021
	(0.0019)	(0.0020)	(0.0026)	(0.0064)	(0.0039)
Method	GMM	GMM	2SLS	GMM	GMM
County FX	Yes	Yes	Yes	Yes	Yes
Time FX	Yes	Yes	Yes	Yes	Yes
N	1440	1440	1374	717	717
1st stage adj. R^2	0.9623	0.9623	0.6803	0.9957	0.9957

Notes: This table reports estimates of Equation 1 for each of our substance segments. The dependent variable is the expenditure share of the product within the substance segment; the expenditure share of the remaining product is determined by the adding-up restriction of the model. Price ratios are defined as the ratio of the specified product's price to the excluded product's price. The MJ available indicator L is one if we observe marijuana sales in the county. The Oregon available indicator is one if the county borders Oregon and the date is October 2015 or later and is zero otherwise. Robust standard errors are in parentheses.

Table 7: Estimated product-by-product cross-price elasticities

		...leads to a X% change in the quantity demanded of...							
		Beer	Wine	Liquor	Cigarette	OTP	Flower	Edible	Concentrate
A 1% change in the price of...	Beer	-1.1692	-0.0612	-0.0518	0.7371	0.0435	-0.0253	-0.0041	-0.0063
		(0.0970)	(0.0879)	(0.0982)	(0.1418)	(0.0084)	(0.0417)	(0.0060)	(0.0119)
	Wine	-0.0098	-1.0186	-0.1172	0.6583	0.0389	-0.0226	-0.0037	-0.0056
		(0.0683)	(0.0773)	(0.0793)	(0.1260)	(0.0075)	(0.0373)	(0.0054)	(0.0106)
	Liquor	0.0010	-0.1070	-1.0300	0.6530	0.0386	-0.0225	-0.0037	-0.0056
		(0.0706)	(0.0745)	(0.0950)	(0.1265)	(0.0075)	(0.0370)	(0.0053)	(0.0105)
	Cigarette	-0.2485	-0.3030	-0.3175	-1.8201	0.0152	0.1564	0.0219	0.0457
		(0.0509)	(0.0624)	(0.0652)	(0.1580)	(0.0110)	(0.0530)	(0.0076)	(0.0151)
	OTP	0.0333	0.0684	0.0514	2.5207	-2.0735	-0.0081	-0.0029	-0.0006
		(0.0446)	(0.0600)	(0.0587)	(0.3289)	(0.1082)	(0.0264)	(0.0041)	(0.0073)
	Flower	0.0692	0.0928	0.0929	2.5028	0.1477	-1.5289	-0.0927	-0.0961
		(0.1696)	(0.2082)	(0.2174)	(0.6720)	(0.0398)	(0.1507)	(0.0232)	(0.0448)
	Edible	0.0621	0.0838	0.0832	2.2367	0.1310	-0.4897	-0.9281	-0.1153
		(0.1514)	(0.1873)	(0.1939)	(0.6094)	(0.0359)	(0.1552)	(0.0597)	(0.0686)
	Concentrate	0.0659	0.0883	0.0884	2.3793	0.1405	-0.2945	-0.0775	-1.2557
		(0.1615)	(0.1982)	(0.2069)	(0.6462)	(0.0383)	(0.1555)	(0.0350)	(0.0687)

Notes: These estimates are calculated by combining the estimates of all three levels via Equation 6. The reported values are means from 2,000 wild bootstrap replications. Standard errors are in parentheses.

Table 8: Decomposing the estimated changes in quantity by product and modeled effect

Product	2013 data	+ MJ legal	+ substance expenditures	+ alcohol prices	+ tobacco prices	+ FE + unobs. (2015 data)
Beer (1M L)	190	194	199	203	184	186
		(9.58)	(9.41)	(9.85)	(9.77)	
Wine (1M L)	76.8	64.9	66.2	68.4	62.5	78.5
		(2.72)	(2.65)	(2.79)	(2.83)	
Liquor (1M L)	33.7	26.2	26.7	28.0	25.6	33.0
		(1.23)	(1.22)	(1.30)	(1.28)	
Cigarettes (1M Ct)	639	564	584	600	753	586
		(30.0)	(29.6)	(30.5)	(38.1)	
OTP (1M Ct)	3.03	2.86	2.87	2.87	4.07	2.87
		(0.33)	(0.33)	(0.33)	(0.36)	
Flower (1M g)	0	33.7	40.7	41.6	29.8	28.7
		(3.40)	(4.06)	(4.18)	(0.87)	
Edibles (1M Ct)	0	1.85	2.23	2.23	1.59	1.98
		(0.22)	(0.27)	(0.27)	(0.14)	
Concentrates (1M Ct)	0	1.90	2.28	2.32	1.68	1.75
		(0.35)	(0.42)	(0.42)	(0.27)	

Notes: This table decomposes the effects captured by our model on the quantity demanded of each product. The first column reports the quantities in our data in 2013. The second column "turns on" the marijuana legalization term in the bottom and middle levels of the model. Prices of alcohol and tobacco products are maintained at 2013 levels; prices of marijuana and fixed effects are set to their 2015 levels. The third column updates the "real expenditure" term in the model to the 2015 model. Prices are equal to those in the second column. The fourth column updates prices of alcohol products to their 2015 levels. The fifth column updates prices of tobacco products to their 2015 levels. The sixth column adds changes in fixed effects and any unobservables; it is equal to the realized 2015 quantity in the data. The reported values are means from 2,000 wild bootstrap replications. Standard errors are in parentheses below each model-estimated number.

Table 9: Decomposing the estimated changes in tax revenue by product and modeled effect

	2013 data	+ MJ legal	+ substance expenditures	+ alcohol prices	+ tobacco prices	+ FE + unobs. (2015 data)
State taxes ($M)						
By product						
Beer	63	64	66	68	62	62
		(3.2)	(3.1)	(3.3)	(3.3)	
Wine	84	71	72	75	68	86
		(3.0)	(2.9)	(3.1)	(3.1)	
Liquor	246	191	195	198	181	233
		(9.0)	(8.9)	(9.2)	(9.1)	
Cigarettes	123	108	112	115	139	108
		(5.7)	(5.7)	(5.9)	(7.0)	
OTP	11	10	10	10	12	8
		(1.2)	(1.1)	(1.1)	(1.1)	
Flower	0	131	158	161	116	112
		(13.2)	(15.7)	(16.2)	(3.4)	
Edibles	0	14	17	17	12	15
		(1.7)	(2.0)	(2.1)	(1.1)	
Concentrates	0	25	30	31	22	23
		(4.5)	(5.5)	(5.6)	(3.5)	
By substance						
Alcohol	392	326	333	341	311	381
		(13.0)	(12.7)	(13.3)	(13.5)	
Tobacco	133	118	122	125	151	116
		(5.7)	(5.6)	(5.8)	(7.0)	
Marijuana	0	170	205	209	150	150
		(16.0)	(19.1)	(19.6)	(0.3)	
Federal taxes ($M)						
By product						
Beer	27	27	28	29	26	26
		(1.3)	(1.3)	(1.4)	(1.4)	
Wine	27	23	23	24	22	27
		(0.9)	(0.9)	(1.0)	(1.0)	
Liquor	96	75	77	80	73	95
		(3.5)	(3.5)	(3.7)	(3.7)	
Cigarettes	32	28	29	30	38	29
		(1.5)	(1.5)	(1.5)	(1.9)	
OTP	1.4	1.3	1.3	1.3	1.8	1.3
		(0.1)	(0.1)	(0.1)	(0.2)	
By substance						
Alcohol	150	125	127	133	121	148
		(5.0)	(4.9)	(5.2)	(5.3)	
Tobacco	34	30	31	31	40	31
		(1.5)	(1.5)	(1.5)	(1.9)	

Notes: This table decomposes the effects captured by our model on state and federal government revenue from each product and substance. The first column is the tax revenues collected from sales of products in our data in 2013. The second column "turns on" the marijuana legalization term in the bottom and middle levels of the model. Prices of alcohol and tobacco products are maintained at 2013 levels; prices of marijuana and fixed effects are set to their 2015 levels. The third column updates the "real expenditure" term in the model to the 2015 model. Prices are equal to those in the second column. The fourth column updates prices of alcohol products to their 2015 levels. The fifth column updates prices of tobacco products to their 2015 levels. The sixth column adds changes in fixed effects and any unobservables; it is equal to the realized 2015 revenue in the data. All units are millions of 2015 dollars. The reported values are means from 2,000 wild bootstrap replications. Standard errors are in parentheses below each model-estimated number.

Table 10: The gradient of Washington's substance tax Laffer curve

A 1% increase in the tax rate on...	...leads to a X% change in tax revenue from... Beer	Wine	Liquor	Cigarette	OTP	Flower	Edible	Concentrate	Total
Individual products									
Beer	.969	-.010	.004	-.046	.005	-.006	-.005	-.005	.085
	(.016)	(.012)	(.012)	(.009)	(.008)	(.028)	(.025)	(.027)	(.009)
Wine	-.015	.985	-.017	-.067	.008	-.008	-.007	-.008	.110
	(.018)	(.017)	(.015)	(.013)	(.012)	(.041)	(.037)	(.039)	(.012)
Liquor	-.038	-.100	1.000	-.193	.022	-.024	-.021	-.022	.306
	(.054)	(.047)	(.054)	(.036)	(.034)	(.119)	(.107)	(.113)	(.036)
Cigarette	.203	.182	.181	.766	.639	.684	.615	.650	.400
	(.039)	(.035)	(.035)	(.044)	(.085)	(.189)	(.172)	(.181)	(.050)
OTP	.016	.014	.014	.008	.549	.053	.047	.050	.029
	(.003)	(.003)	(.003)	(.004)	(.046)	(.015)	(.013)	(.014)	(.004)
Flower	-.007	-.007	-.005	.019	-.002	.895	-.112	-.053	.149
	(.006)	(.006)	(.005)	(.008)	(.004)	(.022)	(.023)	(.022)	(.006)
Edible	-.001	-.001	-.001	.003	-.000	.076	1.097	.080	.042
	(.001)	(.001)	(.001)	(.001)	(.000)	(.003)	(.008)	(.005)	(.001)
Concentrate	-.001	-.001	-.001	.004	-.000	.069	.062	1.044	.051
	(.001)	(.001)	(.001)	(.002)	(.001)	(.005)	(.008)	(.011)	(.001)
Substance categories									
Alcohol	.915	.874	.987	-.305	.035	-.037	-.034	-.035	.501
	(.065)	(.061)	(.057)	(.057)	(.053)	(.189)	(.170)	(.179)	(.056)
Tobacco	.219	.196	.194	.774	1.195	.737	.663	.700	.429
	(.042)	(.038)	(.038)	(.048)	(.092)	(.203)	(.185)	(.195)	(.054)
Marijuana	-.009	-.009	-.007	.025	-.003	.827	.832	.856	.192
	(.008)	(.008)	(.007)	(.010)	(.005)	(.029)	(.028)	(.027)	(.009)

Notes: To calculate these changes, we combine estimates of Equations 1, 3, and 4: a change in the tax rate for a particular product passes-through to the price indices used in the middle and top levels, which change the expenditure terms in the middle and bottom levels. We apply these marginal changes to the 2015 prices, quantities, and tax rates. Pass-through rates from marginal tax increases to prices are taken from the literature, see text for details. The first set of rows changes tax rates for individual products, while the second set of rows changes tax rates for all products within a category simultaneously. The reported values are means from 2,000 wild bootstrap replications. Standard errors are in parentheses.

Appendices

A Difference-in-Differences Estimates of the Effects of Marijuana Legalization in Washington and Oregon

We use the differences-in-differences framework to compare sales of alcohol and tobacco in Washington to sales in Oregon, its neighbor to the south. Let c denote a county and t denote time measured in months. For each product or substance category i, we model the log of the quantity demanded with

$$\ln Q_{ict} = \omega_0 + \omega \ln P_{ict} + \eta_{WA} L_{ct}^{WA} + \eta_{OR} \tilde{L}_{ct}^{OR} + FX_c + FX_t + \nu_{ict}. \tag{5}$$

In this equation, P_{it} is the price of a fixed basket of goods within product type i as discussed in Section 5.4. As retail stores in Oregon opened in October 2015, $\tilde{L}_{ct}^{OR}$ is an indicator which is equal to one if c is in Oregon and t is October 2015 or later. L^{WA} is an indicator for marijuana availability in Washington. We use two definitions of this indicator. First, we define L_{ct}^{WA} equal to one if we observe sales of marijuana in county c at time t (identical to Equation 2). Second, for consistency with $\tilde{L}^{OR}$, we define $\tilde{L}_{ct}^{WA}$ equal to one if c in Washington and the time is after July 2014. We include county- and time- fixed effects to control for regional differences in preferences and the evolution of preferences over time – see Section 5.1 for a discussion of the variation which is subsumed by these fixed effects.

We estimate this model with Nielsen data from Washington and Oregon. Oregon does not allow grocery stores to sell liquor, and so we exclude liquor products from our analysis. Additionally, Hansen et al. (2017b) study marijuana sales along the Washington-Oregon border and find evidence of significant cross-border shopping. We therefore exclude all counties on both sides of the border. The prices of goods are subject to the sources of endogeneity discussed in Section 5.2 and so we instrument price with time-varying local tax rates and Hausman instruments as described there. Similarly, L^{WA} may be endogenous and so we use the local-ban instrument described in Section 5.3. We do not instrument $\tilde{L}^{WA}$ nor $\tilde{L}^{OR}$ because these state-level indicators are uncorrelated with local preferences.

Table A.1 reports summary statistics for the Oregon Nielsen data by product and mirrors Table 2. Sales of substances are generally lower than in Washington, as befitting Oregon's lower population (3.92 million vs 6.96 million in 2013). Tax-inclusive prices of all goods are lower than in Washington. As a result, both state and federal tax revenues are lower as well. Sales and quantities generally decreased from 2013-2015, though the prices of beer, cigarettes, and OTP increased during the period. This pattern differs from Washington, where cigarette and OTP prices decreased. Beer and wine prices move in similar directions in the two states, though the magnitudes are higher in Oregon than they are in Washington.

Table A.2 reports the estimates of the key parameters of Equation 5 for alcohol and tobacco as categories, and beer, wine, cigarettes, and OTP as individual products. The first column for each dependent variable uses the $\tilde{L}$ definition of the Washington marijuana availability indicator while the second column uses the L definition. The results are similar between the two specifications, which provides evidence that our instrument for L satisfies the exclusion restriction.

Under our preferred L specification, the point estimates indicate that the legalization of marijuana in Washington led to an increase in alcohol sales of 1.1% and decreased the quantity of tobacco sold by 2.1%, though these estimates are noisy. At the product-level, the estimates suggest that legalization increased the quantity of beer sold and decreased the quantity of wine and cigarettes. Although these estimates are noisy relative to our main findings, they qualitatively correspond to the results described in Section 6.

Table A.3 decomposes the changes in tax revenue seen in the data into the effects captured by the model for each product using our preferred L specification. The first column reports Washington's 2013 state and federal tax revenues, and the second column "turns on" marijuana by setting L equal to one and holding prices and fixed effects at their 2013 levels. The third column updates prices to their 2015 levels. The fourth column adds changes in fixed effects and any remaining unobservables and is equal to the 2015 data. As these estimates are functions of the parameter estimates, we report the means and standard deviations from 2,000 Wild bootstrap replications. Cigarettes are affected most by legalization, with wine second, though the difference between them is insignificant. The signs of the changes match the signs of the changes seen in Table 9.

Table A.1: Summary statistics for Oregon substances, 2013-2016

	Sales ($1M)				
	2013	2014	2015	2016	%Δ13-15
Beer	347	353	344	366	-1.04
Wine	380	389	378	410	-0.35
Cigarettes	138	132	118	124	-14.87
OTP	126	121	108	114	-14.28
	Quantity (1M)				
	2013	2014	2015	2016	%Δ13-15
Beer	120	121	114	117	-4.32
Wine	43.5	45.5	43.8	45.6	0.57
Cigarettes	399	377	332	347	-16.90
OTP	19.0	18.1	16.2	17.1	-14.58
	Average Price ($ per Q)				
	2013	2014	2015	2016	%Δ13-15
Beer	2.90	2.93	3.00	3.12	3.42
Wine	8.72	8.55	8.65	8.98	-0.91
Cigarettes	0.35	0.35	0.36	0.36	2.44
OTP	6.63	6.69	6.65	6.67	0.35
	State Tax Revenue ($1M)				
	2013	2014	2015	2016	%Δ13-15
Beer	2.66	2.60	2.42	2.48	-9.00
Wine	8.10	8.20	7.75	8.08	-4.36
Cigarettes	27.5	25.2	21.7	22.7	-20.99
OTP	44.8	43.0	38.4	40.6	-14.28
	Federal Excise Tax Revenue ($1M)				
	2013	2014	2015	2016	%Δ13-15
Beer	16.8	17.0	16.1	16.5	-4.32
Wine	15.1	15.8	15.2	15.8	0.57
Cigarettes	20.1	19.0	16.7	17.4	-16.90
OTP	8.56	8.15	7.31	7.73	-14.58

Notes: Prices and sales are in 2015 dollars and include all applicable taxes. All figures are state-wide and calibrated from the Nielsen sample (Lazich and Burton, 2014). Liquor is state-controlled and is therefore not included. State tax revenues include substance-specific sales and excise taxes only; Oregon has no general retail sales tax. Marginal federal income tax rates are identical across substance retailers and are therefore excluded.

Table A.2: Differences-in-differences estimates of the effect of marijuana legalization on alcohol and tobacco sales in Washington and Oregon

	Alcohol		Beer		Wine		Tobacco		Cigarettes		OTP	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
WA MJ	0.0202	0.0106	0.0558	0.0535	-0.0352	-0.0687	0.0196	-0.0214	-0.1273	-0.1714	0.0453	-0.0017
	(0.0139)	(0.0212)	(0.0131)	(0.0163)	(0.0128)	(0.0192)	(0.0433)	(0.0542)	(0.0270)	(0.0368)	(0.0337)	(0.0424)
OR MJ	0.023	0.0223	0.0138	0.0113	0.0579	0.0421	-0.0267	-0.0594	0.0463	0.0258	0.2020	0.1606
	(0.0152)	(0.0150)	(0.0141)	(0.0150)	(0.0151)	(0.0156)	(0.0616)	(0.0645)	(0.0360)	(0.0391)	(0.0485)	(0.0509)
Log P	-0.340	-0.4828	0.3516	0.2332	-1.3134	-1.4450	-2.3547	-2.3471	-1.8698	-1.8661	0.9440	0.9309
	(0.2889)	(0.3135)	(0.1722)	(0.1626)	(0.2256)	(0.2537)	(0.3429)	(0.3396)	(0.2162)	(0.2176)	(0.1531)	(0.1528)
County FX	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FX	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	6,462	6,462	6,462	6,462	6,462	6,462	6,459	6,459	6,459	6,459	6,363	6,363
WA MJ def'n	$\tilde{L}$	L	$\tilde{L}$	L	$\tilde{L}$	L	$\tilde{L}$	L	$\tilde{L}$	L	$\tilde{L}$	L
1st st. adj. R^2	0.9412	0.9415	0.9298	0.9439	0.7076	0.7079	0.9478	0.9477	0.9713	0.9706	0.4465	0.4465

Notes: This table reports 2SLS estimates of Equation 5 for alcohol and tobacco products using Nielsen data in Washington and Oregon. An observation is a county-month. The dependent variable is the log quantity sold. Oregon does not allow liquor to be sold in grocery stores, so the alcohol category consists of beer and wine for both states. Counties along the Washington-Oregon border are excluded. Hausman and local tax rate instruments are used for price. The "OR MJ" variable is an indicator which is one if the observation is in Oregon and the date is October 2015 or later. We use two definitions for the "WA MJ" indicator. The $\tilde{L}$ indicator is one if the observation is in Washington and the date is July 2014 or later. Per Equation 2, the L indicator is one if the observation is in Washington and we observe marijuana sales in that county during that month. We instrument L with the proportion of the population in the county living under an entry ban – see Section 5.3 for details. Standard errors are in parentheses and are clustered at the state level.

Table A.3: Decomposing changes in Washington tax revenue by product and effect with differences-in-differences estimates

	2013 data	+ MJ legal	+ 2015 prices	+ FE + unobs. (2015 data)
State taxes ($M)				
Beer	62.8	66.3	67.3	62.4
		(1.08)	(1.15)	
Wine	84.0	78.4	78.7	85.9
		(1.47)	(1.45)	
Cigarettes	122.8	103.7	103.8	107.9
		(3.69)	(3.66)	
OTP	10.6	10.6	7.4	8.4
		(0.44)	(0.38)	
Federal taxes ($M)				
Beer	26.7	28.2	28.3	26.2
		(0.46)	(0.48)	
Wine	26.6	24.9	24.9	27.2
		(0.47)	(0.46)	
Cigarettes	32.2	27.2	28.3	29.5
		(0.97)	(1.00)	
OTP	1.4	1.4	1.2	1.3
		(0.06)	(0.05)	

Notes: This table decomposes the effects captured by our differences-in-differences estimates on state and federal government revenue from each product and substance. We use the 'L' indicator specification for each product. The first column is the tax revenues collected from sales of products in our data in 2013. The second column "turns on" the marijuana legalization term and keeps prices of alcohol and tobacco products at 2013 levels. The third column updates prices to their 2015 levels. The fourth column adds changes in fixed effects and any unobservables; it is equal to the realized 2015 revenue in the data. All units are millions of 2015 dollars. The reported values are means from 2,000 Wild bootstrap replications. Standard errors are in parentheses below each model-estimated number.

B Calculating elasticities

In our model, changes in product prices lead to substitution across substance types through the mechanism of the price index. We follow the approach of Ellison et al. (1997) and Bokhari and Fournier (2013) and report elasticities that are unconditional on both the substance-type expenditure y^m as well as the total substance expenditures Y. For simplicity, we focus on calculating elasticities after marijuana was available (i.e. for $L = 1$). We derive product-level cross-price elasticities with the following Proposition.

Proposition 1. *Suppose the demand for product i in substance segment m and product j in substance segment n is given by the system of Equations (1), (3), and (4). Let $\tilde{\alpha}_m = \alpha_m + \alpha'_m$. Then, the price elasticity of product i with respect to product j unconditional on the expenditure is given by*

$$\varepsilon_{ij} = \frac{\partial \log q_i^m}{\partial \log p_j^n} = \left(\frac{\beta_i^m}{s_i^m} + 1\right)(\tilde{\alpha}_m \lambda s_n + \delta_{mn}) s_j^n + \left(\frac{\gamma_{ij}^m}{s_i^m} + s_j^n\right) \cdot 1_{\{m=n\}} - 1_{\{i=j,m=n\}}. \tag{6}$$

Proof. Let $L = 1$. Let product i be substance type m and product j belong to substance type n. The share of product i is given by $s_i^m = \frac{p_i^m q_i^m}{y^m}$. We take the log of both sides to obtain $\log q_i^m = \log s_i^m + \log y^m - \log p_i^m$. Taking the derivative of both sides with respect to $\log p_j^n$ gives us a general formula for own- and cross-price elasticities:

$$\varepsilon_{ij} = \frac{\partial \log q_i^m}{\partial \log p_j^n} = \frac{1}{s_i^m} \frac{\partial s_i^m}{\partial \log p_j^n} + \frac{\partial \log y^m}{\partial \log p_j^n} - 1_{\{i=j,m=n\}}. \tag{7}$$

The first term represents the extent to which the share of a particular product within a segment changes in response to price changes, and the second term represents the change in expenditures stemming from the price change.

The first term of this expression comes by taking the derivative of Equation (1):

$$\frac{\partial s_i^m}{\partial \log p_j^n} = \beta_i^m \left(\frac{\partial \log y^m}{\partial \log p_j^n} - \frac{\partial \log P^m}{\partial \log p_j^n}\right) + \gamma_{ij}^m 1_{\{m=n\}}.$$

Since $\log P^m = \sum_k s_k^n \log p_k^n$, we have $\frac{\partial \log P^m}{\partial \log p_j^n} = s_j^n 1_{\{m=n\}}$. Plugging in gives

$$\frac{\partial \log q_i^m}{\partial \log p_j^n} = \left(\frac{\beta_i^m}{s_i^m} + 1\right) \frac{\partial \log y^m}{\partial \log p_j^n} + \left(\gamma_{ij}^m - \beta_i^m s_j^n\right) \frac{1_{\{m=n\}}}{s_i^m} - 1_{\{i=j,m=n\}}.$$

Since $Q^m = \frac{y^m}{P^m}$, we can write

$$\begin{aligned}\frac{\partial \log y^m}{\partial \log p_j^n} &= \frac{\partial \log Q^m}{\partial \log p_j^n} + \frac{\partial \log P^m}{\partial \log p_j^n} \\ &= \frac{\partial \log Q^m}{\partial \log p_j^n} + s_j^n 1_{\{m=n\}}.\end{aligned}$$

Let $\tilde{\alpha}_m = \alpha_m + \alpha'_m$. Then using Equation (3) we have

$$\begin{aligned}\frac{\partial \log Q^m}{\partial \log p_j^n} &= \tilde{\alpha}_m \frac{\partial \log Y}{\partial \log p_j^n} + \delta_{mn} \frac{\partial \log P^n}{\partial \log p_j^n} \\ &= \tilde{\alpha}_m \frac{\partial \log Y}{\partial \log p_j^n} + \delta_{mn} s_j^n.\end{aligned}$$

From Equation (4), we have

$$\begin{aligned}\frac{\partial \log Y}{\partial \log p_j^n} &= \lambda \frac{\partial \log \mathbf{P}}{\partial \log p_j^n} \\ &= \lambda s_n \frac{\partial \log P_n}{\partial \log p_j^n} \\ &= \lambda s_n s_j^n.\end{aligned}$$

Plugging in, we get:

$$\begin{aligned}\frac{\partial \log Q^m}{\partial \log p_j^n} &= (\tilde{\alpha}_m \lambda s_n + \delta_{mn}) s_j^n \\ \frac{\partial \log y^m}{\partial \log p_j^n} &= (\tilde{\alpha}_m \lambda s_n + \delta_{mn} + 1_{\{m=n\}}) s_j^n.\end{aligned}$$

Finally, plugging this into our expression for elasticity, we get:

$$\frac{\partial \log q_i^m}{\partial \log p_j^n} = \left(\frac{\beta_i^m}{s_i^m} + 1\right) (\tilde{\alpha}_m \lambda s_n + \delta_{mn}) s_j^n + \left(\frac{\gamma_{ij}^m}{s_i^m} + s_j^n\right) \cdot 1_{\{m=n\}} - 1_{\{i=j,m=n\}}.$$

$\square$

Equation 6 captures the way in which products in our model are interrelated. The first term represents the changes in demand for product i through both changes to the overall price index of substances in the top level and substitution at the middle level. The second term captures the degree to which a change in the price of product j directly affects the share of product i within the segment through γ. Finally, the last term is an adjustment for the own-price elasticity. In summary, price changes of product j in segment n lead to changes in the price index P^n, real expenditures Q^n, the price index of all substances $\bar{P}$, and the total expenditures on all substances $\log Y$. These changes affect the price indices of other segments m, the relative prices between n and m, the real expenditure on segment m, and the share of product i in segment m. Setting λ and $\tilde{\alpha}_m$ equal to 0 and δ equal to -1 yields elasticities conditional on expenditures.

The substance-type (middle) level elasticities unconditional on substance expenditures Y are given by

$$\frac{\partial logQ^m}{\partial logP^n} = \tilde{\alpha}_m \lambda s_n + \delta_{mn}. \tag{8}$$

The overall price elasticity of substances can be easily derived from the top level with

$$\frac{\partial \log Y}{\partial \log \bar{P}} - \frac{\partial \log \bar{P}}{\partial \log \bar{P}} = \lambda - 1. \tag{9}$$