The Substitutability of Recreational Substances: Marijuana, Alcohol, and Tobacco

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Abstract

Proponents of the legalization of recreational marijuana have argued that the policy would result in increased tax revenues for states. However, if sin goods are highly substitutable, tax revenues from marijuana may crowd out pre-existing revenues. We study the interaction between the marijuana, alcohol, and tobacco industries in Washington state, using a combination of detailed administrative data on the marijuana industry and scanner data on alcohol and tobacco sales. We estimate a demand system and find that alcohol and marijuana are substitutes, with the legalization of marijuana in isolation leading to a 12% decrease in alcohol consumption, and a cross price elasticity of demand on the margin of .16. Marijuana legalization results in a 20% decrease in tobacco consumption, but the marginal relationship is unclear. When prices are held fixed, 50% of marijuana tax revenue comes by crowding out alcohol and tobacco taxes. When those industries adjust their prices, only 22% of marijuana tax revenue comes from alcohol and tobacco. Though Washington has the highest marijuana tax rate in the country, a 1% increase in the marijuana tax results in a 1.01% increase in total revenues collected by the state.

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1 Introduction

More than half of American voters support legalizing marijuana for recreational use (Motel, 2015). Eight U.S. states have chosen to legalize marijuana despite continued federal prohibition and many countries have legalized marijuana in some form. Advocates for legalization have pointed to the potential revenue available through taxation: Washington state, which we study in this paper, earned $136 million from marijuana taxes in 2015. However, legalization and accompanying changes in the real price of marijuana may decrease tax revenues from other sources, such as alcohol and tobacco. If these substances are strong substitutes, the gains to total tax revenue stemming from the legalization of marijuana would be smaller than expected. On the other hand, if they are weak substitutes (or even complements), the gains could be potentially larger than expected. Therefore, it is important to identify the nature of the relationship between marijuana and other legal substances empirically.

We evaluate the effect of legalizing recreational marijuana on tax revenues from the sales of legal substances, taking into account the potential for substitution and complementarity effects between marijuana, alcohol, and tobacco. In addition, we estimate the change in the total tax revenue in response to marginal changes in the tax rates of each substance after prices have changed post-legalization (i.e. the gradient of the Laffer curve). We use a detailed dataset of the prices and quantities of substances sold at the retail location level from Washington state, which was the first U.S. state to legalize marijuana for recreational use in 2014 (along with Colorado).

A differences-in-differences analysis between Washington and a neighboring state would not identify the relationship between these substances because tobacco and alcohol prices in Washington decreased by 3% and 12%, respectively, around the time of legalization. To control for these price changes, we model the consumption of substances with a multistage budgeting approach inspired by Hausman et al. (1994). Our model not only allows for flexible substitution patterns between various product types within each substance category, but also allows us to identify the cross-price elasticities between substances. We take advantage of the fact that marijuana retailers opened at different times in different geographies to identify the extensive margin effect of legalizing marijuana in a particular jurisdiction. We use subsequent price variation along with data on the wholesale prices of marijuana products and other instruments to identify the intensive margin effects of price changes post-legalization. We include a flexible set of fixed effects to account for changes in black market prices.

We find that the legalization of marijuana increased total expenditures on legal recreational substances by 15.5%. On the extensive margin, after controlling for price changes in alcohol and tobacco and time trends, the legalization of marijuana decreases the quantity of alcohol demanded by 12% and decreases the quantity of tobacco demanded by 20%. On the intensive margin we find that a 1% decrease in the price of marijuana leads to a .163% decrease in the quantity of alcohol demanded and that the relationship between marijuana and tobacco is unclear.

Between 2013 and 2015, the gross tax revenue from these substances increased by 53%, though alcohol revenue decreased by 3.4% and tobacco revenue decreased by 12.7%. We find that, holding prices and other factors fixed, half of the revenue from marijuana taxation came from a cannibalization of alcohol and tobacco tax revenues. When we allow prices to vary as they do in the data, over 75% of marijuana tax revenues are "new" revenues.

Our approach differs substantially from the existing interdisciplinary literature on the relationships between marijuana and other substances. A recent review by Subbaraman (2016) examined 39 studies across several disciplines employing a variety of approaches and found inconsistent results. In contrast to this literature, which largely investigates black-market and medical marijuana consumption, we estimate the relationships between these substances in an environment with legal recreational marijuana – an environment that reflects the likely future policy path in many jurisdictions – for the first time. Our approach allows us to control for the endogenous price response of alcohol and tobacco retailers to the entry of recreational marijuana firms. In addition, instead of relying on survey data (Miller et al., 2017) or proxies for substitution such as crime reports (Morris et al., 2014), we study the relationship using data on marijuana purchases directly with minimal measurement error.[1]

The multistage budgeting approach we employ to define the demand for recreational substances has been used in a number of contexts. Similar systems have been used to study the demand for pharmaceuticals (Ellison et al., 1997, Goldberg, 2010, Bokhari and Fournier, 2013), competition between PepsiCo. and Coca-Cola Company (Dhar et al., 2005), and the effects of new product introduction (Hausman and Leonard, 2002), among other topics. The multistage approach, coupled with the "almost ideal" demand system of Deaton and Muellbauer (1980) allows consumers to purchase multiple products under the "recreational substance" umbrella, reflecting the reality that corner solutions to the consumer's problem in this context (i.e. consumers who only purchase one product within the recreational substances category) are likely rare exceptions.[2]

We proceed by discussing our data and some descriptive statistics about legal substance markets in Section 2. We describe our model of demand for recreational substances in Section 3. Section 4 presents the results from our model when applied to the data. We conclude in Section 5 with a discussion and suggestions for further research.

2 Data and Descriptive Evidence

To understand the relationship between recreational demand for marijuana, alcohol, and tobacco, we combine administrative data on marijuana sales ob-

[1]The closest work to our own is that of Baggio et al. (2017), who study sales of alcohol in states with medical marijuana laws using a differences-in-differences approach and find that such laws reduce alcohol sales by 15 percent. Since Washington state had already legalized medical marijuana in the period we study, our results on recreational marijuana can be thought of as complementary or additive to the effects created by medical marijuana laws.

[2]Our choice of the multistage approach, as opposed to a discrete choice model in the style of Berry et al. (1995), is driven by this behavior. In addition, the discrete choice approach assumes that products are substitutes whereas it is possible that over the range of prices we observe, these substances are complements. Finally, discrete choice models require researchers to decompose products into bundles of characteristics and it is not clear which characteristics are shared by alcohol, marijuana, and tobacco.

tained from Washington's Liquor and Cannabis Board with the Nielsen Retail Scanner Dataset.

Our administrative dataset covers the period from the start of Washington's legal marijuana market, July 1, 2014, to the end of 2015. We observe prices and quantities for each product, retailer, and day. We also observe the wholesale price paid by the retailer for each product and the product's potency. The data are reported to the state by firms within the industry as a condition of licensing. Compliance and accuracy is enforced through random audits, backed by penalties that include inventory seizure, civil fines, and criminal prosecution.[3]

The Nielsen data captures store-level data from participating retail firms. These chains include four major grocery store chains, two major discount store chains, and two drug store chains. We observe the price and quantity sold of each product (defined by a UPC) offered by each retailer each week from 2013-2015. Retailer locations are observed at the county level. Though the data only captures roughly half of retail sales, the representation is consistent both over time and across product categories (Lazich and Burton, 2014). In particular, data from the Nielsen Consumer Panel Dataset show that sales from the Retail Scanner dataset account for approximately 48% of liquor products sold in the state (Seo, 2017). For expository purposes, in the descriptive statistics that follow we scale the quantities of alcohol and tobacco sales by $\frac{1}{0.48} \approx 2.083$ to account for the missing retailers.[4]

Table 1 summarizes the retail sales captured in our data for the years 2013 and 2015. The first panel reports the total sales in dollars, while the second panel reports market shares within the substance industry. From 2013 to 2015, total substance expenditures increased 15.5% from $2.5 billion to $2.9 billion. At the same time, tobacco sales decreased 11.4% from $385 million to $342 million. Alcohol sales experienced a smaller decrease of 1.35% from $2,142 million to $2.113 million. In 2015, Marijuana captured 16% of the total

[3]See Hansen et al. (2017a) for a detailed description of the Washington marijuana data.

[4]Nielsen also collects household-level panel data on purchases. However, the household panel does not cover all Washington counties in all time periods, and, for those counties that it does cover, participants often report zero alcohol and tobacco purchases.

expenditures on recreational substances, or \$464 million. The third panel reports the gross tax revenues captured by the state on these products. The introduction of legal marijuana increased tax receipts 23% from \$476 million to \$585 million, though receipts from both alcohol and tobacco sales fell, by 3.4% and 12.7% respectively.

The decrease in the total sales of tobacco and alcohol could stem from a decrease in prices, a decrease in quantities, or both. The second panel of Table 1 reports the change in average prices for each substance in the first set of columns and the change in quantities (in counts for tobacco, liters for alcohol, and grams for marijuana) in the second set of columns. Both prices and quantities decreased for both tobacco and alcohol. Tobacco prices decreased by 11.54% and quantities decreased by 9.05%. Alcohol prices decreased 2.55% and quantities decreased 1.16%. Taken together, these data suggest that, unless tobacco and alcohol have upward-sloping demand curves, consumers are substituting away from tobacco and alcohol to some other form of consumption, which could include recreational marijuana.

Each of these substance types include a wide variety of products, and it is possible that these high-level trends obscure substitution patterns within substance types. Our data allow us to examine consumption patterns at a more granular level. Table 2 repeats the analysis of Table 1 for beer, liquor, and wine product categories within the alcohol substance type. The overall pattern of decreasing prices and quantities does not translate uniformly across the products. Prices for beer and wine were held nearly constant from 2013 to 2015, while the average liquor price decreased 2.27%. The quantities of beer and liquor sold decreased by approximately 2% each, while the quantity of wine sold increased by 1.34%.

Table 3 similarly reports sales, market shares, prices, and quantities for two products within the tobacco category: cigarettes and other tobacco products (OTP), which includes cigars, cigarillos, and loose-leaf tobacco. Cigarettes make up over 90% of the tobacco market. While both tobacco products experienced decreases in both prices and quantities, prices decreased more for OTP (16.71% versus 1.71%), while quantities decreased more for cigarettes (9.07%

versus -5.06%).

Finally, Table 4 reports similar summary statistics for marijuana in 2014 and 2015. We subdivide marijuana into three products: flower (also known as 'usable marijuana'), edibles, and concentrates. Sales for all three products increased substantially from 2014 to 2015, though the figures for 2014 represent only a truncated period, as sales began in July of that year. The third panel documents a steep decline in price for all three goods, and the fourth panel shows that the wholesale prices of flower and edible products dropped more than the wholesale price of concentrate products did.

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 the price of marijuana dropped after its introduction, it is not clear from this alone that the legalization of marijuana or subsequent price changes caused these decreases. Indeed, changes in wholesale prices of alcohol and tobacco, combined with own- and cross-price elasticities for those substances could completely explain these changes. Alternative, shifts in consumer preferences, such as a long term trend in preferences for tobacco (Nelson et al., 2008), could also generate the patterns seen here. Teasing apart these various effects requires a model of demand for recreational substances.

3 A Model of Demand for Recreational Substances

In this section, we introduce a model of demand for recreational substances that follows the multistage budgeting approach of Gorman (1971) and Hausman et al. (1994). In the model, a representative consumer makes a series of decisions to allocate spending among different products. These decisions are illustrated in Figure 1. The consumer starts by choosing how much to spend on substances versus all other goods. Next, conditional on the chosen level of overall substance spending, the consumer allocates that spending among three different substance types: marijuana, alcohol, or tobacco.[5] Finally, the consumer allocates the substance-type-level spending to different products. Within marijuana, the consumer allocates spending between flower (also known as "usable marijuana"), edibles, and concentrates. Within alcohol, the consumer chooses between beer, wine, and liquor. Within tobacco, the consumer chooses between cigarettes and other tobacco products (OTP). We proceed by describing the functional form of the demand system at each stage.

3.1 Bottom level: Demand for products

In the bottom level, conditional on a choice of expenditure for a given substance segment, the representative consumer allocates that expenditure among different products. We model this behavior with the Almost Ideal demand system (AI) developed by Deaton and Muellbauer (1980). The representative consumer in county c during month t allocates a share of spending s_{ict}^{m} to a specific product $i \in \{1, \cdots, J^m\}$ within substance type m, where J^m is the number of products within that substance type. Demand is given by

$$s_{ict}^{m} = \beta_0 + \beta_i^m \log\left(\frac{y_{ct}^{m}}{P_{ct}^{m}}\right) + \sum_{j=1}^{J^m} \gamma_{ij}^{m} \log p_{jct} + FX_{ic} + FX_{it} + \varepsilon_{ict}. \quad (1)$$

In this equation, y_{ct}^{m} is the expenditure on the substance type, p_{jct} is the price of product j in county c at time t, and P_{ct}^{m} is a price index for all products within the substance type. Following Hausman, Leonard, and Zona, we use a Stone-weighted price index and define $\log P_{ct}^{m} = \sum_{i=1}^{J^m} s_{ict}^{m} \log p_{ict}$. γ_{ij} has the same sign as the Hicksian elasticity.

To focus our attention on the relationship between point-in-time prices and substance demand, we include two types of fixed effects. First, county-product fixed effects FX_{ic} capture any specific preference a county has for a particular

[5] Within the multistage literature, the choices within this middle level are often referred to as "segments." We use the term "substance types" to more clearly reflect our meaning.

product that remains constant over time. Second, time-product fixed effects FX_{it} captures time-varying patterns in demand in a non-parametric way (such as trends in the preferences for particular products).

This demand system is a first-order approximation to any Gorman-class demand function and allows for flexible substitution patterns (including complementarities) between products. Products may be complements or substitutes, and demand may be non-homothetic. We can restrict expenditures to be homogeneous of degree zero in prices and substance type expenditures by imposing $\sum_i \beta_i = 0$ and $\sum_i \gamma_{ij} = \sum_j \gamma_{ij} = 0$ in estimation. By estimating the equations for multiple products simultaneously, we can also impose Slutsky symmetry, $\gamma_{ij} = \gamma_{ji}$.

If the demand shock ε_{ict} includes a component that is observed by firms (e.g. advertising), it is likely to be correlated with the price of product i. Indeed, if the shock includes components are observed by firms that sell other products, it is likely to be correlated with all prices p_j. As a consequence, all prices in Equation 1 may be endogenous (i.e. $\text{Corr}(\log p_j, \varepsilon_i) \neq 0$). We discuss our instruments for price in Section 4.

3.2 Middle level: Demand for substance types

In the middle level, conditional on choosing a level of overall substance expenditure, the representative consumer chooses how to allocate that expenditure between the alcohol, tobacco, and marijuana segments. Let $Q_{mct} = \frac{y^m_{ct}}{P^m_{ct}}$, that is, the real quantity of substance m purchased in county c at time t is equal to the nominal expenditures on that substance divided by the price index for that substance. We model demand for segment $m \in \{\text{mj, alc, tb}\}$ via

$$\begin{aligned} log(Q_{mct}) =& \alpha_0 + \alpha_m \log Y_{ct} + \theta_m L_{ct} + \alpha'_m \log Y_{ct} L_{ct} + \delta_{m,\text{mj}} \log P^{\text{mj}}_{ct} L_{ct} \\ &+ \delta_{m,\text{alc}} \log P^{\text{alc}}_{ct} + \delta_{m,\text{tb}} \log P^{\text{tb}}_{ct} + FX_{mc} + FX_{mt} + e_{mct}. \end{aligned} \tag{2}$$

In this equation, Y_{ct} is the nominal expenditure on all substances for that county-month and L_{ct} is an indicator which is equal to one if recreational marijuana is available at retail during that county-month. If preferences are homothetic, $\alpha_m = 1$ for all m. The δ parameters are Marshallian own- and cross-price elasticities, conditional on nominal expenditures Y. Changes in product prices lead to substitution across substance types through the mechanism of the price index. In particular, when the price p_n^i changes, the price index for segment n, P^n, also changes, which affects the real expenditures Q_m.

We interact $\log Y_{ct}$ with the indicator variable for marijuana availability because the overall expenditure on substances increases substantially from the sum of tobacco and alcohol expenditures to the sum of tobacco, alcohol, and marijuana revenues. We set $\log P^{mj} * L = 0$ if $L = 0$. As a consequence, θ does not directly translate into the effect of legalization, as at the same time that L changes from zero to one, $\log P^{mj} * L$ changes from zero to some positive number, as does $\log Y * L$. Let Θ_m be the effect of legalizing marijuana alone, holding $\log P^{mj} * L$ and $\log Y * L$ constant. We can write θ_m as

$$\begin{aligned}\hat{\theta}_m &= \Theta_m * 1 + \delta_{m,\text{marijuana}} logP_{ct}^{\text{marijuana}} * 1 + \alpha_m logY_{ct}|_{t\in\text{post}} * 1 \\ &\quad - (\Theta_m * 0 + \delta_{m,\text{marijuana}} * 0 + \alpha_m logY_{ct}|_{t\in\text{pre}}) \\ &= \Theta_m + \delta_{m,\text{marijuana}} * logP_{ct}^{\text{marijuana}} + \alpha_m \left(logY_{ct}|_{t\in\text{post}} - logY_{ct}|_{t\in\text{pre}}\right).\end{aligned}$$

Thus, the effect of legalization itself on $logQ_m$ is

$$\Theta_m = \hat{\theta}_m - \delta_{m,\text{marijuana}} * logP_{ct}^{\text{marijuana}} - \alpha_m * \left(logY_{ct}|_{t\in\text{post}} - logY_{ct}|_{t\in\text{pre}}\right).$$

As with the bottom level, we include two types of fixed effects. FX_{mc} captures variation in demand for substances at the county level which is constant across time, and FX_{mt} captures variation in demand for substances by month which is constant across geography. In particular, since we do not observe black market prices for substances (particularly marijuana), these fixed effects will capture any variation in demand which is due to movements in the black market.[6]

[6] We explored specifications of this system which included data on black-market prices from user reported data collected by `http://priceofweed.com`. However, this black-market

3.3 Top level: Demand for substances

In the top level of the demand system, the representative consumer chooses a level of expenditures for substances overall. As before, let Y_{ct} be the nominal expenditures on all substances for that county month. We write Y_{ct} as a function of income, prices, and fixed effects via

$$log(Y_{ct}) = \phi_0 + \phi_1 \log(\bar{Y}_{ct}) + \lambda \log \mathbf{P}_{ct} + \phi_2 \mathbf{X}_c + u_{ct}. \tag{3}$$

In this equation, $\bar{Y}_{ct}$ is average gross income reported by the Bureau of Labor Statistics (available at the county-quarter level) and $\log \mathbf{P}_{ct} = \sum_m s_m \log P_m$ is the share-weighted price index for substances. As with the middle level, we use instrumented product-level prices to create this index. Due to the short length of our panel, we do not include county-level fixed effects. Instead, we add county characteristics $\mathbf{X}_c$ which include the county's population, population density, mean age, and percentage of female inhabitants.

3.4 Elasticities

The own- and cross-price elasticities of legal substances are key parameters of interest for policy makers and can be used to estimate the gradient of the Laffer curve. To derive elasticities in this model, we follow the logic of Bokhari and Fournier (2013) and note that since the share $s_i^m = \frac{p_i^m q_i^m}{y^m}$, we can 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:

$$\varepsilon_{ij} = \frac{\partial \log q_i^m}{\partial \log p_j^n} = \frac{1}{s_i^m} \frac{\partial s_i^m}{\partial \log p_j^n} + \frac{\partial \log y^m}{\partial \log p_j^n} - 1_{\{i=j,m=n\}}. \tag{4}$$

price data does not vary by county – and it is likely that demand for black-market varies at the county level. As we are primarily concern with the effects of price movements within the market for legal recreational substances, our use of both time and county fixed effects captures any changes in the black market in a flexible way.

The first term in this expression 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. Our model allows changes in the price of any good to affect the consumption of every other good through the mechanism of the price indicies which connect the different levels of the demand system. As a consequence, price changes lead to real expenditures on substances and the elasticity we calculate in this way is a Marshallian (uncompensated) elasticity. In Appendix A, we derive an expression for ϵ_{ij} as a function of the parameters of our model and obtain the following Proposition.

Proposition 1. *Suppose the demand for products i in segment m and product j in segment n is given by the system of Equations 1, 2, and 3. Let $\tilde{\alpha}_m = \alpha_m + \alpha'_m L$. Then the cross price elasticity of demand between i and j is given by*

$$\frac{\partial \log q_i^m}{\partial \log p_j^n} = \left(\frac{\beta_i^m}{s_i^m} + 1\right)(\tilde{\alpha}_m \lambda s_n + \delta_{mn}) s_j^n + \left(\frac{\gamma_{ij}^m}{s_i^m} + s_j^n\right) \cdot 1_{\{m=n\}} - 1_{\{i=j, m=n\}}. \quad (5)$$

Proof. See Appendix A. □

The first term of this expression captures the extent to which changes in the price of product j affects demand for product i through both changes to the overall price index of substances and substitution at the segment level. The second term represents the degree to which a change in the price of product j affects the share of product i within segment m, if both products i and j are in the same segment. Finally, the last term is an adjustment for the own-price elasticity.

It is also useful to measure segment-level elasticities, that is, how a change in the price of an entire segment (e.g. a change in the tax rate for that segment) affects expenditures across all segments. We can derive this elasticity from Equation 2 by taking the derivative with respect to $\log P_n$ to obtain

$$\frac{\partial \log Q_m}{\partial \log P_n} = \tilde{\alpha}_m \frac{\partial \log Y}{\partial \log P_n} + \delta_{mn} \\ = \tilde{\alpha}_{mn} \lambda s_n + \delta_{mn}. \tag{6}$$

Finally, the overall elasticity of substances as a category can be easily derived from Equation 3 with

$$\frac{\partial \log Q}{\partial \log \mathbf{P}} = \frac{\partial \log Y}{\partial \log \mathbf{P}} - \frac{\partial \log \mathbf{P}}{\partial \log \mathbf{P}} = \lambda - 1. \tag{7}$$

4 Estimation and results

To estimate this model, we must first precisely define the price of each product within a segment, as each "product" is comprised of many different UPCs in our data. For alcohol and tobacco, we use the per-unit price for a fixed basket of goods comprising of the top sellers within the product category (e.g. the top 40% for cigarettes and top 12-15% for alcohol), since most retail stores sell most, if not all, of these goods. Since Washington imposes binding quantity restrictions on marijuana producers, which leads to large differences in product availability between different marijuana retailers, we cannot use this approach for marijuana. Instead, we calculate marijuana prices by taking the average price of products within the 25th and 75th percentile range of the potency distribution for any particular month.

As mentioned in Section 3, firms likely observe a component of demand that we do not, and so prices are endogenous. We solve this endogeneity problem by collecting instruments for the price of each product. First, suppose that the price of product i in county c at time t is determined by

$$\log p_{ict} = \psi \log w_{it} + FX_{ic} + \omega_{ict}.$$

In this equation, w_{it} are costs that are not specific to a particular county, such as state-wide wage costs incurred by stores. County fixed effects FX_{ic}

include local transportation costs, wage differentials across counties, and other costs which vary by county. Following the logic of Hausman (1996), if ω_{ict} is uncorrelated with $\varepsilon j c' t \forall j \in J^m, c' \neq c$, then the price of a product in a county c' is a valid instrument for the price of the same product in a different county c. For all substances, we construct instruments via $h_{ict} = \sum_{c' \neq c} \log p_{ic't}$.

In addition to these Hausman instruments, our marijuana data includes the wholesale price paid by the retailer for each product sold. These wholesale prices are cost shifters for the retail firm, but themselves may be correlated with demand shocks if, for example, wholesalers have non-linear pricing contracts with retailers (Bonnet and Dubois, 2010). Thus, we do not use the wholesale price of each marijuana product as an instrument directly, but rather average the wholesale prices of products sold in a county-month to capture underlying changes in the cost structure of marijuana firms that are not due to demand shocks for individual products.

Washington allows localities to set sales tax rates independently and change them each quarter, though they must be constant across all products. Assuming that localities are not setting tax rates in response to (or in expectation of) demand shocks for particular substance products, these tax rates are cost shifters which are uncorrelated with the unobservable component of demand. Additionally, Washington unexpectedly changed the retail tax rate on marijuana from 25% to 37% on July 1, 2015 (Hansen et al., 2017a). We use all of these tax changes as instruments for prices directly.

Since prices are endogenous in the bottom level, the price indices used in the middle and top levels are endogenous as well. We address this endogeneity by using the instrumented prices from the bottom level to construct the price indices used to estimate the middle and top levels. In addition, the availability of marijuana in a given county may be endogenous as well – firms may have been quicker to open in areas which had a stronger preference for marijuana products. We account for this additional dimension of endogeneity by collecting data on county- and municipality-level restrictions on entry and using those indicators to instrument for marijuana availability.

We start by estimating Equation 3 using data from markets where $L = 1$ –

that is, counties where marijuana was legalized and available for purchase. We measure income using the disposable income measure reported by the Bureau of Labor Statistics, which is available at the county-quarter level. We use a Stone-weighted price index with a fixed basket of goods to measure the overall price level of substances and instrument prices using Hausman instruments, tax rates, and marijuana wholesale prices. We include the log of the county population to capture the scale of different county markets. Finally, we include time fixed effects to control for broad trends in consumption behavior.

Results from this estimation are in Table 5. Column (1) estimates the basic equation without any county-level covariates included. The coefficient on the log of the price index for substances indicates that substances are elastic, and the coefficient on the log of income indicates substances are income elastic. Column (2) adds the log of the county population as a control, which attenuates the other two coefficients. 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. In this specification, expenditures on substances increase when income increases, and expenditures scale nearly linearly with population. We find an overall price elasticity of substances in our preferred specification, per Equation 7, to be -0.23.

We next estimate Equation 2 for each of our substance categories. We once again used a fixed basket of goods within each substance category to create a Stone-weighted price index. We treat all prices as endogenous and use the full set of available instruments in the estimation. We also include an indicator variable for the period after Oregon legalized marijuana, as Hansen et al. (2017b) found a substantial drop in marijuana sales along the Oregon-Washington border when Oregon's market opened. Following the multistage AI demand literature, we do not enforce Slutsky symmetry at this level.[7] Finally, we include both county and time fixed effects.

[7] To impose Slutsky symmetry in this estimate, we must hold real expenditures on substances constant and transform the left-hand side into a share. As the introduction of recreational marijuana led to a large increase in the observed expenditures on legal substances, this imposition is unrealistic.

The results are reported in Table 6. All substance segments are price elastic, with marijuana slightly more price elastic in the point estimate than tobacco or alcohol. Conditional on holding the total substance expenditure fixed, a 1% increase in the price of marijuana is associated with a 0.163% increase in the quantity of alcohol purchased, and a 1% increase in the price of alcohol is associated with a 1.66% increase in the quantity of marijuana purchased. We thus conclude that alcohol and marijuana are substitutes. While we find positive coefficients on the relationships between tobacco and marijuana, they are imprecisely estimated.

We use these results to analyze the effect of the legalization of marijuana itself (as opposed to changes in the price of marijuana once it has been legalized) on alcohol and tobacco purchases in Table 7. We decompose the overall effect on tobacco and alcohol, reported in the last row, into several effects. The first row isolates the effect of legalization itself, holding prices and other demand characteristics fixed. Legalization decreases consumption of tobacco and alcohol by 20% and 12%, respectively. The second and third rows report the effects of contemporaneous price responses from those industries, and the last row reports other effects in our model, including the overall change in substance expenditures and changes in the time fixed effects. Figure 2 illustrates these changes as they flow through prices and tax rates to tax revenue.

Next, we estimate the parameters of Equation 1 for the products within each substance category. We impose homogeneity of degree zero and Slutsky symmetry on the estimated parameters by estimating $n - 1$ equations for n products simultaneously and using the adding-up restrictions to calculate the parameters of the remaining equation. For the tobacco category, we estimate the parameters for cigarettes. For alcohol, we estimate the beer and wine equations, and for marijuana, we estimate the flower and edible equations. For each estimation, we include both county and time fixed effects, and use the full slate of available instruments for prices.

We present the coefficients for the tobacco, alcohol, and marijuana equations in Tables 8, 9, and 10 respectively. Since prices in these equations are relative to the excluded good, the parameters cannot be interpreted as elasticities directly. We therefore calculate elasticities for products within each segment, conditional on holding segment-level expenditures constant per Equation 6, in Tables 11, 12 and 13 for tobacco, alcohol, and marijuana, respectively.

Table 14 presents a matrix of own- and cross-price elasticities for all products in the model after taking into account the segment-level substitution patterns and the overall price elasticity calculated in the top level per Equation 5. Each product, with the exception of beer, is price elastic at the point estimate. Cigarettes are the most price elastic, which, as with our result for tobacco in the middle level, likely reflects the limitations of our data. We find that the own-price elasticities for marijuana edible and concentrate products are higher in the point estimate than the elasticity of marijuana flower, though the confidence intervals overlap slightly. We also report income elasticities for each good. The most income elastic good is marijuana concentrate, with a mean income elasticity of 0.42, whereas the least is marijuana edibles with an income elasticity of 0.16.

Finally, Table 15 presents the effects of a 1% increase in the tax rate of each substance on the total tax revenue collected by the state. To calculate these effects, we start with passthrough rates from the literature. For marijuana, we use the rate of 0.44 found by Hansen et al. (2017a), and for tobacco, we adopt the rate of 0.85 found by Harding et al. (2012). Kenkel (2005) estimated tax passthrough rates for a variety of alcohol products. We use the median rate for off-site beer products, 1.71. We use these rates to calculate new prices, and then combine estimates from Tables 5 and 6 to calculate the change in the quantity purchased of each good. Differences in passthrough rates, as well as asymmetries in our estimated cross-price elasticities, result in asymmetries in our estimated revenue changes. For example, we estimate that a 1% increase in the tax on tobacco would lead to a 0.03% increase in the tax revenue from alcohol sales. In contrast, a 1% increase in the alcohol tax rate would result in a 1.59% increase in tobacco tax revenues. Overall, we find that Washington is on the left-hand side of the Laffer curve for each of the three substances. The biggest potential gains come from alcohol taxes. These gains are driven by the low own-price elasticity, relative to the other goods, and the outsized role alcohol plays in the overall substance market, and are partially offset by alcohol's high tax passthrough rate. While Washington has the highest tax rate on marijuana in the country, 37%, we find that a 1% increase in the marijuana tax rate would result in a 1.22% increase in total tax revenue, including a 3.22% increase in tax revenue from marijuana.

5 Conclusion

As more and more voters shift toward supporting the legalization of marijuana for recreational use, 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 crucially on the interaction between the marijuana industry and industries that produce other substances. We present a model that places the legal marijuana industry in the context of other legal recreational substances, alcohol and tobacco and that allows consumers to freely substitute between different goods within substance segments.

We find that marijuana and alcohol are substitutes on both the intensive and extensive margins, and while marijuana and tobacco are substitutes on the extensive margin, they have little effect on each other on the intensive margin. Furthermore, 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 – but would also come with increased alcohol consumption. These results suggest that policymakers should weigh the costs and benefits of different marijuana policies and tax regimes carefully, taking into account both the impact of legalization on public finances as well as on public health.

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, discuss a method for determining the optimal tax regime, and speak to potential public health implications of our findings.

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 studied the impact of medical marijuana availability on illegal consumption of opiates by examining high level trends in sales of these goods. 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 view into demand behavior but does not incorporate supply-side responses. 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 static Nash equilibrium in prices. The supply parameters could be estimated and equilibrium outcomes as a function of tax rates could be simulated. 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.

Public health implications. Opponents of marijuana liberalization have pointed to the potential for significant public health costs, across a number of dimensions including traffic accidents (Hansen et al., 2018), use of the substance by teenagers (Anderson et al., 2015), and trafficking of legal marijuana to other jurisdictions (Hansen et al., 2017b). On the other hand, given our findings, it is possible that the public health externalities associated with marijuana consumption are lower than the significant externalities associated with other recreational substances and therefore that legalizing marijuana provides a net benefit to public health (Levitt and Porter, 2001, Pacula et al., 2014). As more precise estimates of marijuana externalities become available, such estimates could be combined with existing alcohol estimates and used in conjunction with the optimal tax model discussed above to provide a broader perspective on optimal marijuana policy.

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6 Figures and Tables

Figure 1: Substance demand segment tree

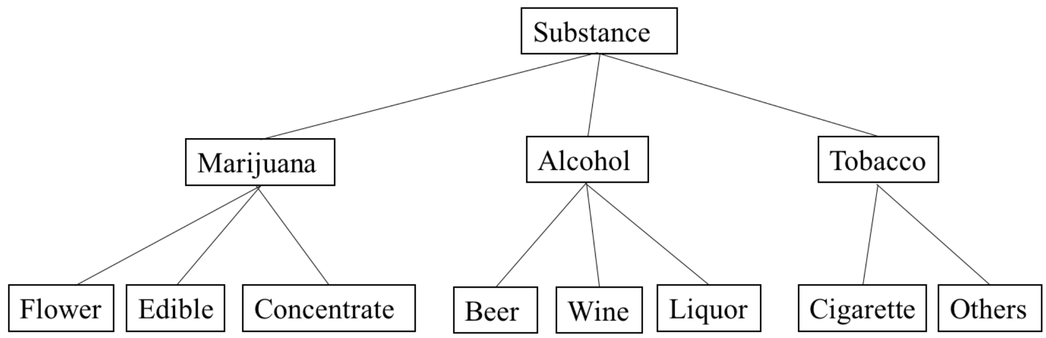
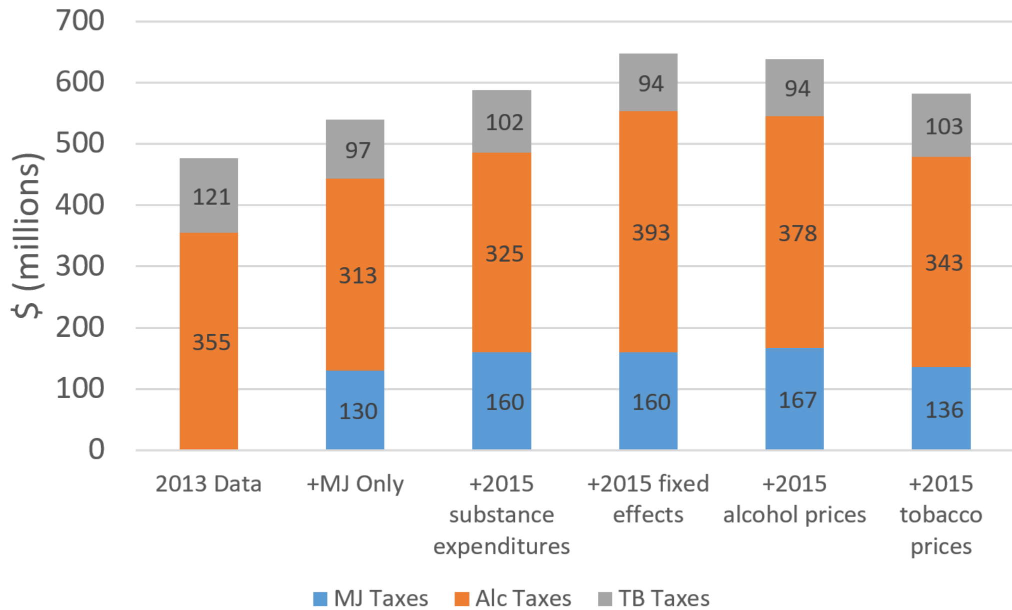


Figure 2: Model estimated substance tax revenue under alternative scenarios



This figure uses the estimates of the middle level equations to calculate Washington's tax revenue under alternative scenarios. The first bar illustrates the revenue Washington obtained in 2013, according to our data. The second bar uses our model estimates to simulate outcomes when marijuana is legalized, but no prices or other details change. The third bar allows the variation in the total expenditures on substances to enter the model. The fourth bar updates the constant terms in the model to reflect our estimated 2015 fixed effects. The fifth bar reflects the change in alcohol prices. Finally, the sixth bar reflects the change in tobacco prices and matches the 2015 tax revenues in our data.

Table 1: Summary statistics for legal substances, 2013-2015

Substance		Alcohol	Tobacco	Marijuana	Overall
Sales ($1M)	2013	2,141	386		2,527
	2015	2,111	342	464	2,918
	%Δ	-1.35	-11.4		15.5
Share	2013	0.85	0.15		1.0
	2015	0.72	0.12	0.16	1.0
	%Δ	-14.6	-23.1		
Gross Tax Revenue ($1M)	2013	355	121		476
	2015	343	106	136	585
	%Δ	-3.40	-12.72		22.86
Average price	2013	12.92	0.96		
	2015	12.59	0.85	17.4	
	%Δ	-2.55	-11.5		
Quantity (1M)	2013	301	620		
	2015	298	564	33	
	%Δ	-1.16	-9.05		

Prices and sales include all applicable taxes. Quantities for alcohol, tobacco, and marijuana are liters, counts, and grams, respectively. Quantities and sales of alcohol and tobacco are scaled from Nielsen data by $\frac{1}{0.48}$.

Table 2: Sales, market share, prices, and quantities for alcohol products, 2013-2015

Substance		Beer	Liquor	Wine
Sales ($1 M)	2013	623	800	719
	2015	615	769	729
	%Δ	-1.31	-3.99	1.45
Share	2013	0.29	0.37	0.34
	2015	0.29	0.36	0.35
	%Δ	0.08	-2.64	2.88
Average price	2013	3.28	23.71	9.26
	2015	3.30	23.17	9.27
	%Δ	0.79	-2.27	0.11
Quantity (1M L)	2013	190	33	77
	2015	186	32	80
	%Δ	-2.08	-3.03	3.90

Prices and sales include all applicable taxes. Quantities are measured in millions of liters. Quantities and sales are scaled from Nielsen data by $\frac{1}{0.48}$.

Table 3: Sales, market share, prices, and quantities for tobacco products, 2013-2015

Substance		Cigarettes	OTP
Sales ($1 M)	2013	364	21
	2015	325	17
	%Δ	-10.62	-20.92
Share	2013	0.94	0.06
	2015	0.95	0.05
	%Δ	0.66	-10.95
Average price	2013	0.59	7.21
	2015	0.58	6.01
	%Δ	-1.71	-16.71
Quantity (1M ct)	2013	617	4
	2015	560	3
	%Δ	-2.08	-3.03

Prices and sales include all applicable taxes. Quantities are measured in millions of counts. Quantities and sales are scaled from Nielsen data by $\frac{1}{0.48}$.

Table 4: Sales, market share, prices, and quantities for marijuana products, 2014-2015

Substance		Flower	Edible	Concentrate
Sales	2014	36	3.3	3.9
($1 M)	2015	344	47	70
Share	2014	0.83	0.08	0.09
	2015	0.74	0.10	0.15
Average	2014	21.67	35.64	54.07
price ($)	2015	12.26	24.42	41.45
Wholesale	2014	8.09	14.17	14.44
price ($)	2015	3.89	7.97	13.25
Quantity	2014	1.7	0.1	0.1
(1M)	2015	28	1.9	1.7

Prices and sales include all applicable taxes. Quantities are measured in millions of grams for flower, and counts for edibles and concentrates. Note that Washington marijuana sales began in July, 2014.

Table 5: **Top-level estimates, $L = 1$ markets**

	(1)	(2)	(3)
Intercept	1.3105	-0.6057	0.5139
	(1.2623)	(0.5108)	(3.0113)
Log income	1.8919	0.2606	0.3046
	(0.1124)	(0.0771)	(0.0757)
Log price index	-0.1595	0.3995	0.5168
	(0.5430)	(0.1807)	(0.1670)
Log population		1.1147	1.1419
		(0.0334)	(0.0364)
Percent male			-4.6788
			(4.9213)
Percent aged 15-34			-1.2199
			(0.5545)
Percent white			0.8408
			(0.5371)
Year FX	Yes	Yes	Yes
N	281	281	281
R-sq adj	0.4490	0.8769	0.8799

Observations: year-quarter-county level, $L = 1$ markets only
IVs: Hausman, tax, wholesale
SE: robust to heteroskedasticity

Table 6: **Middle level estimates**

	Tobacco	Alcohol	Marijuana
Intercept	5.0249	9.0516	-9.0851
	(0.7019)	(0.7008)	(2.5836)
Log substance expenditure	0.3161	0.2598	1.4545
	(0.0364)	(0.0398)	(0.1342)
Log P^{tb}	-1.3950	0.7959	1.6943
	(0.1590)	(0.1597)	(1.0681)
Log P^{alc}	0.0204	-1.1975	1.6556
	(0.2295)	(0.2047)	(0.7914)
MJ indicator * Log P^{mj}	0.0793	0.1629	-1.4565
	(0.0866)	(0.0575)	(0.1851)
MJ indicator	-0.6873	-0.6638	
	(0.2353)	(0.1562)	
MJ indicator * Log substance expenditure	0.0303	0.0093	
	(0.0062)	(0.0057)	
Oregon legalization indicator	0.0148	0.0223	-0.1643
	(0.0267)	(0.0243)	(0.0426)
County FX	Yes	Yes	Yes
Time FX	Yes	Yes	Yes
N	910	910	297
R-sq adj	0.9974	0.9964	0.9747

The dependent variable for each of these regressions is the log of the quantity of the particular substance. Hausman, tax, and wholesale instruments are used for price in each regression. In addition, the percentage of population in areas in which marijuana retail is banned is used as an instrument for the MJ indicator. These results are used to calculate the unconditional elasticities in Table (14).

Table 7: **The effect of marijuana legalization on demand for other substances**

	Tobacco	Alcohol
MJ legalization effect	-20.0%	-11.8%
Alcohol price change	-0.05%	3.15%
Tobacco price change	18.5%	-9.23%
Other factors	-3.19%	25.6%
Total effect	-8.30%	3.68%

Note: We use the estimates in Table 6 with our data to calculate these effects. "Other factors" consist of the change in substance expenditures corresponding with the introduction of marijuana and the evolution of time fixed effects.

Table 8: **Bottom level: Tobacco**

	Cigarettes
Intercept	0.3409
	(0.1188)
Log real expenditure	0.0578
	(0.0129)
Log price ratio	-0.0059
	(0.0042)
County FX	Yes
Time FX	Yes
Hausman IV	Yes
Tax IV	Yes
Wholesale IV	N/A
Two-step	Yes
N	1029
R-sq adj	0.7692

Note: The price is defined as the ratio of cigarette prices to the price of other tobacco products. Robust standard errors are in parentheses.

Table 9: **Bottom level: Alcohol**

	Beer	Wine
Intercept	0.2116	-0.1419
	(0.0737)	(0.0175)
Log real expenditure	0.0099	-0.1898
	(0.0070)	(0.0141)
Log beer price ratio	-0.0459	-0.0151
	(0.0188)	(0.0162)
Log wine price ratio	-0.0151	-0.1283
	(0.0162)	(0.0130)
County FX	Yes	Yes
Time FX	Yes	Yes
Hausman IV	Yes	Yes
Tax IV	Yes	Yes
Wholesale IV	N/A	N/A
Two-step	Yes	Yes
N	1080	1080
R-sq adj	0.9722	0.9722

Note: The price is defined as the ratio of beer or wine prices to the price of liquor. Robust standard errors are in parentheses.

Table 10: **Bottom level: Marijuana**

	Flower	Edible
Intercept	0.6570	-0.0748
	(0.0689)	(0.0170)
Log real expenditure	0.0231	-0.0543
	(0.0092)	(0.0184)
Log flower price ratio	-0.0207	0.0031
	(0.0124)	(0.0065)
Log edible price ratio	0.0031	-0.0474
	(0.0065)	(0.0121)
County FX	Yes	Yes
Time FX	Yes	Yes
Hausman IV	Yes	Yes
Tax IV	Yes	Yes
Wholesale IV	Yes	Yes
Two-step	Yes	Yes
N	339	339
R-sq adj	0.9957	0.9957

Note: The price is defined as the ratio of flower or edible prices to the price of concentrates. Robust standard errors are in parentheses.

Table 11: **Conditional elasticities for tobacco segment**

		Cigarette	OTP
Mean elas.	Cigarette	-1.0670	0.0046
		(0.0182)	(0.0069)
	OTP	1.3056	-1.0885
		(0.3572)	(0.1215)
Med elas.	Cigarette	-1.0669	0.0052
		(0.0182)	(0.0068)
	OTP	1.3987	-1.1003
		(0.3822)	(0.1314)
gammas elas.	Cigarette	-0.0078	0.0078
		(0.0066)	(0.0066)
	OTP	0.0078	-0.0078
		(0.0066)	(0.0066)
Mean income elas.		1.0620	-0.1036
		(0.0165)	(0.2948)
Med income elas.		1.0615	-0.1905
		(0.0163)	(0.3197)

Table 12: **Conditional elasticities for alcohol segment**

		Beer	Wine	Liquor
Mean elas.	Beer	-1.1650	-0.0658	0.1972
		(0.0698)	(0.0581)	(0.0672)
	Wine	0.1307	-1.1881	0.6510
		(0.0597)	(0.0270)	(0.0621)
	Liquor	0.0173	0.2232	-1.7346
		(0.0543)	(0.0459)	(0.0706)
Med elas.	Beer	-1.1649	-0.0655	0.1964
		(0.0697)	(0.0577)	(0.0668)
	Wine	0.1194	-1.1749	0.6293
		(0.0576)	(0.0263)	(0.0621)
	Liquor	0.0202	0.2213	-1.7424
		(0.0537)	(0.0459)	(0.0720)
gammas elas.	Beer	-0.0450	-0.0150	0.0600
		(0.0199)	(0.0170)	(0.0183)
	Wine	-0.0150	-0.1290	0.1440
		(0.0170)	(0.0143)	(0.0174)
	Liquor	0.0600	0.1440	-0.2040
		(0.0183)	(0.0174)	(0.0261)
Mean income elas.		1.0350	0.4409	1.4899
		(0.0267)	(0.0459)	(0.0224)
Med income elas.		1.0350	0.4603	1.4965
		(0.0267)	(0.0454)	(0.0229)

Table 13: **Conditional elasticities for marijuana segment**

		Flower	Edible	Concentrate
Mean elas.	Flower	-1.0451	-0.0012	0.0178
		(0.0606)	(0.0469)	(0.0504)
	Edible	0.4531	-1.4152	0.5794
		(0.3856)	(0.1796)	(0.4671)
	Concentrate	-0.0538	0.2966	-1.4481
		(0.2688)	(0.2451)	(0.4033)
Med elas.	Flower	-1.0447	-0.0011	0.0177
		(0.0598)	(0.0463)	(0.0498)
	Edible	0.4452	-1.3753	0.5307
		(0.3787)	(0.1648)	(0.4326)
	Concentrate	-0.0509	0.2829	-1.4330
		(0.2607)	(0.2377)	(0.3897)
gammas elas.	Flower	-0.0180	0.0016	0.0164
		(0.0441)	(0.0321)	(0.0379)
	Edible	0.0016	-0.0480	0.0464
		(0.0321)	(0.0194)	(0.0376)
	Concentrate	0.0164	0.0464	-0.0628
		(0.0379)	(0.0376)	(0.0580)
Mean income elas.		1.0282	0.4861	1.2102
		(0.0386)	(0.5490)	(0.2227)
Med income elas.		1.0277	0.5297	1.2021
		(0.0378)	(0.4955)	(0.2160)

Table 14: **Average unconditional elasticities**

		Cigarette	OTP	Beer	Wine	Liquor	Flower	Edible	Concentrate
Mean elas.	Cigarette	-2.1919	-0.0676	0.0937	0.1042	0.1141	0.2182	0.0315	0.0462
		(0.7707)	(0.0522)	(0.2718)	(0.2982)	(0.3288)	(0.1438)	(0.0213)	(0.0301)
	OTP	1.2329	-1.1542	0.0173	0.0161	0.0185	0.0237	0.0009	0.0069
		(0.6443)	(0.1405)	(0.0710)	(0.0760)	(0.0836)	(0.0679)	(0.0121)	(0.0140)
	Beer	1.3687	0.0922	-0.9440	0.1772	0.3957	0.0903	0.0126	0.0193
		(0.6692)	(0.0450)	(0.2879)	(0.3160)	(0.3459)	(0.0875)	(0.0130)	(0.0184)
	Wine	0.3984	0.0273	0.2356	-1.1142	0.7570	0.0241	0.0035	0.0053
		(0.2292)	(0.0149)	(0.1199)	(0.1354)	(0.1431)	(0.0252)	(0.0038)	(0.0054)
	Liquor	2.0099	0.1353	0.2719	0.5377	-1.3473	0.1329	0.0185	0.0284
		(0.9807)	(0.0660)	(0.4094)	(0.4468)	(0.4958)	(0.1286)	(0.0190)	(0.0271)
	Flower	0.1685	0.0113	0.2810	0.3125	0.3428	-1.2535	-0.0298	-0.0195
		(1.7466)	(0.1176)	(0.5771)	(0.6325)	(0.6974)	(0.2132)	(0.0358)	(0.0510)
	Edible	0.1231	0.0082	0.1936	0.2193	0.2380	0.1943	-1.4469	0.4568
		(1.1465)	(0.0762)	(0.3945)	(0.4378)	(0.4800)	(0.2813)	(0.1786)	(0.2843)
	Concentrate	0.1865	0.0125	0.3188	0.3565	0.3902	-0.2346	0.2228	-1.4606
		(2.0635)	(0.1389)	(0.7040)	(0.7739)	(0.8532)	(0.2920)	(0.1633)	(0.2086)
Med elas.	Cigarette	-2.1982	-0.0558	0.0915	0.1058	0.1131	0.2135	0.0322	0.0458
		(0.7762)	(0.0446)	(0.2646)	(0.3031)	(0.3226)	(0.1446)	(0.0219)	(0.0304)
	OTP	1.3893	-1.1583	0.0271	0.0261	0.0314	0.0590	0.0083	0.0127
		(0.6983)	(0.1495)	(0.0865)	(0.0856)	(0.1021)	(0.0641)	(0.0091)	(0.0138)
	Beer	1.3763	0.0778	-0.9504	0.1808	0.3950	0.0858	0.0129	0.0188
		(0.6736)	(0.0385)	(0.2816)	(0.3214)	(0.3429)	(0.0868)	(0.0132)	(0.0186)
	Wine	0.4729	0.0286	0.2261	-1.0963	0.7341	0.0285	0.0040	0.0057
		(0.2493)	(0.0148)	(0.1239)	(0.1415)	(0.1471)	(0.0296)	(0.0041)	(0.0059)
	Liquor	1.9706	0.1185	0.2685	0.5453	-1.3592	0.1251	0.0190	0.0280
		(0.9617)	(0.0592)	(0.3977)	(0.4585)	(0.4887)	(0.1262)	(0.0194)	(0.0274)
	Flower	0.1686	0.0093	0.2748	0.3170	0.3421	-1.2715	-0.0287	-0.0248
		(1.7534)	(0.1000)	(0.5613)	(0.6417)	(0.6862)	(0.2057)	(0.0351)	(0.0493)
	Edible	0.1224	0.0072	0.1961	0.2210	0.2437	0.1772	-1.4047	0.4224
		(1.1647)	(0.0674)	(0.3917)	(0.4403)	(0.4847)	(0.2823)	(0.1648)	(0.2626)
	Concentrate	0.1851	0.0106	0.3111	0.3611	0.3862	-0.2476	0.2114	-1.4463
		(2.0542)	(0.1192)	(0.6846)	(0.7870)	(0.8383)	(0.2785)	(0.1576)	(0.2023)
Mean income elas.		0.4989	0.3161	0.4935	0.3888	0.5597	0.4978	0.2134	0.6156
		(0.1633)	(0.1159)	(0.1614)	(0.1289)	(0.1834)	(0.1628)	(0.2125)	(0.2181)
Med income elas.		0.4988	0.3035	0.4936	0.3963	0.5608	0.4977	0.2267	0.6106
		(0.1632)	(0.1147)	(0.1615)	(0.1309)	(0.1837)	(0.1628)	(0.2053)	(0.2153)

Note: In the bottom level, Hausman, tax, and wholesale instruments are used.
In the middle level, percentage of population in banned areas is used as an instrument for L_{ct} in addition to the same set of instrumer bottom level.
All prices are treated endogenous, year-month and county fixed effects are included in the bottom level, and county and year fixed effects level.
Results in Table (6) are used to calculate the unconditional elasticities.

Table 15: **Marginal tax rate analysis**

		An 1% increase in the tax rate for...		
		Tobacco	Alcohol	Marijuana
Leads to a X% change in tax revenue for...	Tobacco	2.9	1.59	0.13
	Alcohol	0.03	5.99	0.74
	Marijuana	0.15	1.29	3.26
	Total	0.58	4.1	1.22

Appendices

A Proof of Proposition 1

Consider the general formula for elasticities given by Equation 4:

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

We can calculate the first term of this expression by taking the derivative of Equation 1 to obtain

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

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 and collecting like terms 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 $\tilde{\alpha}_m = \alpha_m + \alpha'_m L$. Then using Equation 2 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 3, 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:

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