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 legal substances 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 demand, and a marginal cross price elasticity of demand of .16. Marijuana legalization results in a 20% decrease in tobacco demand, but the marginal relationship is unclear. When prices are held fixed, 50% of marijuana tax revenue comes from cannibalizing 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

Most 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 substances, such as alcohol and tobacco. If these products are strong substitutes, the gains to total tax revenue stemming from the legalization of marijuana would be smaller than would be expected from an analysis that did not take into account the interaction of these products. On the other hand, if they are weak substitutes (or even complements), the gains could be larger than expected. Therefore, it is important to identify the nature of the relationship between marijuana and other legal substances empirically.

We evaluate the extensive margin 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 intensive margin changes in the total tax revenue in response to changes in the tax rates of each substance after prices have changed post-legalization (i.e. the slope of the Laffer curve). We use a detailed panel dataset of the prices and quantities of each substance sold at the retail 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 12% and 3%, respectively, around the time of legalization. Other states did not experience similar decreases in prices, violating the parallel trends assumption required by the differences-in-differences approach (Bureau of Labor Statistics, 2015, Orzechowski and Walker, 2017). To control for these price changes, we model the consumption of substances with a multistage budgeting approach inspired by Hausman et al. (1994). We extend the approach to allow for the introduction of a new class of products. Our model allows for flexible relationships between various product types within each substance category, including substitutability and complementarity, and also allows us to identify the cross-price elasticities between substances. We use 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, exogenous variation in local tax rates, and Hausman instruments to identify the intensive margin effects of price changes post-legalization. We include county and time fixed effects to account for changes in black market activity.

We find that the legalization of marijuana alone increased total expenditures on legal recreational substances by 13.5%. 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. In reality, since prices of tobacco and alcohol decreased, only 22% of marijuana revenues were cannibalized from alcohol and tobacco.

Our approach differs substantially from the existing interdisciplinary literature on the relationships between marijuana and other substances. Recent reviews by Subbaraman (2016) and Guttmannova et al. (2016) examined 39 and 15 studies, respectively, 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,[1] we study 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. Moreover, we explicitly consider the endogenous prices responses of alcohol and tobacco retailers to the entry of recreational marijuana. In addition, instead of relying on survey data (Miller et al., 2017) or proxies for substitution such as crime reports (Morris et al., 2014) or emergency room reports (Model, 1993), we study the relationship between these substances and the effect of legalizing marijuana using data on marijuana purchases directly with minimal measurement error.

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.[2] We extend the model and allow for the introduction of a new class of goods to affect the consumption patterns of other goods though both relative prices and the overall level of expenditures on substances chosen by the consumer.

We proceed by discussing our data and providing descriptive statistics about legal substance markets in Section 2. We describe our model of demand for recreational substances in Section 3. Section 4 details the particulars of our estimation strategy and Section 5 presents the results from our model when applied to the data. We conclude in Section 6 with a discussion and suggestions for further research.

[1] See, for example, Baggio et al. (2017), who study sales of alcohol in states with medical marijuana laws using a differences-in-differences approach.

[2] In contrast to a discrete choice approach to modeling demand, such as that of Berry et al. (1995), our approach does not assume substitution, and instead allows for either substitution or complementarity between products.

2 Data and Descriptive Evidence

To understand the relationship between recreational demand for marijuana, alcohol, and tobacco, we combine administrative data on marijuana sales obtained 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 dataset captures store-level sales data from participating retail firms. We observe the price and quantity sold of each tobacco and alcohol product (defined by a UPC) offered by each retailer each week from 2013-2015. Retailer locations are observed at the county level. The stores in the dataset include four major grocery store chains, two major discount store chains, and two drug store chains. We observe stores in 37 out of 39 Washington counties. 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).[4]

Table 1 summarizes the retail sales captured in our data for the years 2013 and 2015.[5] The first panel reports the total sales in dollars, while the second panel reports market shares within the substance industry. From 2013 to

[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 participants often report zero tobacco purchases in multiple counties, making it difficult to construct prices.

[5]In Tables 1-3 we scale the quantities of alcohol and tobacco sales by $\frac{1}{0.48} \approx 2.083$ to account for the missing retailers.

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 expenditures on recreational substances, or \$464 million. The third panel reports the gross tax revenues collected 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 fourth panel of Table 1 reports the change in average prices for each substance and the fifth panel reports the change in quantities. Both prices and quantities decreased for both tobacco and alcohol. Tobacco prices decreased by 11.5% and quantities decreased by 9.1%. Alcohol prices decreased 2.6% and quantities decreased 1.2%. 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 (measured in liters) 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 (measured in counts) decreased more for cigarettes (9.07% versus 5.06%).

Finally, Table 4 reports similar summary statistics for marijuana in 2014 and 2015. Stores opened in 32 out of 39 counties during our sample period. We subdivide marijuana into three products: flower, edibles, and concentrates.[6] 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 2015 as the market ramped up, though the figures for 2014 represent only a truncated period, as sales began in July of that year (see Hansen et al. (2017a) for more background on the history of legalization in Washington). The third panel documents a steep decline in the retail price of all three products, and the fourth panel shows that the wholesale prices of flower and edible products dropped more than the wholesale price of concentrate products.

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 all substances dropped after marijuana was legalized, it is not clear from this alone that the legalization of marijuana 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. Alternatively, shifts in consumer preferences, such as a long term trend in preferences for tobacco (Nelson et al., 2008), could also generate these patterns.[7] Teasing apart these various effects

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

[7]Changes in the black market for marijuana may have also affected demand for these substances. To explore this possibility, we collected black market price data from `www.priceofweed.com` and Perfect Price. These prices were only available at the state level and were very close to the legal market prices net of sales taxes. We incorporate time fixed effects in our empirical analysis to help control for changes in the black market for marijuana.

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 over three stages. These decisions are illustrated in Figure 1. The consumer starts in the top level by choosing how much to spend on substances versus all other goods. Next, in the middle level, conditional on the chosen level of overall substance spending, the consumer allocates that spending among three different substance types: marijuana, alcohol, and tobacco.[8] Finally, in the bottom level, the consumer allocates the substance-type-level spending to different products. Within marijuana, the consumer allocates spending between flower, edibles, and concentrates. Within alcohol, the consumer chooses between beer, wine, and liquor. Within tobacco, the consumer chooses between cigarettes and 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^m_{ict} 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

[8]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.

$$s^m_{ict} = \beta_0 + \beta^m_i \log\left(\frac{y^m_{ct}}{P^m_{ct}}\right) + \sum_{j=1}^{J^m} \gamma^m_{ij} \log p_{jct} + FX_{ic} + FX_{it} + \epsilon_{ict}. \quad (1)$$

In this equation, y^m_{ct} is the expenditure on the substance type, p_{jct} is the price of product j in county c at time t, and P^m_{ct} is a price index for all products within the substance type. Following Hausman, Leonard, and Zona 1994, we use a Stone-weighted price index and define $\log P^m_{ct} = \sum_{i=1}^{J^m} s^m_{ict} \log p_{ict}$. As a consequence, $\log\left(\frac{y^m_{ct}}{P^m_{ct}}\right)$ is a measure of real quantity. 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 product that remains constant over time (e.g. any preferences that come from county-level variation in the distribution of age, income, and other demographic characteristics, or the size of the black market in that county). Second, time-product fixed effects FX_{it} capture time-varying patterns in demand in a non-parametric way such as trends in the preferences for particular products or changes in the price of marijuana on the black market or the quantity supplied by the black market.[9]

This demand system is a first-order approximation to any Gorman-class demand function and allows for flexible substitution patterns between products. Products are allowed to be complements or substitutes, and demand may be non-homothetic. We can restrict shares to be homogeneous of degree

[9]Estimates of the size of the black market (measured in annual consumption) prepared before legalization vary substantially, from 85 to 225 metric tons (Washington Office of Financial Management, 2013, Kilmer et al., 2013). In 2015, the total consumption of flower in the legal market was only 29 metric tons. While this may seem like a big discrepancy, it's important to note that these weights are not directly comparable. First, the potency of flower sold in the legal market (as measured by THC content) has increased substantially as the market has grown. It is reasonable to conclude that legal market flower is more potent than the black market flower used in those estimates. Additionally, edibles and concentrates make up 25% of the sales of the legal market and can be more potent than the equivalent weight of flower.

zero in prices and expenditures by imposing $\sum_i \beta_i = 0$ and $\sum_j \gamma_{ij} = 0$ 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 that 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. $\text{Corr}(\log p_j, \epsilon_i) \neq 0$). 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 P^m_{ct}. We model demand for segment $m \in \{\text{mj, alc, tb}\}$ via

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

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. Since L may be correlated with unobserved marijuana demand shocks we instrument it (See Section 4). If preferences are homothetic, $\alpha_m = 1$. 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. For example, if the price of flower changes, the price index for marijuana will also change, which will affect the real expenditures Q_m for all three substances and therefore change the expenditures of alcohol and tobacco products in the bottom level.

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 expenditures. 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 non-zero number. We net out these effects to report the effective change in demand from the legalization of marijuana.

Hansen et al. (2017b) found a substantial drop in marijuana sales along the Washington-Oregon border when Oregon's market for recreational marijuana opened in October 2015. We include an indicator variable OR which is one if the county in question is adjacent to the Oregon border and the time period is after Oregon's market opened.

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. These fixed effects will capture variation in demand which is due to movements in the black market, as long as black market movements don't occur at both the county and time levels simultaneously. Additionally, the prices in this level suffer from the same endogeneity concerns as those in the bottom level, which we address in Section 4.

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

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

In this equation, $\bar{Y}_{ct}$ is the 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. We include year fixed effects FX_t.

3.4 Elasticities

The own- and cross-price elasticities of substances are not readily interpretable from the bottom level parameters. To derive elasticities in the model, we extend the approach of Ellison et al. (1997) and Bokhari and Fournier (2013). Let product i belong to 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:

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

Our model allows for changes in the price of any good to affect the consumption of every other good through the price indices which connect the different levels of the demand system. As a consequence, price changes of product j in segment n lead to changes in the price index as well as real expenditures on segment n, resulting in changes in the total expenditures on all substances $\log Y$. These affect the price indices of other good's segment m, the relative prices between n and m, and the real expenditure on segment m, leading to changes in quantity of product i in segment m. The elasticity we calculate in this way is unconditional on the expenditure on all substances as well as the segment-level expenditures. We derive an expression for ε_{ij} in 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, 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*

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

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 directly affects the share of product i through γ if both products i and j are in the same segment. Finally, the last term is an adjustment for the own-price elasticity. We can calculate price elasticities between products within the same segment conditional on holding the segment-level expenditures constant by setting λ and $\tilde{\alpha}_m$ equal to 0 and δ equal to -1.

The overall elasticity of substances as a category can be easily derived from Equation 3 with

$$\frac{\partial \log Q}{\partial \log \mathbf{P}} = \frac{\partial \log Y}{\partial \log \mathbf{P}} - \frac{\partial \log \mathbf{P}}{\partial \log \mathbf{P}} = \lambda - 1. \tag{6}$$

4 Estimation details

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—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 between the 25th and 75th percentile range of the potency distribution (which we call "medium" potency) 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. Moreover, if substances are closely related (either substitutes or complements), the demand shocks of one substance can be correlated with the price of other substances. Therefore, the price of each substance may be endogenously determined in part by the demand shocks for each other substance. We solve this endogeneity problem by applying the instrumental variable approach for each product. First, suppose that the price of product i in county c at time t is determined by

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

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 $\epsilon_{jc't}$ $\forall j \in J^m, c' \neq c$, then the price of a product in a different county c' is a valid instrument for the price of the same product in a county c. For all substances, we construct these "Hausman" 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 of medium potency 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 UPCs in a product category. Assuming that localities are not setting tax rates in response to (or in expectation of) demand shocks for particular substance UPCs, these tax rates are cost shifters which are uncorrelated with the unobservable component of demand. Roughly half of Washington's counties changed their tax rate at least once during the sample period. 20% changed their tax rate two or more times.[10]

We use all three of these instruments—Hausman, wholesale prices, and tax rates—to estimate the bottom level of the model. 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 the percentage of population living in areas where entry was banned to instrument for marijuana availability. Table 4 reports these percentages for 2014 and 2015.

In the bottom level, 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 fact that the sum of shares within a substance segment is 1 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. We estimate the bottom level with a multiple

[10]Additionally, Washington unexpectedly changed the retail tax rate on marijuana throughout the state from 25% to 37% on July 1, 2015 (Hansen et al., 2017a). Our use of time fixed effects precludes the use of this change as an instrument.

equation GMM procedure and we estimate the middle and top levels via 2SLS. We calculate heteroskedasticity-robust standard errors throughout.

5 Results

We start by estimating Equation 3 (the top level) using data from markets where $L = 1$ – that is, counties where marijuana was legalized and available for purchase. We use these observations because legalization caused a large increase in the level of expenditures on substances 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. 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 that 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 6, to be -0.48.

We next estimate Equation 2 (the middle level) for each of our substance categories. Following the multistage AI demand literature, we do not enforce Slutsky symmetry at this level.[11] 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

[11]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.

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 and thus we conclude the relationship is unclear. The coefficient on the indicator for Oregon legalization Oregon indicator is significant for marijuana and indicates that the quantity of marijuana demanded dropped by 15% for those counties, which is consistent with the results of Hansen et al. (2017b).

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 parts. The first row isolates the effect of legalization itself, holding prices and other demand characteristics fixed. Legalization decreases the quantity demanded of tobacco and alcohol by 20% and 12%, respectively. The second and third rows report the effects of contemporaneous price drops in those industries. 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 from prices and tax rates to tax revenue through the lens of our model. The first bar shows that the total tax revenue earned from substance sales captured by our data in 2013 was $476 million. If marijuana was legalized and the other determinants of demand remained fixed, Washington would have earned $130 million in tax revenue from marijuana, as seen in the second bar. However, the total tax revenue from all substances would only have increased by $65 million to $540 million. We conclude that, holding everything else fixed, half of the tax revenue that comes from legalizing marijuana is cannibalized from alcohol and tobacco revenues. Each subsequent bar takes one determinant of demand captured in our model to its 2015 value. After allowing for the change in substance expenditures, time fixed effects, and changes in alcohol and tobacco prices, Washington earned $136 million in marijuana tax revenue, only 22% of which was cannibalized from existing substance revenues.

Alternatively, one could ask what the counterfactual revenues from alcohol and tobacco would have been had marijuana not been legalized. While we do not explicitly model the price-setting behavior of alcohol and tobacco retailers, we can use the demand characteristics from 2015 along with 2013 prices as an estimate of this scenario. When we do so, we find that Washington would have earned \$527 million in tax revenues, as opposed to the \$582 million which occurred in the data. As marijuana tax revenues were \$136 million, we conclude under this approach that 48% of the increase in total tax revenue which occurred in the data would have occurred even without legalizing marijuana.

Table 8 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 turn to the literature to find the rate at which tax increases are passed through to consumers. 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 substance. Differences in passthrough rates, as well as asymmetries in our estimated cross-price elasticities, result in asymmetries in our estimated tax 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.

Finally, we estimate Equation 1 (the bottom level) for the products within each substance category. We present the coefficients for these estimations in Appendix B, as the parameters cannot be easily interpreted on their own. We calculate elasticities for products within each segment, conditional on holding segment-level expenditures constant. We do this by using Equation 5 with λ and $\tilde{\alpha}_m$ equal to 0 and δ equal to -1. Tables 9, 10 and 11 report these conditional elasticities for tobacco, alcohol, and marijuana, respectively. All products have own-price elasticity point estimates of greater than one in absolute value. Liquor is the most elastic with a point estimate of -1.73, while flower is the least price elastic with a point estimate of -1.05. The point estimates for most cross-price elasticities are positive, indicating that products within the substance categories are substitutes. Those that are not are imprecisely estimated, implying that we cannot reject the null hypothesis that those products are substitutes. The reported cross price elasticities are not symmetric, though the estimated coefficients are symmetric, because of differences in product-level shares and the effect of substance expenditures.

Table 12 presents a matrix of own- and cross-price elasticities for all products in the model after taking into account the substance-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 likely reflects the fact that the Nielsen data does not include sales from corner stores or gas stations. 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.

6 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 products within different substance segments to be substitutes or complements.

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. We also find that, holding tobacco and alcohol prices fixed, half 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 – 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 potentially 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 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 does not endogenize 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. 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.

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). Furthermore, the extent to which legal marijuana markets crowd out black market marijuana is unknown. 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 estimates of the size of alcohol and tobacco externalities and used with the optimal tax model discussed above to provide a broader perspective on optimal marijuana policy.

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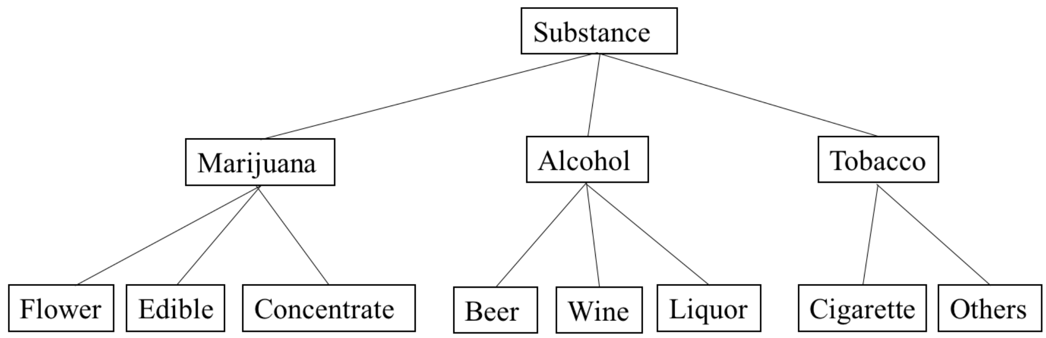
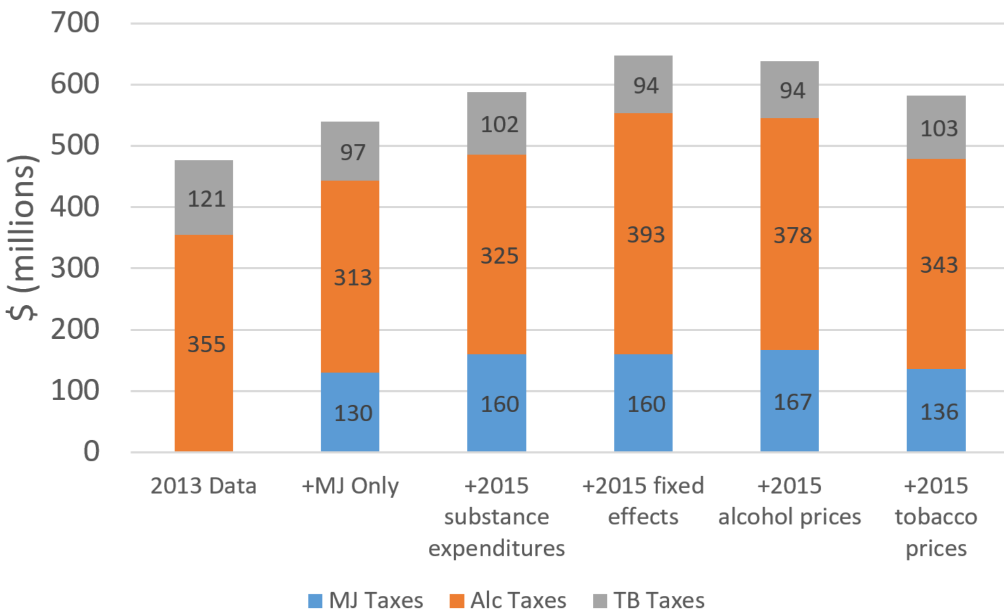
7 Figures and Tables

Figure 1: Substance demand segment tree



This figure illustrates the sequence of decisions made by the representative consumer in our model. At the top of the tree the consumer chooses how much to spend on legal recreational substances. In the middle level, the consumer allocates that spending between three substance categories: marijuana, alcohol, and tobacco. Finally, in the bottom level, conditional on the chosen level of spending on the particular substance, the consumer allocates that spending to individual substance products.

Figure 2: Estimated substance tax revenue under alternative scenarios



This figure uses our estimates of model parameters to calculate Washington's tax revenue under alternative scenarios. The numbers in each bar indicate the amount of tax revenues from that source, in millions of dollars. 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

	Product	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

	Product	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

	Product	Flower	Edible	Concentrate
Sales ($1 M)	2014	36	3.3	3.9
	2015	344	47	70
	%Δ[1]	856	1,324	1,695
Share	2014	0.83	0.08	0.09
	2015	0.74	0.10	0.15
	%Δ	-10.8	25	67
Average price ($)	2014	21.67	35.64	54.07
	2015	12.26	24.42	41.45
	%Δ	-43.4	-31.5	-23.3
Wholesale price ($)	2014	8.09	14.17	14.44
	2015	3.89	7.97	13.25
	%Δ	-51.9	-43.8	-8.2
Quantity (millions)	2014	1.7	0.1	0.1
	2015	28	1.9	1.7
	%Δ	1,547	1,978	2,241
Number of retail locations	2014		86	
	2015		206	
	%Δ		139.5	
Proportion of population where entry is banned	2014		0.096	
	2015		0.133	
	%Δ		38.5	

Prices and sales include all applicable taxes. Quantities are measured in grams for flower, and counts for edibles and concentrates.
[1]Washington marijuana sales began in July, 2014.

Table 5: Parameter estimates for the overall demand for substances

	(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
1st stage adj. R-sq	0.6710	0.6855	0.7322

The dependent variable for these regressions is the log of the nominal expenditures on all substances for that county-month. Hausman, tax, and wholesale instruments are used to construct the price index. The observations for these estimates came from the period after Washington legalized marijuana. Robust standard errors are in parentheses.

Table 6: Parameter estimates for substance segments

	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 legal ind. * Log P^{mj}	0.0793	0.1629	-1.4565
	(0.0866)	(0.0575)	(0.1851)
MJ legal ind.	-0.6873	-0.6638	
	(0.2353)	(0.1562)	
MJ legal ind. * Log substance expenditure	0.0303	0.0093	
	(0.0062)	(0.0057)	
Oregon legal ind.	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
1st stage adj. R-sq	0.8402	0.8402	0.9737

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 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.

Table 7: The effect of marijuana legalization on the quantity demanded of 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 captured by model	-3.19%	25.6%
Total change from 2013 to 2015	-8.30%	3.68%

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. The total effect is calculated from the data directly, and differs slightly from the sum of the rows due to changes in demand that are not captured by the model.

Table 8: The slope of the Laffer curves for substance taxes

		...leads to a X% change in tax revenue from...			
		Tobacco	Alcohol	Marijuana	Total
A 1% increase in the tax rate for...	Tobacco	2.90	0.03	0.15	0.58
	Alcohol	1.59	5.99	1.29	4.10
	Marijuana	0.13	0.74	3.26	1.22

We use the estimates in Tables 5 and 6 with our data on 2015 prices, quantities, and tax rates to calculate these marginal effects.

Table 9: Mean elasticities for tobacco products conditional on segment-level expenditure

		...leads to a X% change in the quantity demanded of...	
		Cigarette	OTP
An 1% increase in the price of...	Cigarette	-1.0670	0.0046
		(0.0182)	(0.0069)
	OTP	1.3056	-1.0885
		(0.3572)	(0.1215)

These estimates are calculated using the parameter estimates for the bottom level as reported in Appendix Table B.1 and Equation 5. Bootstrapped standard errors are in parentheses.

Table 10: Mean elasticities for alcohol products conditional on segment-level expenditure

		...leads to a X% change in the quantity demanded of...		
		Beer	Wine	Liquor
An 1% increase in the price of...	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)

These estimates are calculated using the parameter estimates for the bottom level as reported in Appendix Table B.2 and Equation 5. Bootstrapped standard errors are in parentheses.

Table 11: Mean elasticities for marijuana products conditional on segment-level expenditure

		...leads to a X% change in the quantity demanded of...		
		Flower	Edible	Concentrate
	Flower	-1.0451	-0.0012	0.0178
		(0.0606)	(0.0469)	(0.0504)
An 1% increase in	Edible	0.4531	-1.4152	0.5794
the price of...		(0.3856)	(0.1796)	(0.4671)
	Concentrate	-0.0538	0.2966	-1.4481
		(0.2688)	(0.2451)	(0.4033)

These estimates are calculated using the parameter estimates for the bottom level as reported in Appendix Table B.3 and Equation 5. Bootstrapped standard errors are in parentheses.

Table 12: Mean unconditional elasticities by product

		...leads to a X% change in the quantity demanded of...							
		Cigarette	OTP	Beer	Wine	Liquor	Flower	Edible	Concentrate
A 1% change in the price of...	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)

These estimates are calculated using the parameter estimates for all levels and Equation 5. Bootstrapped standard errors are in parentheses.

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:

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

B Bottom level parameter estimates

Table B.1: Bottom level estimates for tobacco products

	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
N	1029

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

Table B.2: Bottom level estimates for alcohol products

	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
N	1080	1080

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

Table B.3: Bottom level estimates for marijuana products

	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
N	339	339

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